Libyan Journal of Science & Technology 16:1 (2026) 308-315

Faculty of Science - University of Benghazi

Libyan Journal of Science & Technology

journal home page: https://journals.uob.edu.ly/LJST

Reworked Oligo-Miocene Corals from North-eastern Libya: Implications for Paleoenvironment and Paleogeographic Importance.

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Highlights

- **The documented *Meandrina subcircularis* and *Porites solida* reworked coral colonies have been documented at Wadi Derna in Derna city and Wadi El Zeitun near Tobruk, respectively.**
- ***Meandrina subcircularis* from the Middle–Upper Oligocene Al Abraq Formation. Whereas *Porites solida* from the Middle Miocene Al Jaghboub Formation.**
- **The stratigraphic distribution and paleogeographic affinity of both species support regional correlations with coeval carbonate platforms across the southern Tethyan margin and the broader Mediterranean realm.**

A R T I C L E I N F O

Article history:

Received 11 February 2026
Revised 18 June 2026
Accepted 20 June 2026

Keywords:

Abraq Formation, Al Jabal al Akhdar, Corals, Meandrina subcircularis, Nummulites Oligo-Miocene, Libya

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A B S T R A C T

The sedimentary successions of northeastern Libya preserve diverse coral assemblages that provide valuable insights into Oligocene–Miocene marine environments along the southern margin of the Tethys Ocean. The Middle to Upper Oligocene Al Abraq Formation of Wadi Derna, the meandroid coral *Meandrina subcircularis,* an ex-situ coral, occurs in non-reefal skeletal limestones deposited in a shoal–channel complex. Its highly sinuous, uniserial valleys and well-developed paliform lobes indicate morphological adaptations to fluctuating hydrodynamic regimes and episodic sediment influx. Elsewhere, a massive colony of the reef-building coral *Porites solida* was recovered ex-situ from Wadi El Zeitun near Tobruk, representing material reworked from the Middle Miocene Al Jaghboub Formation. The specimen, characterized by compact, radially septate corallites and a dome-shaped colony form, reflects deposition in high-energy, shallow marine reefal settings. Both occurrences exhibit evidence of storm-related reworking. highlighting the role of episodic high-energy events in the transport and redistribution of coral material across carbonate platforms. Together, these findings provide a framework for reconstructing Oligocene–Miocene palaeoecological conditions in Cyrenaica and emphasize the importance of coral taphonomy for interpreting depositional dynamics, tectonic influences, and the broader paleogeographic evolution of the southern Tethyan margin.

1. Introduction

This paper adds new information in relation to coral buildups within the Cyrenaica region of northeastern Libya (Fig. 1). In this context, the term coral refers not simply to individual coral colonies but to larger accumulations of coral carbonates that formed distinct topographic reef features on the seafloor. These buildups developed in association with a wide range of organisms, particularly algae and foraminifers, which played important roles in stabilizing and contributing to the carbonate framework (Stoddart, 1969; Humblet and Webstar, 2017; Khameiss, 2015; Khameiss, *et al.*, 2016; Khameiss, *et al*., 2024). The study also documents how these coral structures, originally preserved in place, were later reworked, fragmented, and displaced because of the catastrophic storm event (i.e., Daniel Medicane that struck the region in 2023

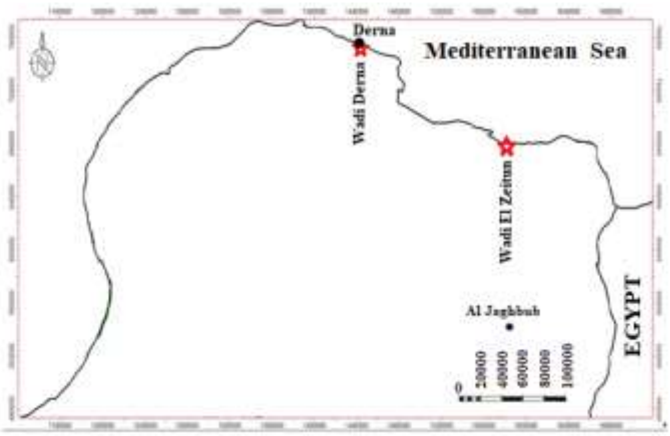

Fig. 1. Location Map showing the coral localities *P. solida* from the mouth of Wadi El Zeitun and *M. subcircularis* at Wadi Derna in Northeastern Libya.

 ISSN 2663-1407; National Library of Libya, Legal number: 390/2018

Oligocene fossil reefs also shed light on the evolution and biodiversity of marine ecosystems. This epoch is significant for understanding the diversification of reef-associated organisms and the ecological changes that occurred after the widespread warm reef systems of the Eocene. The coral assemblages document both extinction and recovery patterns, linking ancient and modern reefs (Johnson *et al*.,2009). Their geographic distribution reveals clues about past tectonic events, including the Tethys Ocean's closure and new basin formation (Khameiss, 2013). Comparing ancient and modern reefs provides valuable insights into reef resilience and responses to environmental changes, offering lessons for current conservation efforts amid rising human-induced impacts on marine ecosystems (Hoppit *et al*., 2025; Khameiss and Zubi, 2024; Khameiss *et al*., 2016).

1.1. Methods and Materials

The two coral specimens were picked from the floor of the two wadies near their mouths. Their identification was carried out based on detailed morphological and lithological descriptions. Thin sections were prepared by Sirt Oil Company, who is highly appreciated.

The two coral specimens were picked from the floor of the two wadies near each mouth. Their identification of the coral species and the associated microfossils content was carried out based on detailed microscopic examinations by using both episcopy and diascopy, as necessary; however, for lithological descriptions, only a diascopy microscope was used. To distinguish between these two hard corals, look at the growth pattern, size, and skeletal density, as they belong to entirely different families. *Meandrina subcircularis* forms a dense, solid, brain-like (meandroid) colony characterized by deep, winding valleys that are 10 to 20 mm wide, lined with thick, smooth, plate-like septa and a continuous sheet-like columella. In contrast, *Porites solida* forms a massive, mound-like colony featuring a highly porous, lattice-like skeleton covered in miniature, shallow, polygonal pits (cerioid layout) that measure only 1.5 to 2 mm in diameter and house granular, fused septa. Additionally, the coral hand specimens are measured and described in detail to unveil the taphonomic criteria to differentiate both “ex-situ” species. This was inferred from the textural and microfossil contents of the host rocks, the distance of transport in accordance with the roundness or flatness of the described hand specimens, and knowledge of the surface geology of the area to predict their transport pathway from the nearby possible exposure. Thin section preparation was carried out at Sirt Oil Company, in Marsa El Brega city.

1.2 Stratigraphic Background

The Al Jabal al Akhdar area in the Cyrenaica region of northeastern Libya (Fig. 1) records a long geological history, extending from the Late Cretaceous to the Late Miocene. Among this sequence, the Tertiary successions are represented by nine distinct rock units, almost separated from each other by unconformity surfaces (Fig. 2). Only two rock units, the Al Abraq Formation (Middle-Upper Oligocene) and the Al Jaghboub Formation (Middle Miocene), are highlighted in this study as they contain the two studied coral taxa.

1.2.1. Abraq Formation:

The Abraq Formation consists primarily of skeletal limestone deposited in a shoal–channel complex, though it lacks true reefal facies (El- Werfalli, *et al*., 2000; El Hawat and Abdulsamad, 2004; Abdulsamad, 1999; Muftah *et al*., 2007; and Khameiss *et al*., 2016). This unit was first defined near the village of Al Abraq (Röhlich, 1974) and rests disconformably on the Al Bayda Formation, while being overlain by the Al Faidiyah Formation.

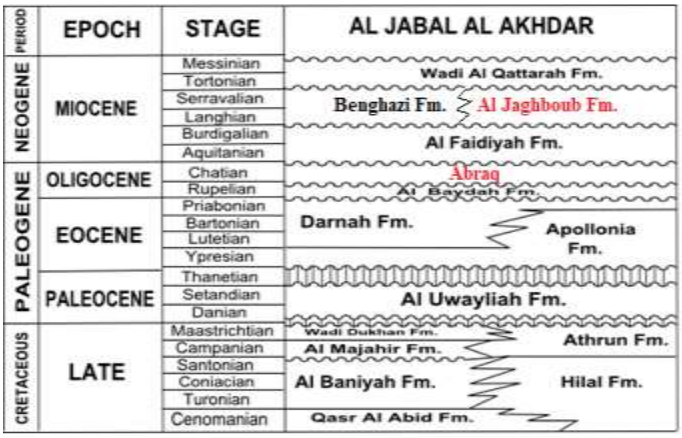

Fig. 2. The stratigraphic chart of the exposed rock units in the study area; the concerned rock units are in red (modified after El Hawat and Abdulsamad 2004; Muftah et al., 2007).

Lithologically, the Abraq Formation is composed of yellowish-white limestone, ranging from soft to moderately hard, with calcarenitic to calcilutitic textures. Intervals of moderate dolomitic limestone, dolomite, and marl are also present. The microfossil assemblage includes abundant foraminifera such as *Nummulites fichteli* (Michelotti 1841), *Lepidocyclina dilitata* (Michelotti 1861), and *Operculina complanata* (Defrance in Blainville, 1822) whereas the macrofossil elements include oysters, echinoderms, and biogenic burrows. Notably, the upper part of the unit contains abundant *Nummulites* debris, consisting of fragmented tests with varying degrees of breakage, interpreted as evidence of reworking. A comparable lithological and paleontological association occurs in the Wadi al Kuf section, where numerous small-sized *Nummulites vascus* Joly and Leymeri 1848, also reported (Abdulsamad *et al*., 2009; Muftah, 2014).

The studied coral-bearing specimen consists of Foraminiferal wackestone microfacies from the Abraq Formation with common larger benthic foraminifers including *Operculina complanata* (Defrance in Blainville, 1822), *Amphistegina* sp., and *Lepidocyclina dilitata* (Michelotti, 1861) (Fig. 3).

1.2.2 Al Jaghboub Formation

The Al Jaghboub Formation consists of highly fossiliferous sandy to argillaceous limestone, interbedded with subordinate calcareous shale. Multiple studies, including Desio (1928); Burollet (1960); Annoscia (1968); Bellini (1969); El Deftar and Issawi (1977); Imam (1999); Muftah *et al.* (2017); Abdulsamad et al. (2018); and Adam (2018), have explored the stratigraphy and paleontology of the Al Jaghboub Formation. The Al Jaghboub Formation (Early Middle Miocene age) is the most widely distributed in the Tobruk area, with a maximum recorded thickness of 34.5 meters (Adam, 2018). It is composed of yellowish-white to reddish, firm limestone and is well-exposed in multiple localities, particularly in the Abdominal regions (Fig. 2). Its widespread occurrence reflects shallow marine depositional conditions associated with reef-building environments during the Early to Middle Miocene. The Al Jaghboub Formation is crucial for understanding the paleoecology of Miocene coral reefs and the evolution of Mediterranean–Tethys paleogeography (Khameiss *et al*., 2024). Its extensive exposure and distinctive lithological characteristics make it an essential reference for geological mapping and stratigraphic correlation along the eastern Libyan coast (Abdulsamad *et al*., 2018). The possible stratigraphic source of the reported specimen is highly attributed to the Al Jaghboub Formation from the upstream of Wadi Al Zeitun (Fig. 4).

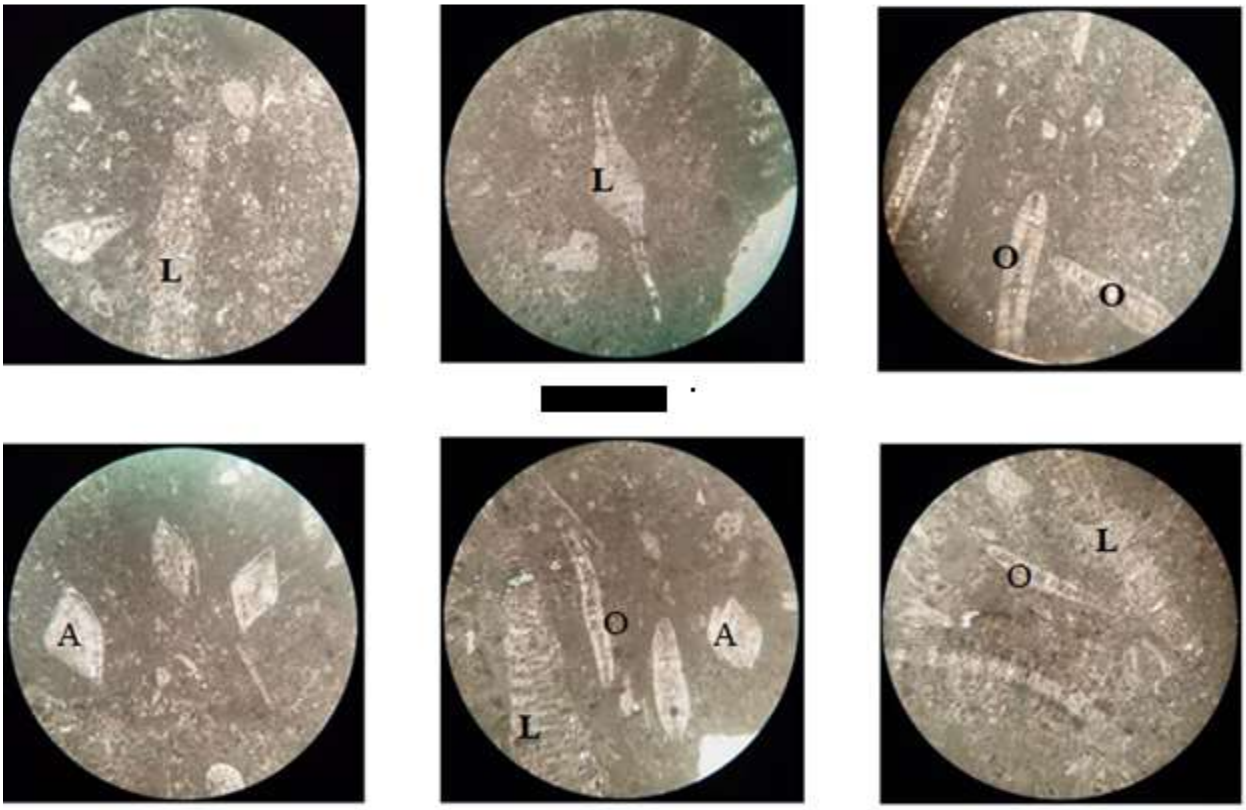

Fig. 3. Photomicrographs of coral bearing lithotype (Foraminiferal wackestone microfacies Abraq Formation) show *Operculina complanata* (O), *Amphistegina* sp. (A), and *Lepidocyclina (Eulepidina) dilitata* (L), PPL, Scale bar = 250 µm.

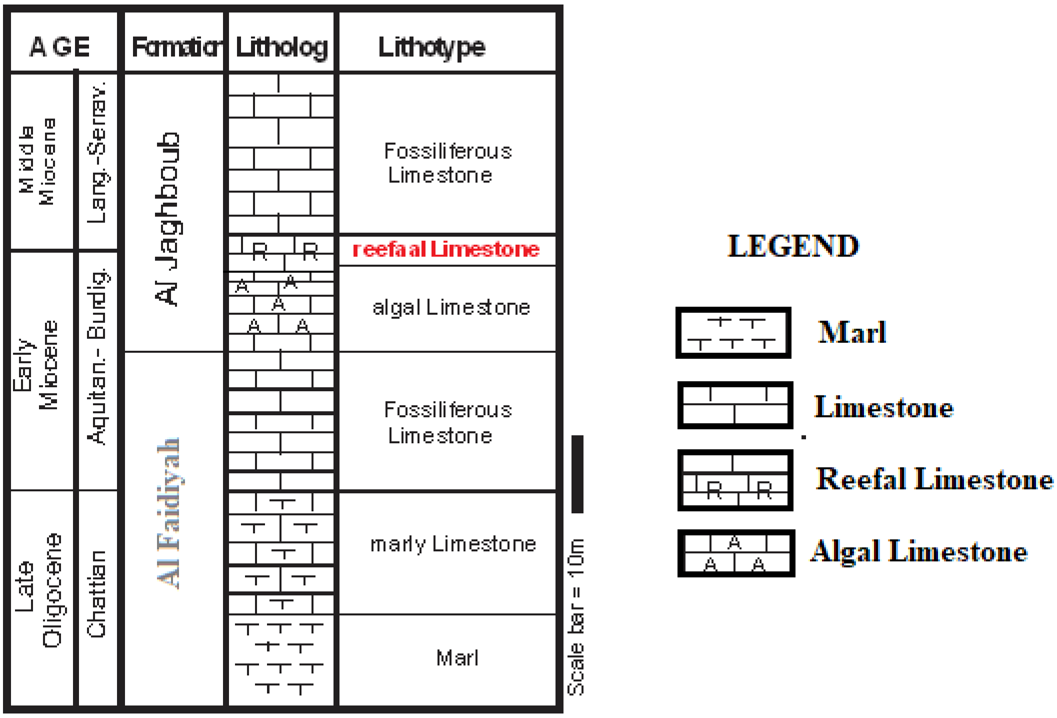

Fig. 4. Stratigraphic column of the upper part in Wadi Al Zeitun, Tobruk area. (Note: possible coral specimen source in red color) (modified after Abdulsamad *et al.*, 2018)

1. Results

1.1. Meandrina subcircularis coral from Wadi Derna, Northeast Libya

This meandroid type of coral is collected from the unconsolidated wadi deposits of Wadi Derna. It is a genus of stony corals that can form large, flat plates or hemispherical heads. Some species of Meandrina are commonly called brain corals because of their characteristic convoluted appearance.

Diagnosis: Highly sinuous uniserial valleys (45–centers) with bulbous ends, U-shaped; well-developed paliform lobes.

Meandrina subcircularis Catullo, 1857 (Fig. 5) (Table .1)

Meandrinidae Gray, 1847

Meandrina Lamarck, 1801

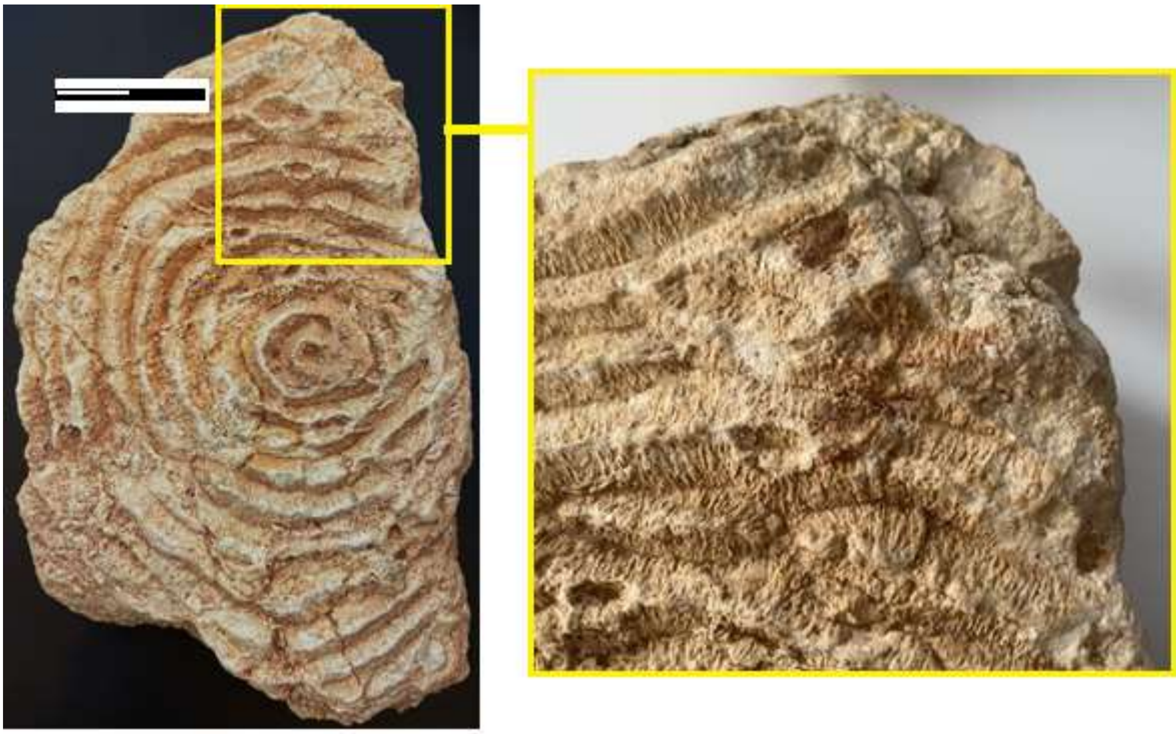

Fig. 5. A hand specimen of *Meandrina subcircularis* (Catullo, 1857) shows the sinuous uniserial valleys with paliform lobes from Wadi Deran, NE Libya. (Scale bar = 4cm) with enlarged view (yellow square).

Occurrence and Paleoenvironment: *Meandrina subcircularis* (Catullo, 1857) has been documented in various fossiliferous deposits, particularly from the Miocene period. Fossil specimens of this species have been reported from the Mediterranean and North African regions, including Monteviale, Crosara, and Vicenza (Rupelian) (Catullo, 1857; Fuchs, 1873). *Meandrina subcircularis* (Catullo, 1857) typically inhabited shallow, warm, tropical to subtropical marine environments. Its growth is associated with well-lit, clear, and nutrient-balanced waters, often forming part of coral shoals or carbonate platforms. In the Miocene deposits of North Africa and the Mediterranean, this species indicates deposition in relatively high-energy, shallow-marine settings, such as reef fronts, shoal channels, and back-reef lagoons, where water circulation facilitated carbonate sedimentation and supported diverse benthic communities including other corals, algae, and foraminifera.

1.2. *Porites solida* coral from Wadi El Zeitun, Northeast Libya

A well-preserved specimen of transported *Porites solida* was recovered from the mouth of Wadi El Zeitun, northeast of Tobruk, in northeastern Libya. Identification is based on its massive to submassive colony form with closely packed, radially septate corallites, characteristic of reef-building taxa of the genus *Porites*, which thrived in shallow marine environments during the Miocene. Although found ex-situ, the lithological nature and the associated fossil content strongly indicate that the specimen originated from the Middle Miocene Al Jaghboub Formation, well exposed in the uplands (i.e., Wadi El Zeitun upstream). The colony was likely dislodged and transported downstream by erosional processes from its original reefal limestone beds (Table. 1).

Porites solida was confirmed via micro-morphological analysis of individual corallites under a stereomicroscope. Diagnostics focused on the distinct bilateral symmetry and fusion pattern of the 12 septa characteristic of the genus. Specimen calices exhibited exceptionally large diameters (1.5–2.0 mm) bound by thin, acute walls and deep calice relief. Diagnostic septal architecture revealed a highly regular fusion pattern consisting of a single dorsal directive septum, two pairs of lateral duets, and a ventral triplet. Within the triplet, the central septum was firmly fused to the lateral margins rather than remaining free. The inner margins of the septal fusion zones terminated in a highly conspicuous, circular paliform crown composed of eight well-developed, prominent pali, reliably differentiating *P. solida* Forskål, 1775 from the weakly developed paliform structures of co-occurring *Porites lobata.*

Porites solida Forskål, 1775 (Figs. 6, 7 and Table 1)
Porites Link, 1807
Poritidae Gray, 1840

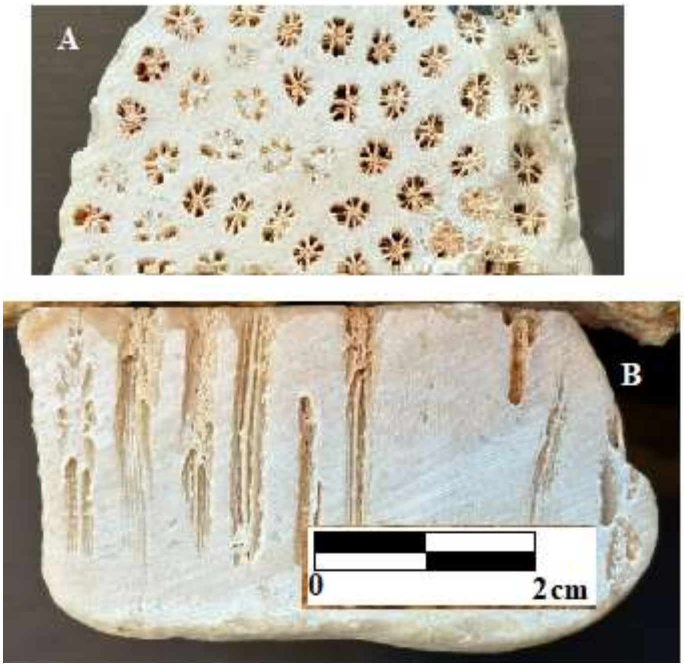

Fig. 6. A hand specimen of *Porites solida* Forskål, 1775 shows compact corallite walls without obvious separation from Wadi El Zeitun, NE Libya. (Note: A- Transverse view; B- Longitudinal view).

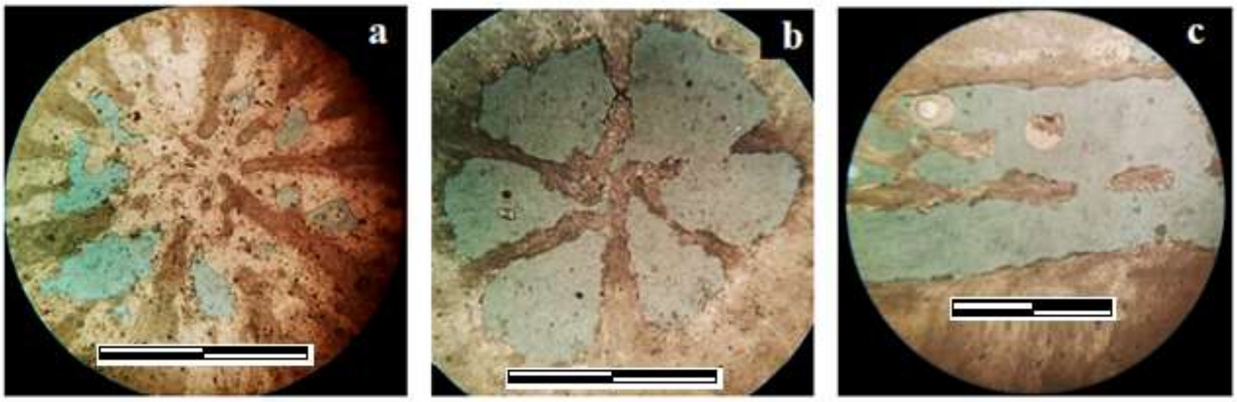

Fig. 7. Photomicrographs of *Porites solida* Forskål, 1775 transverse section (a,b); Longitudinal section (c) through the corallites. Scale bar = 1mm, PPL (Blue dye to show porosity)

Occurrence and paleoenvironment: *Porites solida* Forskål, 1775 is well-documented from Miocene reefal carbonates of the Mediterranean and Tethyan regions, including northeastern Libya (e.g., Jabal Al Akhdar). The depositional setting corresponds to shallow, high-energy reefal platforms, reflecting warm, clear marine conditions suitable for hermatypic coral proliferation. The present record of this taxon in Wadi El Zeitun contributes to the understanding of coral reef development and paleoenvironmental reconstructions in Cyrenaica during the Miocene.

Table 1.

Summary of the two coral species

Species	Formation	Age	Depositional setting	Paleoecological significant
Meandrina subcircularis	Al Abraq Formation	Middle-Upper Oligocene	Shallow, marine environments of coral shoals or carbonate platforms	Shallow, warm, and well-lit tropical marine environments **(critical indicators of high-sedimentation thresholds, paleodepth constraints, and changing ancient current systems)**
Porites solida	Al Jaghboub Formation	Middle Miocene	shallow, high-energy reefal platforms,	Dominates shallow marine waters, usually found from just beneath the lowest tide lines down to intermediate shelf depths**(acting as a primary shelter for fish and host to boring marine organisms**)

Taphonomical notes: The contrasting preservation states of the two ex-situ coral hand specimens reveal entirely different transport distances and depositional pathways before their collection at the wadi mouths. The *Porites solida* specimen exhibits extreme mechanical modification characterized by a very well-rounded morphology and a polished surface, which indicates a history of prolonged tumbling, either via long-distance fluvial transport from a far-inland upstream exposure or intensive marine wave reworking in a high-energy shore face zone near the wadi mouth or both scenarios. Conversely, the *Meandrina subcircularis* specimen shows no taphonomic change, retaining its pristine, sharp skeletal structures and growth margins; this structural integrity suggests a very short transport pathway with negligible grain-to-grain abrasion. This pristine coral was likely eroded from a highly proximal geologic source near the wadi mouth and immediately encased and protected by a rapid, sediment-dense wadi flooding event that shielded it from physical wear.

2. Discussion

The studied coral specimens, although recovered from unconsolidated wadi deposits, yield robust paleoenvironmental and stratigraphic information when evaluated within an integrated framework of lithological observations, microfacies analysis, and regional stratigraphic context. The combined application of coral taxonomy, associated microfossil assemblages, and sedimentological characteristics enables reliable reconstruction of the original depositional environments despite post-depositional reworking.

Both specimens exhibit clear evidence of ex-situ preservation, having been collected from wadi floors near their mouths. Such depositional settings are characteristic of arid to semi-arid carbonate provinces in Cyrenaica, where episodic, high-energy fluvial events commonly erode and redeposit lithified carbonate material from upstream outcrops. Notably, neither specimen displays pronounced mechanical abrasion, bioerosion, or surface dissolution, suggesting relatively short transport distances and rapid redeposition following detachment from their source strata. The stratigraphic provenance of the coral specimens is well constrained by the lithological nature of the host material and the associated fossil assemblages. The *Meandrina subcircularis* (Catullo, 1857) specimen occurs within foraminiferal wackestone microfacies dominated by larger benthic foraminifers, including *Operculina complanata*, *Amphistegina* sp., and *Lepidocyclina dilitata*. This assemblage is diagnostic of the Middle–Upper Oligocene Abraq Formation. In contrast, the *Porites solida* specimen is lithologically consistent with the firm, highly fossiliferous reefal limestones of the Middle Miocene Al Jaghboub Formation, which is extensively exposed in the uplands of Wadi El Zeitun. The occurrence of *Meandrina subcircularis* (Catullo, 1857) within the Al Abraq Formation provides important insights into the nature of Oligocene carbonate systems in northeastern Libya. This species is characterized by highly sinuous, uniserial valleys with well-developed paliform lobes, morphological adaptations commonly associated with corals inhabiting moderate- to high-energy shallow-marine environments (Budd and Bosellini, 2016). Such skeletal architecture enhances colony stability and facilitates sediment rejection under fluctuating hydrodynamic conditions. The absence of true reefal frameworks within the Abraq Formation, together with the dominance of skeletal limestones and reworked larger benthic foraminifera, suggests deposition within a shoal–channel complex rather than a rigid reef system. The presence of *Meandrina subcircularis* (Catullo, 1857) in this setting indicates localized coral colonization on firm substrates or hardgrounds embedded within a foraminifera-dominated carbonate factory. This interpretation is consistent with the abundance of fragmented Nummulites tests in the upper part of the formation, reflecting episodic reworking under elevated energy conditions. *Meandrina subcircularis* (Catullo, 1857) indicates shallow, warm, oligotrophic waters within the photic zone, where sufficient circulation promoted carbonate production while inhibiting the development of extensive reef frameworks. Its occurrence supports regional correlations with Oligocene shallow-marine carbonate platforms across the central and eastern Mediterranean, reinforcing paleogeographic continuity along the southern margin of the Tethys during this interval. The *Porites solida* Forskål, 1775 specimen recovered from Wadi El Zeitun represents a typical reef-building taxon indicative of fully developed Miocene coral reef ecosystems (Plass-Johnson *et al.*,1016). The massive to submassive colony morphology, densely packed corallites, and compact skeletal fabric are characteristic adaptations to high-energy reefal environments, where resistance to wave action and mechanical stress is critical (Ketchum and Reyes Bonilla, 2001). Petrographic analysis reveals well-preserved corallite architecture in both transverse and longitudinal sections, with dense skeletal walls and limited primary porosity. Blue-dye impregnation highlights secondary porosity, suggesting early diagenetic stabilization before reworking and transport. The attribution of *Porites solida* Forskål, 1775 to the Al Jaghboub Formation is further supported by its lithological similarity to reefal limestones widely documented in the Tobruk area. During the Middle Miocene, this formation records a phase of extensive shallow-marine carbonate deposition under warm climatic conditions and relative tectonic stability. The presence of *Porites solida* (Forskål, 1775) confirms the establishment of hermatypic coral reefs along the Cyrenaican margin, reflecting optimal environmental conditions including high water transparency, normal marine salinity, and efficient nutrient cycling. The combined occurrence of *Meandrina subcircularis* (Catullo, 1857) and *Porites solida* (Forskål, 1775) documents a major evolutionary and environmental transition in northeastern Libya, from Oligocene shoal-dominated carbonate systems to fully developed Miocene reefal platforms. This transition mirrors broader palaeoceanographic changes within the Mediterranean–Tethys realm, including climatic warming, relative sea-level fluctuations, and shifts in carbonate factory dynamics. Despite their ex-situ preservation, the studied coral taxa retain diagnostic morphological and ecological characteristics that permit confident paleoenvironmental reconstruction. Their stratigraphic and paleoecological significance highlights the value of reworked coral material in arid carbonate settings, where wadi systems commonly function as natural repositories of upstream stratigraphic information. Reworked corals also contribute to refining regional biostratigraphic frameworks. Taxa such as *Meandrina subcircularis* (Catullo, 1857), with a relatively constrained stratigraphic range spanning the Oligocene–Miocene, provide time-diagnostic markers that facilitate correlation of depositional sequences across Cyrenaica and the broader southern Tethyan margin. In this context, reworked specimens complement in situ assemblages, enhancing the resolution of stratigraphic correlations and age determinations. Furthermore, documentation of reworked coral assemblages provides insights into high-energy depositional processes, including storm events, sea-level oscillations, and tectonic reorganization. The downslope transport of *Porites solida* Forskål, 1775 colonies from reefal platforms underscores the role of episodic high-energy events in redistributing carbonate material across the Cyrenaica margin. Recognition of these processes improves interpretations of carbonate platform evolution and elucidates the interaction between tectonic uplift, hydrodynamic energy, and sedimentary infill. The species-level coral identification has direct implications for hydrocarbon exploration. Oligocene–Miocene reefal carbonates commonly form high-quality reservoir units, and accurate recognition of coral taxa aids in predicting the distribution, geometry, and continuity of subsurface reef complexes. This linkage between coral paleontology and economic geology underscores the importance of precise taxonomic analysis, regardless of whether specimens are preserved in situ or reworked.

Geological distribution of both coral species: Both species have been documented across a broad paleogeographic range, including the Caribbean region, the Red Sea, the Mediterranean Sea, and North Africa (Fig. 8). This wide distribution indicates their ecological tolerance to diverse marine conditions and supports their significance for regional biostratigraphic and paleoenvironmental correlations.

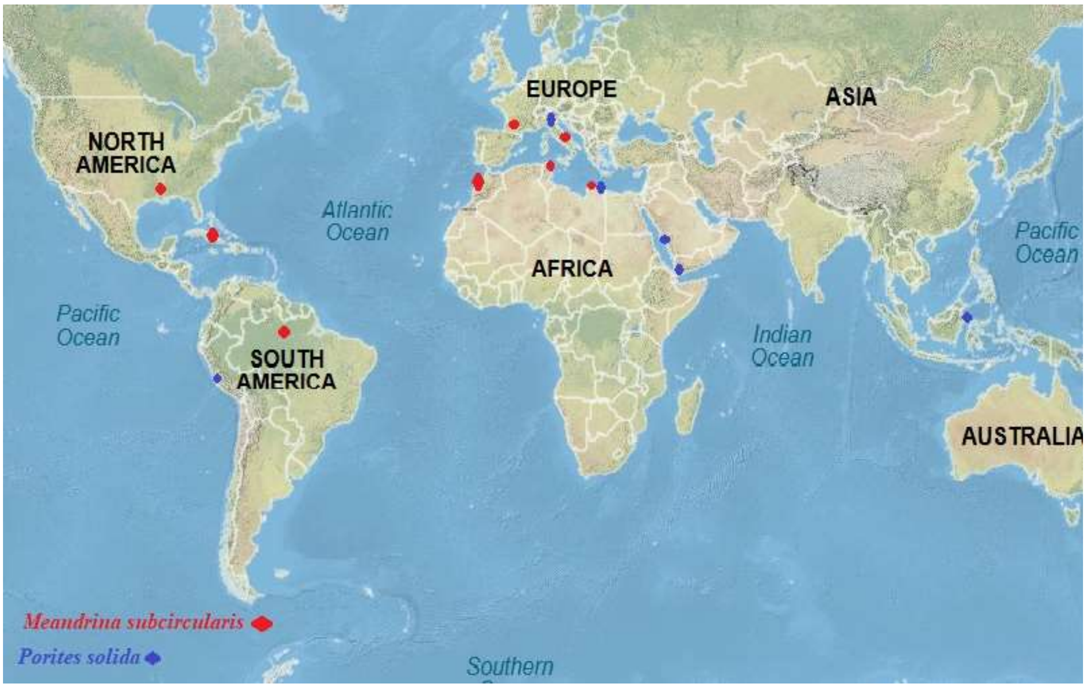

Fig. 8. The global distribution of the *Meandrina subcircularis* (Catullo, 1857) and *Porites solida* Forskål, 1775, including the newly introduced two Libyan sites (Dernah and Tubruk).

3. Conclusions

The investigated coral specimens from northeastern Libya demonstrate that reworked coral material, when analyzed within a robust lithological, microfacies, and stratigraphic framework, can provide reliable paleoenvironmental and stratigraphic information.

Despite their ex-situ occurrence within wadi deposits, the preservation of diagnostic morphological features and their association with well-characterized carbonate microfacies allow confident attribution to the Oligocene Al Abraq Formation and the Middle Miocene Al Jaghboub Formation.

The studied corals record a fundamental shift in carbonate depositional systems along the Cyrenaica margin. The presence of *Meandrina subcircularis* (Catullo, 1857) within foraminiferal-dominated wackestones reflects Oligocene shoal-related carbonate production with only localized coral colonization, whereas *Porites solida* (Forskål, 1775) documents the establishment of fully developed Miocene reefal platforms under stable, high-energy shallow-marine conditions. This transition marks an important evolutionary and environmental change in carbonate factory dynamics during the Oligocene–Miocene interval.

The stratigraphic distribution and paleogeographic affinity of both taxa support regional correlations with coeval carbonate platforms across the southern Tethyan margin and the broader Mediterranean realm. Their occurrence indicates sustained warm-water conditions, open-marine circulation, and effective carbonate production, while their reworking into wadi systems reflects episodic high-energy processes associated with sea-level fluctuations, storm activity, and tectonic uplift affecting the Cyrenaica hinterland.

Beyond their paleoecological significance, species-level identification of fossil corals has direct implications for subsurface reservoir characterization. Reef-building taxa such as *Porites solida* provide valuable constraints on the geometry, continuity, and diagenetic evolution of carbonate bodies that commonly form high-quality hydrocarbon reservoirs. Integrating reworked coral assemblages with sedimentological and microfacies analyses therefore enhances regional stratigraphic models and contributes to a more refined understanding of Oligocene–Miocene carbonate platform development in northeastern Libya.

Acknowledgment

The authors are thankful to the geological laboratory staff members of Sirte Oil Company for thin section preparation, particularly Mr. Hssien Metwalli. Thanks are also extended to Prof. Hwedi El-Rishi for his trimming and important role in supporting this paper scientifically.

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