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Case Report

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Ecological and Sedimentological Insights from Middle Miocene Rhodolith Coral Successions: Coral Dominance, Facies Shifts, and Reef Stability

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Abstract

This study examines the sedimentological and ecological dynamics of a Middle Miocene carbonate succession, emphasizing the facies transition from rhodolith-dominated packstones to coral-boundstones and subsequently to overlying dolomitic limestone. The basal 20 meters are defined by mobile rhodolith nodules, which indicate shallow, high-energy, and well-oxygenated marine environments. From 20 to 45 meters, the succession shifts to a coral-dominated boundstone containing at least five coral species, with Poritidae comprising approximately 75% of the assemblage. Porites lobata is the most abundant species (40%), reflecting a stable, stress-tolerant reef environment that supports diverse benthic communities. The uppermost 10 meters are composed of dolomitized limestone, indicative of diagenetic alteration and a transition to more restricted environmental conditions. These facies change illustrates ecological competition between rhodoliths and corals, with corals outcompeting algae as environmental stability increased. The findings highlight the ecological and evolutionary importance of coral diversity, reproductive strategies, and structural roles in reef resilience. These Miocene reef systems offer valuable analogs for interpreting modern reef adaptation and persistence amid environmental fluctuations.

Keywords: Miocene corals, Benghazi Formation, *Porites lobatam,* paleogeographic distribution.

Introduction

Although carbonate rocks serve as significant reservoir rocks for oil exploration, particularly in the Sirt Basin's Intisar and Sahabi Fields, research on corals in Libya remains limited. While Paleocene coral reefs are essential for these hydrocarbon-rich regions, Cyrenaica presents a contrasting scenario, with corals largely absent from Tertiary subsurface rocks (Asheibi & Shams 2025; Sakran et al. 2016). Jurassic corals are present but have frequently lost porosity due to subsequent geological processes. This study provides the first documentation of eight extant scleractinian coral species from northern Libya at the surface, including six species from Al Jabal al Akhdar. These taxa, ranging from the Middle Eocene to Upper Miocene, include Caulastrea sp., Stylophora sp., Antiguastrea sp., Cyphastrea sp., *Aleveopora* sp., Tarbellastraea sp., Astraeaopora sp., and Actinacis paroraia (Khameiss et al, 2016). Elevated water temperatures compromise the chemical and physical defenses of corals, resulting in reduced growth rates and

diminished competitive ability. Certain crustose algae facilitate coral larval settlement by inducing a frondose morphology, which benefits the algae but inhibits coral growth. Algae rapidly recolonize dead reefs by exploiting stable substrates. Findings from this study contribute to predictions regarding the response of modern coral reefs to future climate warming and provide insights into potential future reef configurations (Khameiss et al., 2024).

Recent investigations have identified well-preserved Miocene Scleractinian corals within two geological units in Northeast Libya: the Benghazi Formation in the As-Sahabi area of the north-central Sirt Basin and the Al Jaghbub Formation near Tobruk. The latter yielded two hermatypic species, *Echinopora gemmacea* and *Montastraea pelouaensis,* which are indicative of early to middle Miocene (Aquitanian–Serravallian) shallow, subtropical reef environments with Mediterranean-Tethys biogeographic affinities. These discoveries underscore the region's potential for further research on coral taxonomy, diversity, and paleoecology, particularly regarding ecological interactions and adaptive strategies in ancient reef ecosystems (Khameiss and William, 2023; Khameiss, 2013). Miocene carbonate platforms in the Mediterranean exhibit a progression from small coral-algal mounds in pre- to late Tortonian times to well-developed barrier reefs with reef-crest structures reaching sea level during the late Tortonian–early Messinian. This transformation likely reflects the coevolution of corals and Symbiodinium zooxanthellae, driven by global cooling and regional geochemical changes that favored aragonite precipitation ((Smith 1991;Pomar and Hallock, 2007; Khameiess et al., 2024).

Location of the study area

Haush Al Akab Quarry is situated approximately 8 km from Al Nawagiyah village and about 30 km southwest of Benghazi, at coordinates 31°52′21.7″ N and 20°09′31.9″ E (Fig. 1).



Fig. 1: Location of the studied section at Hush Al Akaab Quarry, SW of Benghazi city.

Methodology

Coral specimens were collected from exposed outcrops at the quarry site. Following field collection, detailed measurements and morphological analyses were conducted in the laboratory to facilitate accurate identification of the coral species**.**

Results

El-Hawat and Abdulsamad (2004) subdivided Miocene rocks in NE Libya into the Ar Rajmah Group, comprising the Aquitanian-Serravallian Benghazi Formation and Tortonian-Messinian Wadi al Qattarah Formation, separated by a major unconformity. Later studies support this (Abdulsamad and Bu-Argoub, 2006; Abdulsamad and El-Zanat, 2013; Faraj et al., 2016; Elwerfalli et al., 2000). The Benghazi Formation is a massive, fossil-rich limestone with red algae, deposited in a shallow mid-ramp setting (Hassan and Muftah, 2008). It is unconformably underlain by the Late Oligocene Al Faidiyah Formation.

Facies Transition from Rhodolith Packstone to Coral Boundstone and Dolomitic Limestone: Evidence of Environmental and Diagenetic Shifts

The lower 20 m of the succession consist of rhodolith-rich packstone, indicating deposition in shallow, high-energy marine conditions characterized by well-lit, agitated waters that inhibited coral colonization. These free-rolling coralline algal nodules developed through continuous hydrodynamic movement, reflecting open-shelf to shoal settings. Between 20 and 45 m, the facies transition to coral-dominated boundstone, marking a shift to relatively lower-energy and more stable environmental conditions that facilitated the establishment of reef-building corals (Fig. 2). The disappearance of rhodoliths reflects substrate stabilization, linked to relative sea-level rise, or reduced hydrodynamic energy.

The uppermost 10 m comprises dolomitic limestone lacking both corals and algae, indicating strong diagenetic alteration. This suggests a shift to more restricted or evaporitic conditions, where dolomitization overprinted and destroyed the original carbonate fabric

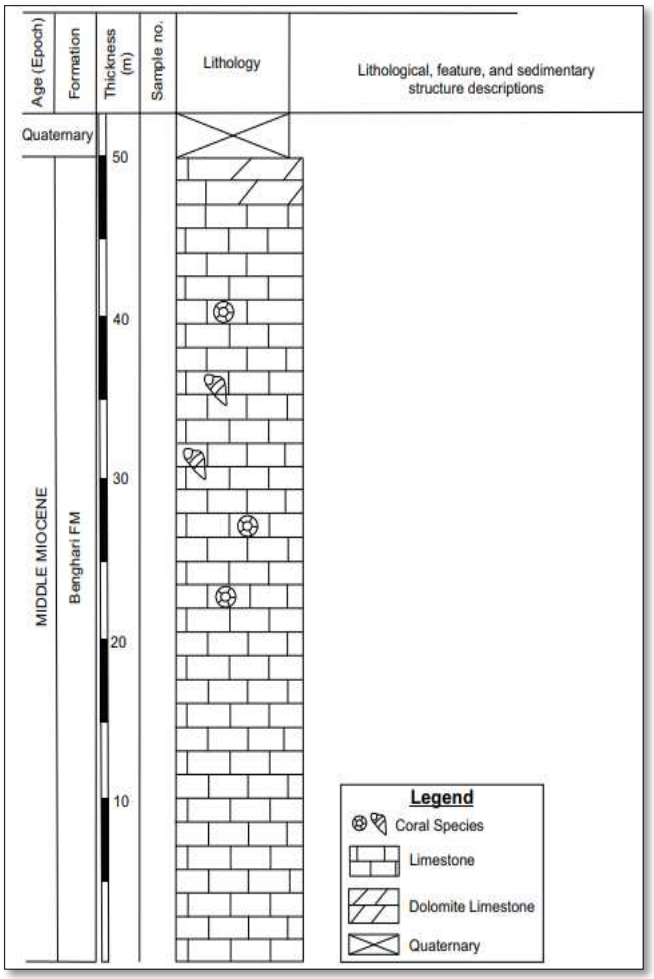


Fig. 2: Lithological column of the Hush Al Akaab Quarried section.

Ecological Significance of Coral Family and Species Distribution: Evidence of Poritidae and Porites Dominance in a Stable Reef Environment

Figure 3 illustrates a clear dominance of the Poritidae family, which constitutes approximately 75% of the coral assemblage, underscoring its ecological significance and resilience in reefal environments. Species such as Porites lobata play a major role in reef framework construction and are indicative of stable, stress-tolerant conditions. In contrast, the families Merulinidae (~15%) and Faviidae (~10%) are less abundant but still contribute meaningfully to biodiversity and structural complexity. Despite their lower representation, their presence enhances habitat heterogeneity and supports the overall health and functioning of the coral reef ecosystem.

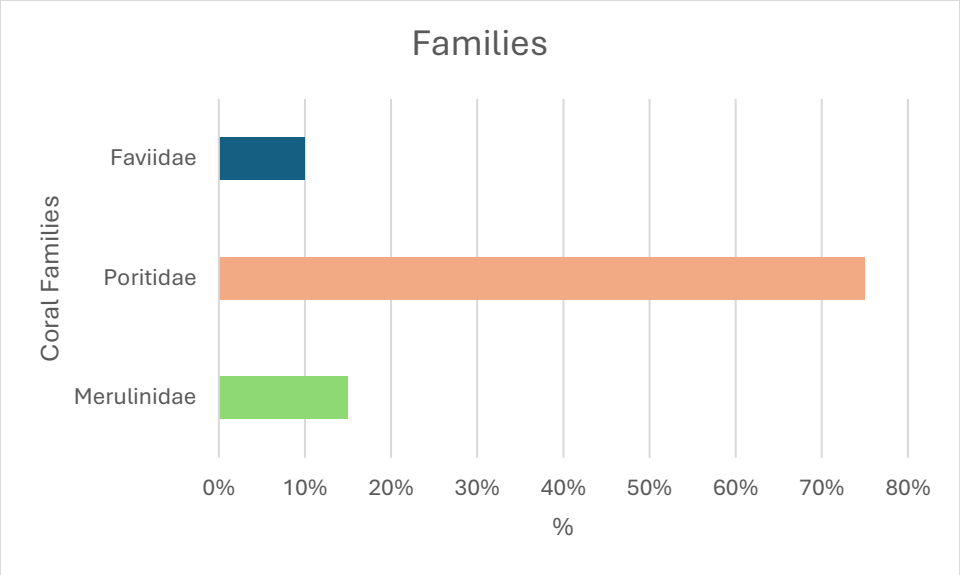


Fig. 3: A histogram displaying the percentage distribution of coral families.

Figure 4 shows that Porites lobata is the dominant species, comprising approximately 40% of the assemblage. Its prevalence indicates favorable environmental conditions and a high tolerance to stress factors such as elevated temperatures and sedimentation. *Porites ramosa* and *Porites branneri* are also well represented (about 20% each), suggesting that members of the genus Porites are particularly well adapted to the local reef setting.

Less abundant taxa, including *Favites abdita* and *Favia fragum* (around 10% each), nonetheless play an important role in maintaining reef biodiversity and ecological balance. Overall, the assemblage reflects a diverse yet Porites-dominated community, in which species diversity contributes to reef resilience and supports ecosystem stability and recovery.

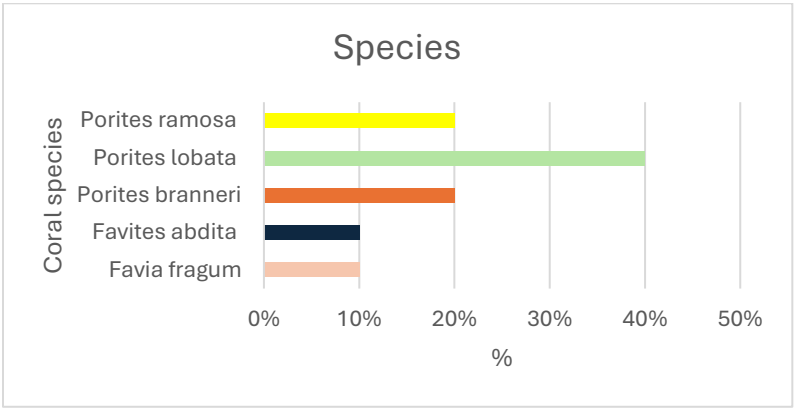


Fig. 4: A histogram displaying the percentage breakdown.

of coral species identified.

Cnidaria Hatschek, 1888

Poritidae Gray, 1840

Porites Link, 1807

Porites lobata Dana, 1846. Fig. 5



Fig. 5: *Porites lobate* from Benghazi Formation at Haush Al Akaab Quarry, Al Nawagiyah, Benghazi.

Morphology and Identification

Porites lobata is a reef-building (hermatypic) coral characterized by high environmental adaptability and variable colony morphology. In high-energy settings it forms encrusting structures, whereas in calmer conditions it develops large dome-shaped colonies that may reach several meters in size. It exhibits very slow growth rates (≈1 cm/year), meaning large colonies can be centuries old. Coloration ranges from greenish to tan due to symbiotic zooxanthellae, while its skeletal structure is defined by exceedingly small, tightly packed corallites with fused, porous walls and delicate tissue covering**.**

Habitat, Distribution, and Abundance

This species is widely distributed across the tropical Indo-Pacific, including the Red Sea, East Africa, the Indian Ocean, Southeast Asia, and extending across the Pacific to Central America and the Gulf of California (Veron, 2000; Glynn et al., 1994). In Hawaii, *P. lobata* is the most common coral species and often dominates reef crests, fringing reefs, and lagoons down to depths of 30 meters (Maragos, 1995). It tends to inhabit slightly deeper zones than species like *Pocillopora meandrina*, commonly known as cauliflower coral (Glynn et al., 1994). Porites lobata has been documented along the East African coast, particularly in regions bordering the Western Indian Ocean, including Kenya, Tanzania, Mozambique, Madagascar, and the Red Sea Obura, (2012).

Biology and Reproductive Strategy

Porites lobata is a gonochoristic coral that reproduces through broadcast spawning, releasing gametes into the water column for external fertilization. The resulting larvae drift before settling to form new colonies, although recruitment success can be low. It can also reproduce asexually through fragmentation, where broken pieces reattach and grow. Reproductive activity varies regionally, with seasonal peaks influenced by environmental conditions such as upwelling and lunar cycles**.**

Ecological Interactions

As a fundamental component of coral reef ecosystems, *P. lobata* provides structural habitat and shelter for a range of reef-associated species. Fish such as the spotted puffer (*Arothron meleagris*) are known to graze on its polyps, while the commensal pistol shrimp (*Alpheus deuteropus*) inhabits the coral lobes, often creating tunnels and grooves in the process (Glynn et al., 1994).

Cnidaria Hatschek, 1888

Poritidae Gray, 1840

Porites Link, 1807

Porites ramosa Catullo, 1857 Fig. 6



Fig. 6: *Porites ramosa* from Benghazi Formation at Haush Al Akaab Quarry*,* Al Nawagiyah, Benghazi.

Morphology and Identification

These coral forms robust, branching colonies with thick, blunt-ended, interconnected branches. Corallites are circular and embedded, with short columellae and two unequal cycles of septa. The coenosteum is finely ornamented, and tentacles are often visible during the day. Colonies typically range in color from cream to pinkish brown**.**

Similar Species and Differentiation

Palauastrea is frequently mistaken for *Porites cylindrica* in underwater settings due to their similar colony morphology. However, a closer inspection reveals that *Palauastrea* possesses star-like corallites, which clearly distinguish it. It may also resemble *Stylocoeniella*, but the latter lacks coenosteum styles and has a different growth form. *Madracis mirabilis* may appear similar as well and should be considered during comparative identification.

Habitat, Distribution, and Abundance

In Australian waters, this species occurs in turbid, sandy-bottom habitats, while in tropical and equatorial regions it is typically found on upper reef slopes. Its Indian Ocean distribution includes the Red Sea, Aden–Djibouti, Minikoi Atoll, the Maldives, Seychelles, by Rosen (1971a, b, and c); and Lachowski (1975).

Cnidaria Hatschek, 1888

Poritidae Gray, 1840

Porites Link, 1807

Porites branneri Rathbun, 1887 Fig. 7



Fig. 7: *Porites branneri* from Benghazi Formation at Haush Al Akaab Quarry, Al Nawagiyah, Benghazi.

Morphology and Identification

Porites branneri is a small, massive to finger-like colonial coral with a compact growth form and closely spaced subcircular corallites (1–2 mm in diameter). It has low corallite walls, weak septa, and shallow calices, giving a richly textured surface. The coenosteum is dense and smooth with little ornamentation. Colonies are typically yellow brown to gray, contain symbiotic zooxanthellae that support calcification, and rarely show visible tentacles during the day(Goreau and Wells, 1967; Veron, 2000).

Similar Species and Differentiation

Porites branneri may be confused with other small-polyp Porites species, such as *Porites porites* or *Porites astreoides*. However, it can be distinguished by its finer corallite spacing, smaller calice size, and more finger-like or encrusting growth habits (Hoeksema and Ten Hove, 2017a,b). In fossil contexts, its compact morphology and minute septa can also help differentiate it from co-occurring faviid and agariciid corals (Bosellini and Ginsburg, 1971a,b).

Habitat, Distribution, and Abundance

Porites branneri inhabits shallow reef environments ranging from 1 to 20 meters deep, favoring calm lagoonal zones and back reef settings. It is commonly found in the western Atlantic, including the Caribbean Sea, Gulf of Mexico, and along the Florida coast (Rathbun, 1887; Goreau and Wells, 1967). The species exhibits notable tolerance to sedimentation and variable environmental conditions, making it a resilient reef-builder in marginal reef environments (Veron, 2000).

Fossil Record and Geological Significance

Although modern occurrences are restricted to the western Atlantic, fossil and subfossil representatives of Porites including morphotypes resembling *P. branneri* have been documented from Miocene to Recent formations across North and East Africa (Wells, 1956; El-Asmar and Wood, 2000a,b). Notably, uplifted reef terraces and shallow marine limestones in Libya, Egypt, and coastal East Africa host Porites-dominated frameworks, which serve as indicators of past reefal environments and sea-level changes (Bosellini and Ginsburg, 1971; MacRae and De Meyer, 2020; Roos, 1971a,b).

Faviidae Milne Edwards and Haime, 1857

Favia De Blainville, 1820

Favia fragum (Esper, 1793) .Fig. 8

Morphological Description of Favia fragum (Golfball Coral)

Favia fragum is a small-sized scleractinian coral, typically forming compact, hemispherical colonies. While solitary growth is common, it may also occur in clusters or develop as an encrusting form under certain environmental conditions. The colony is composed of closely spaced corallites, each usually harboring one to three polyps. Corallites are generally circular in outline but may become oval during budding events as new corallites are formed.



Fig. 8: *Favia fragum* from Benghazi Formation at Haush Al Akaab Quarry, Al Nawagiyah, Benghazi.

Each corallite is defined by four distinct cycles (whorls) of septa, which are well-developed but do not extend prominently above the colony surface. Inter-corallite costae are clearly differentiated, lacking continuity between neighboring corallites. The skeletal surface of *F. fragum* exhibits subtle coloration, commonly ranging from pale brown to yellowish hues, depending on symbiotic zooxanthellae content and local environmental factors.

Geographical Distribution and Habitat

Favia fragum is widely distributed in the tropical western Atlantic, ranging from West Africa across the Caribbean to South America and the southern United States. It occurs in shallow marine habitats such as coral reefs, rocky areas, seagrass beds, and macroalgal zones, typically down to 30 m depth. The species is ecologically resilient and maintains stable populations throughout its range.

Merulinidae Milne Edwards and Haime, 1857

Favites Link, 1807

Favites abdita (Ellis and Solander, 1786) Fig. 9



Fig. 9: *Favites abdita* from Benghazi Formation at Haush Al Akaab Quarry, Al Nawagiyah, Benghazi.

Morphological Description of F*avites abdita*

Favites abdita is a massive, colonial scleractinian coral that typically develops rounded to irregular mound-shaped colonies. The corallites measure approximately 10–14 mm in diameter and are characterized by thick, robust walls. The septa are straight and bear well-developed dentations (Sprung, 1999).

Geographical Distribution and Habitat

Favites abdita is an Indo-Pacific coral found in shallow tropical to subtropical waters, ranging from the Red Sea and East Africa through the Indian Ocean to Japan, Australia, and central Pacific islands. It typically occurs down to about 15 m depth on reef slopes, rocky substrates, lagoons, and reef channels, and may also be found in deeper rubble zones. Stratigraphically, it ranges from the Late Miocene to the present. (Sprung, 1999).

Global Distribution and Biogeography of Selected Coral Species

The global distribution map (Fig. 10) indicates that coral species are predominantly concentrated in warm, shallow marine environments, exhibiting clear biogeographic patterns. *Favites abdita* is widely distributed across the Indo-Pacific, including Southeast Asia, northern Australia, and parts of the western Indian Ocean, whereas *Favia fragum* is largely confined to the Caribbean and western Atlantic regions.

Species of Porites show variable distributions: *Porites branneri* occurs in scattered localities across both the Atlantic and Pacific oceans, while *Porites ramosa* and Porites lobata are more prevalent in the Pacific, particularly within Oceania and around the Hawaiian region. Africa, especially along the eastern coastline and the Red Sea, constitutes a significant center of coral diversity, with extensions into adjacent Indian Ocean regions such as Madagascar and the Maldives. Overall, these distribution patterns reflect strong environmental controls, including sea surface temperature, water depth, reef development, and oceanic circulation, which collectively influence larval dispersal, habitat suitability, and coral biogeography.



Fig. 10: A Global distribution map shows the identified coral species.

Rhodolith–Coral Facies Replacement as an Indicator of Environmental Stabilization in the Middle Miocene

Evidence from Middle Miocene carbonate successions across the Mediterranean and North Africa reveals a clear ecological competition between coralline algae (rhodoliths) and scleractinian corals. Both groups acted as major carbonate producers but occupied distinct ecological niches: rhodoliths thrived in shallow, high-energy settings with mobile substrates, whereas corals favored more stable, lower-energy environments. With relative sea-level rise or a reduction in hydrodynamic energy, corals progressively colonized these substrates, ultimately replacing rhodolith-dominated assemblages. This transition is widely documented across Tethyan carbonate platforms, including those in Libya, Italy, and Egypt.

In the studied section, the disappearance of rhodoliths and the establishment of coral-dominated boundstone between 20 and 45 m reflect this shift toward more stable environmental conditions and competitive replacement. The overlying dolomitic limestone, which lacks both rhodoliths and corals, indicates a subsequent transition to more restricted and/or diagenetically altered conditions that were unfavorable for their development (Fig. 11).

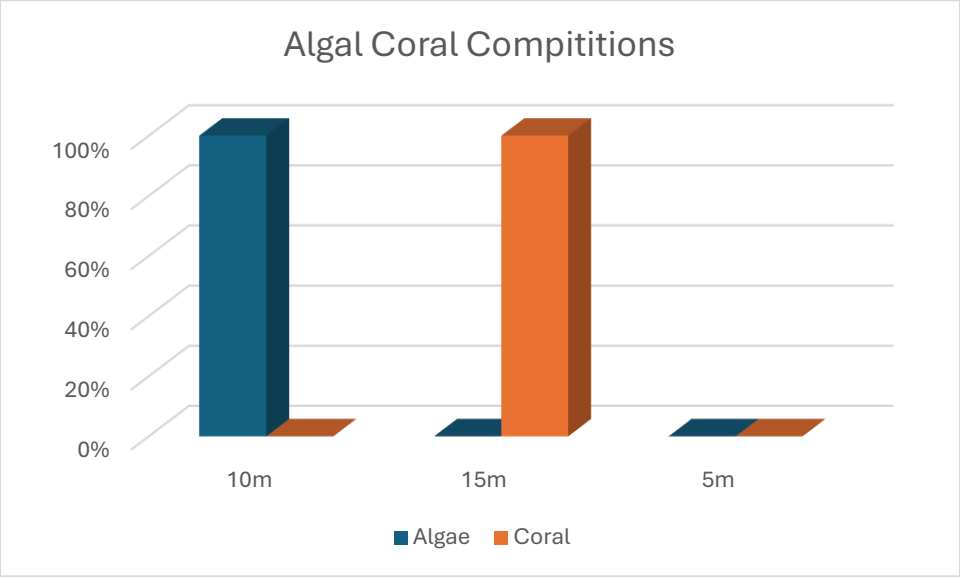


Fig. 11: A histogram displaying the percentage breakdown of coral and algae identified in the study.

Discussion

The studied Middle Miocene succession exhibits a distinct facies transition from rhodolith-dominated packstones to coral-boundstones, reflecting significant environmental and ecological changes. The lower 20 meters are characterized by abundant, unattached rhodoliths, indicative of a high-energy, shallow marine environment. Constant water agitation in these settings inhibited the establishment of sessile organisms, such as corals, while promoting the growth of free-rolling, multi-celled red algae. The prevalence of rhodoliths suggests well-lit, oxygenated waters that supported diverse benthic communities, typical of open-shelf or shoal environments.

Between 20 and 45 meters, the succession transitions to a coral-dominated boundstone, signaling a reduction in hydrodynamic energy that enables corals to colonize and stabilize the substrate. The coral assemblage is overwhelmingly dominated by Poritidae (75%), with Porites lobata alone accounting for 40% of the population. This dominance reflects a reef environment capable of withstanding stressors such as increased turbidity and temperature fluctuations. The presence of less abundant families, including Merulinidae and Faviidae, enhances reef complexity and biodiversity, indicating niche partitioning and reduced competition for resources. This interval exemplifies ecological replacement, where corals outcompeted rhodoliths as environmental conditions became more stable.

The uppermost ten meters, composed of dolomitic limestone, record a further environmental and diagenetic shift. The absence of both rhodoliths and coral frameworks reflects conditions unsuitable for carbonate-producing organisms, resulting from restricted circulation, hypersalinity, or post-depositional dolomitization. Overall, the succession highlights the interplay of environmental energy, substrate stability, and biotic interactions in shaping Miocene reef ecosystems, emphasizing corals as primary reef builders in stabilized marine settings.

Conclusion

The Middle Miocene reef assemblage shows strong ecological balance, with Porites lobata as the dominant species (~40%), reflecting its tolerance to environmental stress such as warming and sediment input. Other species, including *Porites ramosa, Porites branneri, Favites abdita,* and Favia fragum, contribute to overall diversity, reef complexity, and ecosystem resilience through varied morphologies and life strategies that reduce competition and support coexistence.

The succession also records clear environmental and sedimentological changes: rhodoliths dominate lower high-energy settings, corals develop in more stable, lower-energy conditions, forming reef frameworks, and the upper dolomitic limestone reflects diagenetic alteration under restricted conditions unsuitable for both groups. Overall, these patterns highlight the role of environmental control, community structure, and diagenesis in shaping Miocene reef development, offering useful analogs for understanding modern reef resilience under environmental stress.

Declarations

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Data availability: No datasets were generated or analyzed during the

current study.

Declarations

Conflict of interest: The authors declare no competing interests.

Ethical approval: The manuscript does not report on or involve the use

of any animal or human data.

Consent to participate: Not applicable.

Consent for publication. All authors have reviewed the manuscript and

consented to its publication.

Coral samples were collected with permission from the relevant Libyan authorities, in accordance with local regulations governing geological fieldwork and sample collection.

Clinical trial number:

There is no Clinical Trial Number associated with this study, as it is a geological investigation and not a clinical research trial.

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