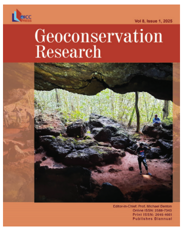

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The *Crassostrea* Coquina Bed in the Qeshm Geopark (Southern Iran): Paleontology, Paleoecology and Geotourism Potential

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Abstract

The *Crassostrea* coquina bed on Qeshm Island is named for its high abundance of Crassostrea virginica fossils. Field surveys and photographic documentation from two key locations show that there are three lithostratigraphic units deposited in deltaic or estuarine environments. Morphological changes in the oyster community suggest an upward increase in sediment load and depositional rate. Evidence of mechanical abrasion and erosion on disarticulated oyster shells indicates accumulation by strong storm and flood or tsunami currents. A Plio-Pleistocene age is confirmed through comparison with identified taxa (*Crassostrea virginica, Pecten vasselii, Pecten jacobaeus?, Chlamys varia, Placuna placenta,* and *Conus* sp.) and the surrounding Aghajari Formation. The outcrops of the *Crassostrea* coquina bed in Qeshm Island could be considered as new geosites in the Qeshm International Geopark. Coquina beds hold significant geotourism potential due to their unique bioclastic composition, fossil-rich layers, and paleoenvironmental insights. Their aesthetic appeal and educational value attract both scientific and general visitors, offering opportunities for geoheritage interpretation. Sustainable management, including controlled access and taphonomic monitoring, is essential to preserve these fragile geological archives.

Keywords: Persian Gulf, Bivalvia, Aghajari Formation, Geosite, Ostrea

Introduction

Coquina beds are among the most striking geological phenomena, consisting almost entirely of fossil shells. They have significant geoheritage value for their unique paleoenvironmental value, offering insights into past coastal dynamics, climatic conditions, and biodiversity. Composed of fragmented shell material cemented into a porous limestone, these deposits serve as key stratigraphic markers and archives of high-energy shallow marine or lagoonal settings. Their study aids in reconstructing Quaternary sea-level fluctuations, sedimentological processes, and biotic responses to environmental change. Additionally, coquina beds are often associated with fossil-rich assemblages, enhancing their educational and scientific appeal. Their durability and aesthetic qualities also make them culturally important as historical building materials, further underscoring their multidisciplinary relevance in geoconservation.

In Iran, such beds have been documented from the Devonian (Hassani *et al.* 2020), Cretaceous (Rahiminejad & Hassani 2016), and Miocene (Hosseinipour & Dastanpour 2013). However, Qeshm Island hosts a unique *Crassostrea* coquina bed (Fig. 1) that has not been previously studied. Although the bed's thickness varies across the island, it outcrops as spectacular dome-like features in some localities (Fig. 2). Given the presence of the Qeshm International Geopark, which includes 38 geosites (an updated list and map of geosites is always available at https://qeshmgeopark.ir/geosites), the *Crassostrea* coquina bed could be added as a new geosite. This paper presents the

Figure 1. Outcrop of the *Crassostrea* coquina bed on Qeshm Island, near Dayyerestan village

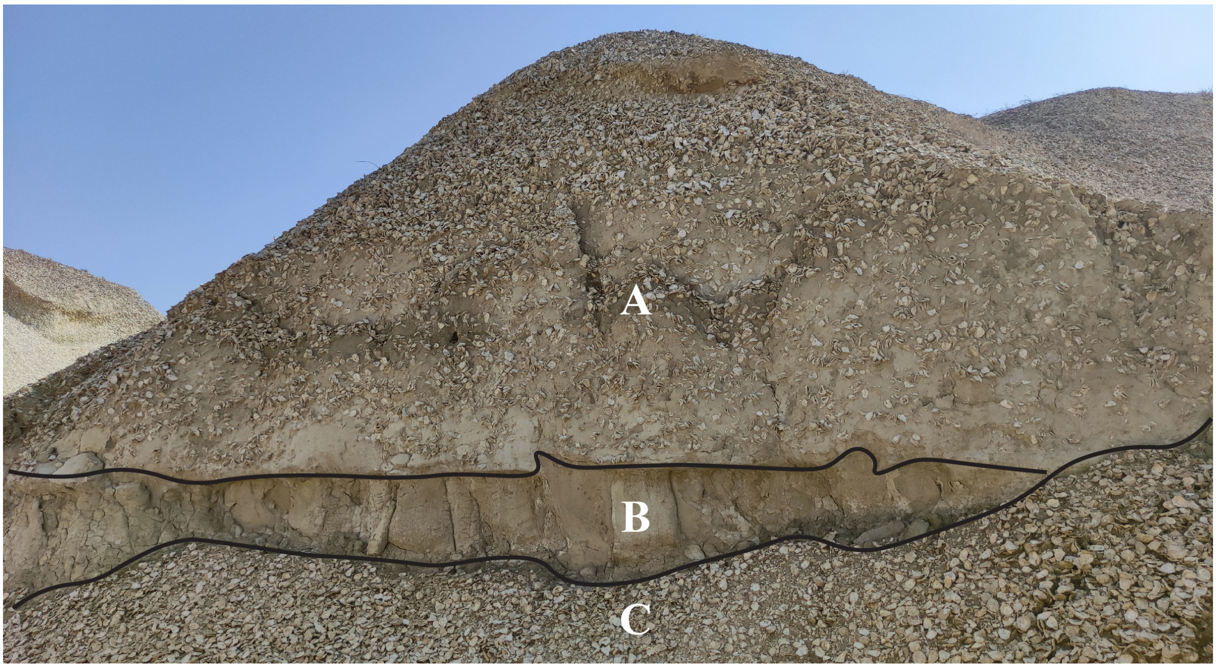

Figure 2. Dome-like outcrop of the *Crassostrea* coquina bed in Qeshm Island, near Dayyerestan village. A) main oyster bearing layer; B) basal fossil lens layer; C) oyster shells that accumulated by erosion of the layer A.

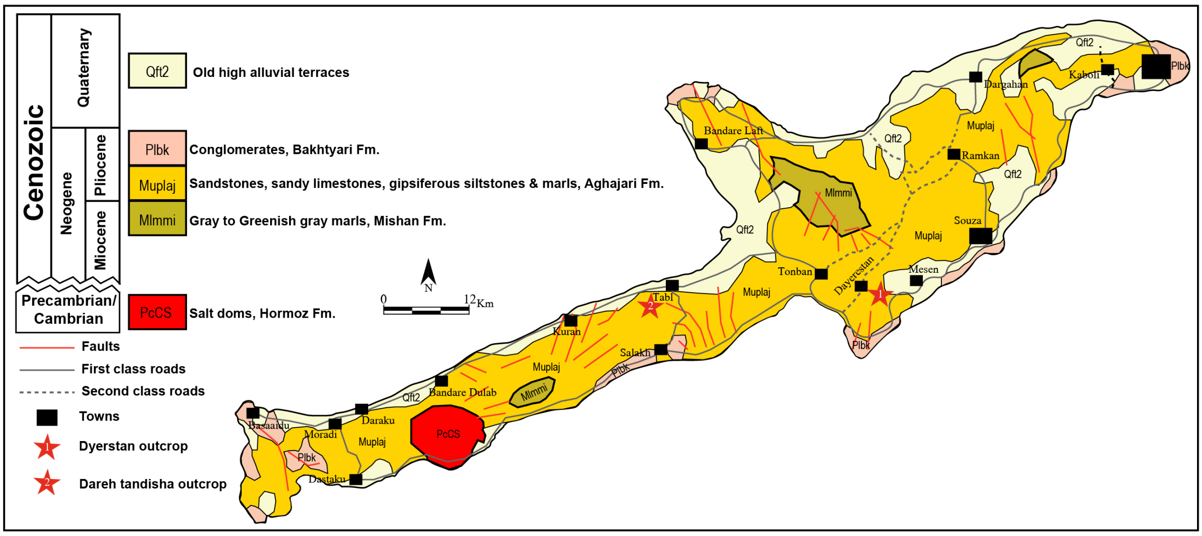

Figure 3. Simplified geological map of Qeshm Island and location of the studied outcrops.

first paleontological, paleoecological, and geological study of the bed at two locations: Dayyerestan and Dareh Tandisha. The *Crassostrea* coquina bed is unique to Qeshm Island and has no counterparts along the Persian Gulf's marginal coasts or other islands.

Geographic and Geological Setting

Qeshm Island lies south of Bandar Abbas in the Persian Gulf, accessible via a short cruise. The island attracts tourists through its attractive ecotourism and geotourism aspects. Qeshm Island is the largest island in the Persian Gulf, situated in the Strait of Hormuz, characterized by an arid climate, rugged terrain, anticlines and extensive salt domes (Hormoz Formations) that shape its distinctive geomorphology. Its physical geography includes coastal plains, mangrove forests (Hara Biosphere Reserve), and uplifted limestone terraces, reflecting dynamic erosional and depositional processes. Tectonically, the island lies within the Zagros fold-thrust belt, a seismically active zone resulting from the ongoing collision between the Arabian and Central Iran plates. This convergence has produced folding, faulting, and salt diapirism, making Qeshm a critical area for studying neotectonics and hydrocarbon-related structures in the region. The study focuses on two outcrops: The outcrop (1) near Dayyerestan village (55°56′24.42″E, 26°44′13.60″N) and the second, at Dareh Tandisha Geosite (55°41′54.09″E, 26°45′6.01″N). The island is primarily composed of clastic deposits from the Upper Miocene–Pleistocene Aghajari Formation (Fig. 3), with the coquina bed occurring at its uppermost strata.

Lithostratigraphy

The *Crassostrea* coquina bed exhibits a consistent lithostratigraphic framework across Qeshm Island. It overlies the Aghajari Formation, which consists of loose siltstone and sandstone with marly and limestone intercalations (Motiee 1990). Field observations reveal three lithostratigraphic units:

1. **Basal Unit (Unit 1)**: A semi-lithified, fossil-poor, dark gray siltstone layer (up to 2 m thick) with erosional features, cross-bedding, and ripple marks, indicative of nearshore deposition (Fig. 4). The upper contact is sharp.

2. **Middle Unit (Unit 2)**: A light green marly layer (up to 2.5 m thick) with increasing mollusk shell density upward. Dominated by in situ and jointed oysters and pectinid

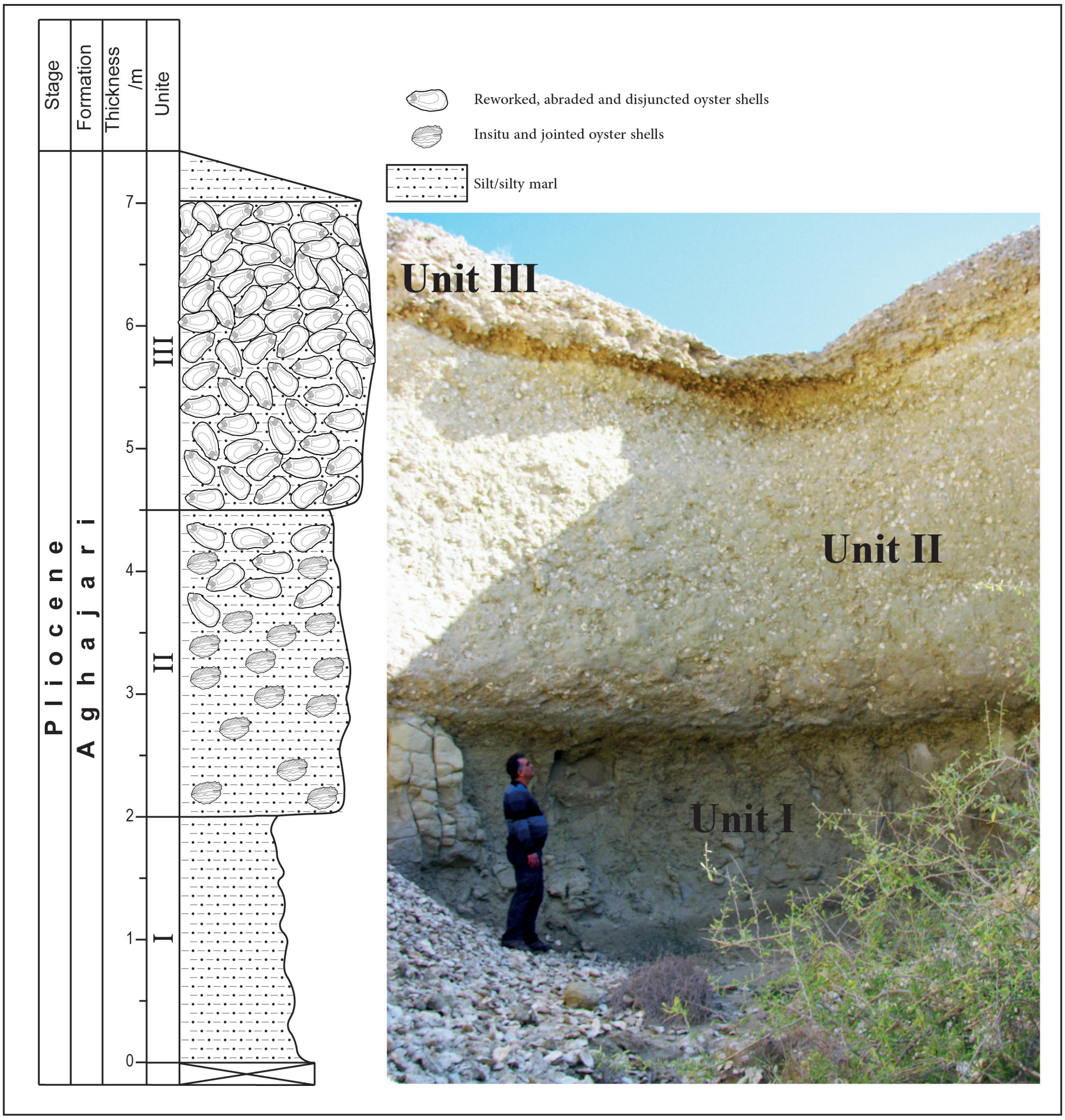

Figure 4. Lithostratigraphic column and field photograph of the *Crassostrea* coquina bed system.

bivalves (Fig. 5), its upper contact appears erosional.

3. **Upper Unit (Unit 3)**: The bulk of the coquina bed, is composed of densely packed oyster shells. Field evidence suggests deposition by strong storm and flood or tsunami currents, which reworked Unit 2's upper strata. Hydraulic sorting, abrasion, and bioerosion support this interpretation.

Lateral tracing shows the system thins and merges into typical Aghajari Formation layers (Fig. 6), confirming a lens-like geometry. Sedimentary structures (e.g., ripple marks) suggest deposition in a submerged delta or estuary.

The upper unit (unit No. 3) is the bulk of the *Crassostrea* coquina bed. The lithology of this unit is not clear because of the heavy density of oyster shells. Based on repeated field observations, we concluded that this unit may have been deposited by washing and in situ redeposition of the top of

Figure 5. In situ and jointed shells of oyster and pectinid bivalves at the base of unit No.2.

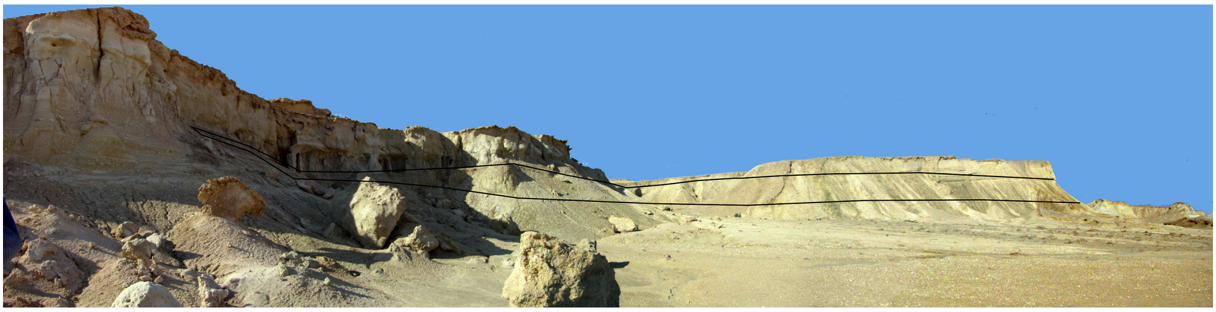

Figure 6. West view of the lateral edge of the *Crassostrea* coquina bed near Dayyerestan village.

unit No. 2 by a strong storm and flood currents or maybe a tsunami. The accumulation of disjunct oyster shells, signs of mechanical abrasion, bio-erosion and hydraulic sorting confirms that the uppermost strata of unit No. 2 had been affected by strong currents that resulted in mass mortality in the domestic oyster community.

By tracing the lateral continuity of the *Crassostrea* coquina bed system in the field, it is evident that the whole system verges out laterally and is replaced by normal layers of the Aghajari Formation (Fig. 6). Therefore, it may be concluded that the *Crassostrea* coquina bed system is lens-like in 3D aspect.

The geometry of the *Crassostrea* coquina bed and present sedimentary structures (ripple marks and cross-bedding) suggest that the whole *Crassostrea* coquina bed system was deposited on a submerged proximal part of a delta or an estuary.

Paleontology

The *Crassostrea* coquina bed preserves a low-diversity but taphonomically significant molluscan assemblage, dominated by bivalves with rare gastropod and echinoderm elements. To consider and identify the fossil community many specimens were collected, 271 from the Dayyerestan and 87 from the Dareh Tandisha. Systematic studies have only been conducted on 300 well-preserved specimens .Systematic analysis reveals four bivalve genera) *Crassostrea*, *Pecten*, *Chlamys*, *Placuna*) and the gastropod *Conus* sp., all exhibiting diagnostic preservation states that constrain both paleoecological and depositional conditions.

Among Ostreidae*, Crassostrea virginica* (Gmelin 1791) constitutes >85% of the assemblage. Specimens occur in three preservational modes:

- *Articulated* (15%): Paired valves with intact ligamental areas (Fig. 7A–B), indicating minimal postmortem transport.
- *Disarticulated but complementary* (60%): Valves displaying congruent abrasion patterns (Figs. 7C–D), suggesting local reworking.
- *Hydraulically sorted* (25%): Size-segregated shell layers (Fig. 12E), diagnostic of high-energy events.

Morphometric analysis confirms two ecophenotypes:

- *Recliners* (H/L ratio 0.4–0.6): Dominant

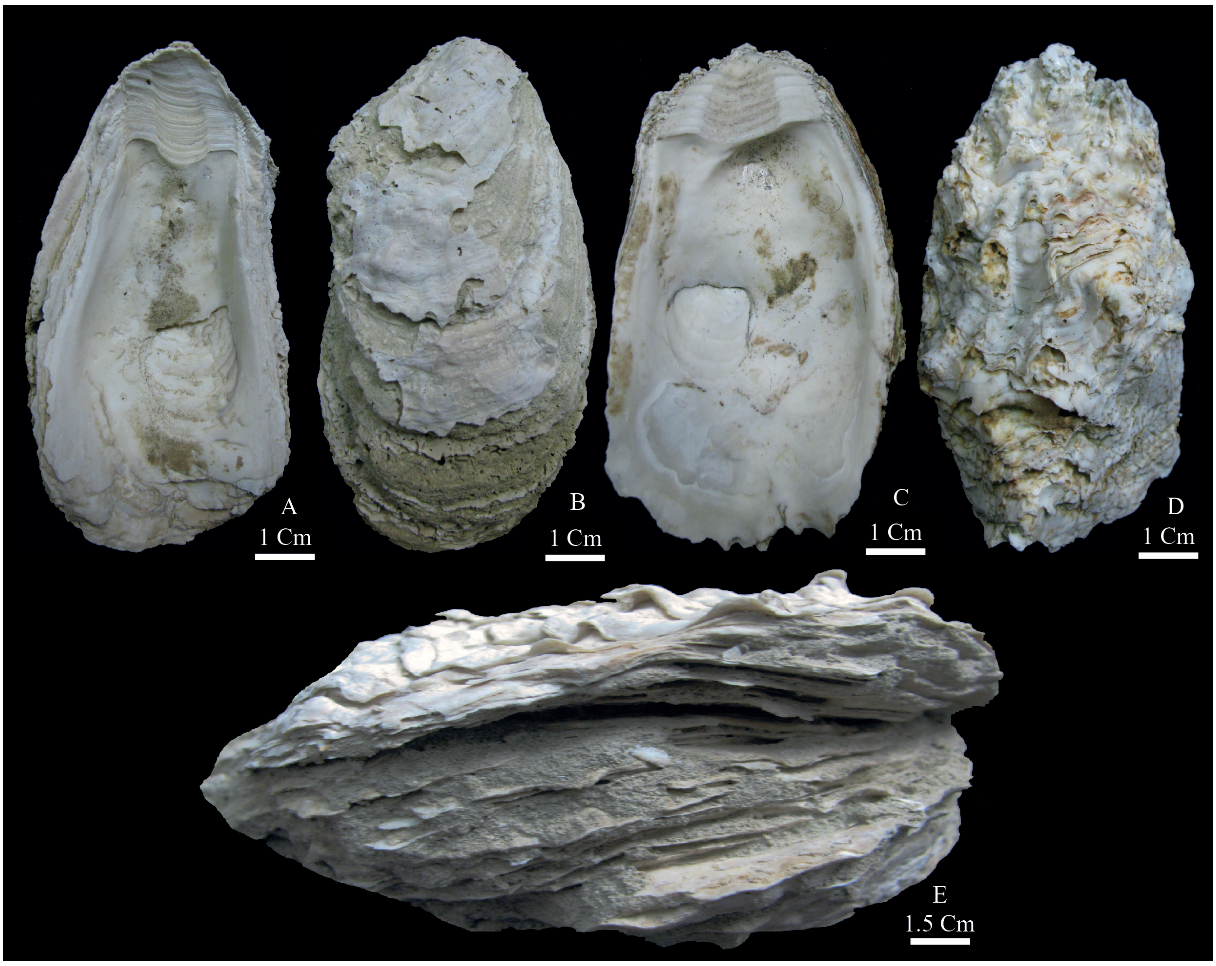

Figure 7. The ostraeid *Crassostrea virginica*. A) internal view of left valve; B) external view of left valve; C) internal view of right valve; D) external view of right valve; E) lateral view.

in Unit 2, associated with low sedimentation rates (Seilacher *et al.* 1985).

- *Mud-stickers* (H/L 0.2–0.3): Abundant in Unit 3, reflecting turbid, high-sediment conditions (Kirby 2001).

Among Pectinidae, we note *Pecten vasselii* (Fuchs 1878) comprising complete specimens (Figs. 8, 9) restricted to Unit 2, with prismatic shell layers intact, confirming low-energy burial, as well as *Pecten jacobaeus?* (Linnaeus 1758), comprising rare, abraded valves (Figs. 10A–B) in Unit 3; taxonomic assignment remains provisional due to taphonomic alteration.

Accessory taxa include *Chlamys varia* (Linnaeus 1758) and *Placuna placenta*, comprisingragmentary hinges (Fig. 10C) that imply mechanical destruction before final burial, as well as *Conus* sp., comprising apertural fragments (Fig. 10D) lacking abrasion that suggest rapid entombment.

The assemblage's preservational bias toward thick-shelled oysters reflects both the original community structure and taphonomic overprinting. The size-frequency distribution is unimodal, with a peak at 8–12 cm (Fig. 7E), matching modern *C. virginica* populations in stressed environments (Powell *et al.* 2016). As for bioerosion, 32% of Unit 3 shellsexhibit *Oichnus* borings (Figs. 12F–H), indicating prolonged exposure on the seafloor before burial. Valves in Unit 3 score 3–4 on the Brett & Baird (1986) abrasion scale, consistent with tsunami transport (cf. Massari *et al.* 2009; Razzhigaeva *et al.* 2006).

The co-occurrence of *P. vasselii* (Late Miocene–Pliocene) and *C. virginica* (Plio-Pleistocene) supports correlation with the uppermost Aghajari Formation (Motiee 1990). Sr-isotope dates from comparable Persian Gulf assemblages (Gholamalian *et al.* 2022) further constrain the age to 2.1–0.8 Ma.

Figure 8. In-situ specimen of Pecten vasselii at the base of the second lithostratigraphic unit.

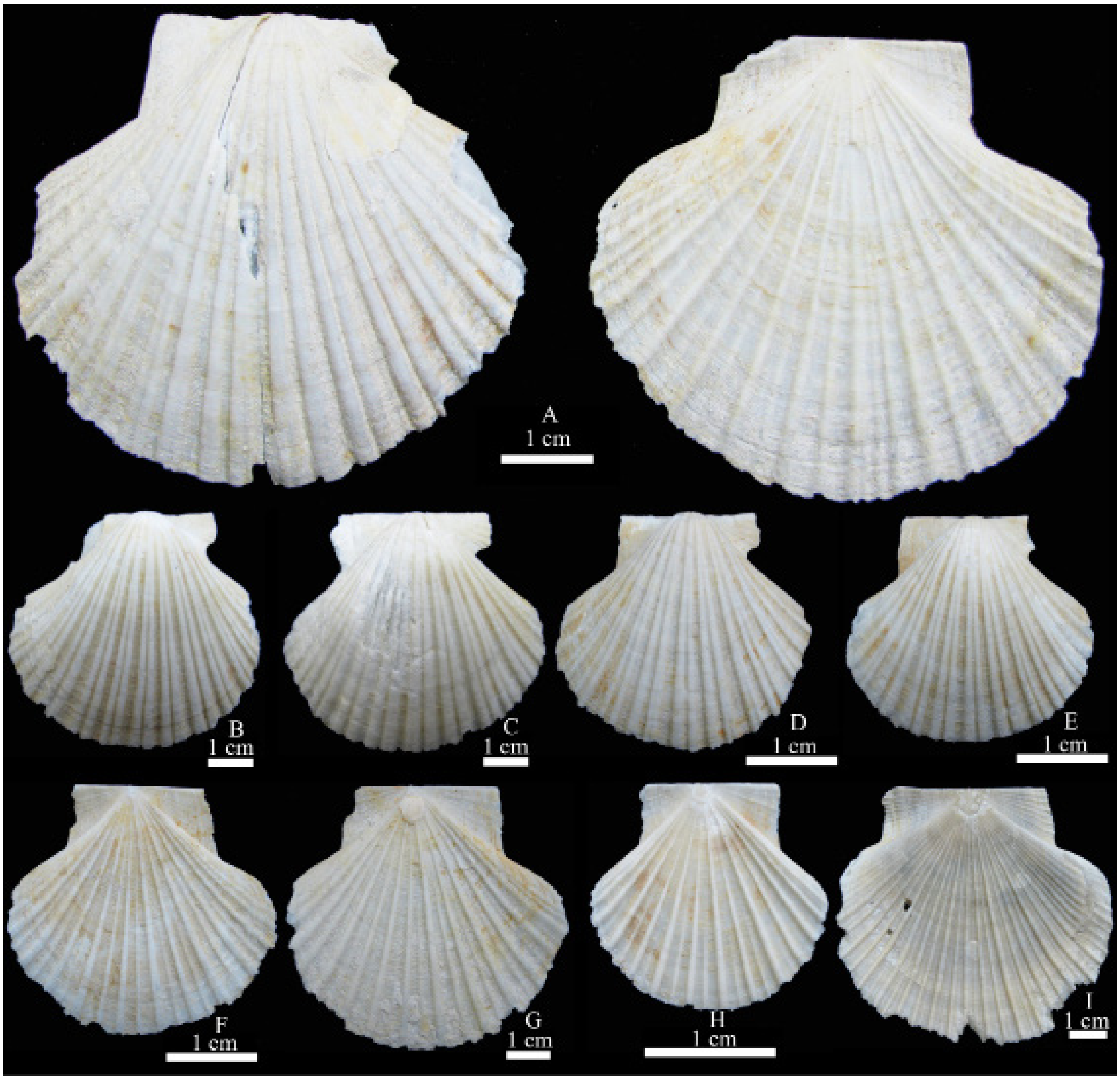

Figure 9. The pectinid bivalve *Pecten vasselii.* A) right and left valves of a complete and jointed shell; B–E) right valves of variously sized examples; F–I) left valves of variously sized examples.

Paleoecology

The paleoecological interpretation of the *Crassostrea* coquina bed integrates sedimentological context, taphonomic analysis, and functional morphology of the dominant taxa. The lensoidal geometry of the deposit, coupled with associated sedimentary structures, strongly supports deposition within a marginal marine setting, specifically a delta-front or proximal estuarine environment (Tyler & Miall 1991; Cuitiño *et al.* 2013). Such settings are characterized by heightened nutrient fluxes and episodic sediment pulses (Hoffman 1978), conditions that would have selectively favored robust, eurytopic taxa such as oysters.

The exceptional preservation of *Crassostrea virginica* specimens provides critical insights into paleoenvironmental dynamics. As demonstrated by Seilacher (1984) and Stenzel (1971), oyster shell morphology serves as a sensitive proxy for ambient conditions: reclining plano-convex forms dominate under low-energy conditions with limited siliciclastic input, whereas elongated, heavily ribbed morphotypes characterize high-energy, sediment-laden environments. The stratigraphic

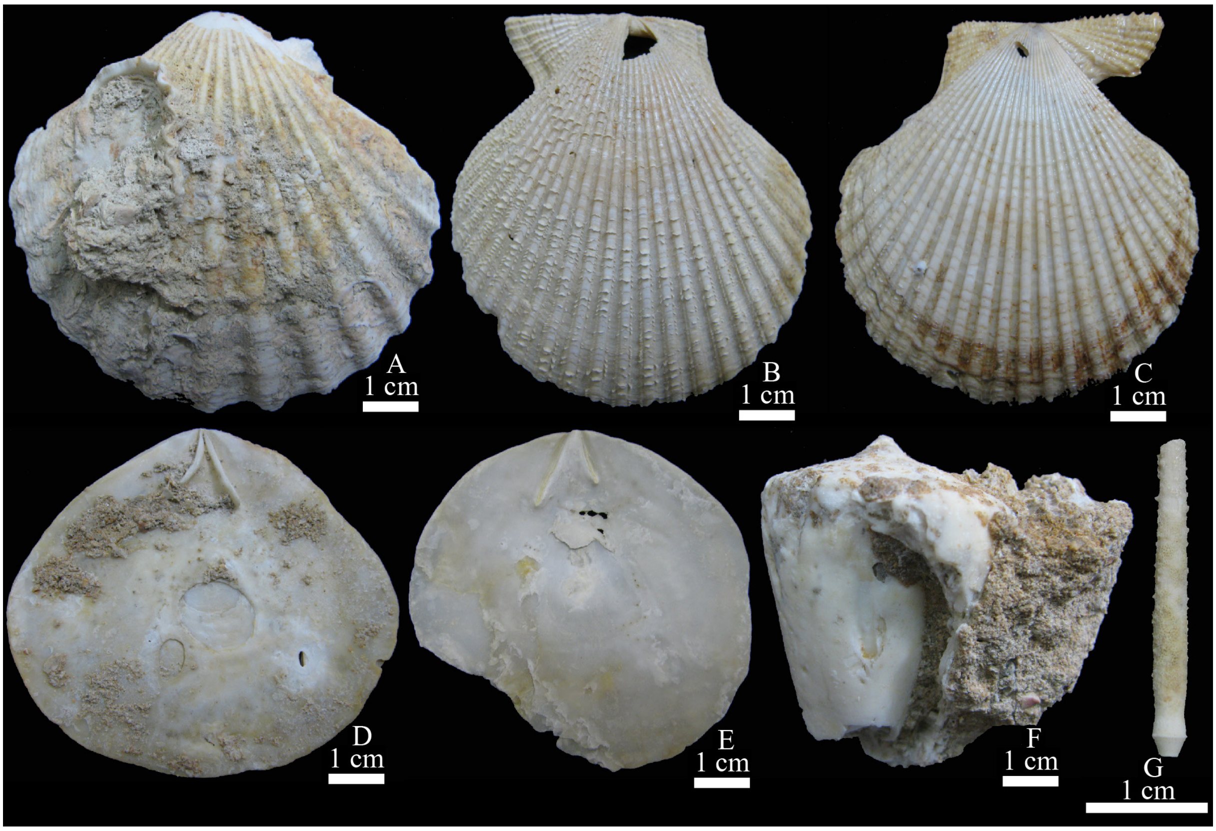

Figure 10. Various bivalves. A) right valve of *Pecten jacobaeus*; B), right valve of Chlamys varia, C) left valve of the *Chlamys varia*; D-E) right valves of the *Placuna placenta;* F) *Conus* sp.; G) echinoid spine.

transition from recliners to mud-sticker morphologies within Unit 2 (Fig. 11) corresponds to a temporal increase in both sediment flux and hydrodynamic energy. This interpretation is further corroborated by the stratigraphic disappearance of thinner-shelled pectinids (*Pecten vasselii*, *P. jacobaeus?*), which exhibit lower tolerance to turbid conditions.

Taphonomic signatures constrain the depositional history with remarkable precision. The co-occurrence of articulated shells, disarticulated valves with complementary abrasion patterns (Figs. 12A-D), and hydraulically sorted shell layers (Fig. 12E) preclude gradual accumulation. Rather, these features collectively indicate a high-energy depositional event of limited duration. The absence of tempestite bedding or graded turbidite sequences effectively excludes storm or flood origins. Instead, we posit that the bed is a seismic-triggered tsunami based on three lines of evidence:

1. **Molar-tooth structures** in the underlying Unit 1 (Pratt 1998) suggest synsedimentary seismic activity;
2. **Bioerosion traces** (Figs. 12F,H) demonstrate post-event marine inundation; and
3. **Global analogs** (Massari *et al.* 2009; Le Roux *et al.* 2008) document nearly identical shell beds formed by tsunami backwash.

While tsunamite deposits remain rare in the Persian Gulf stratigraphic record, the 2017 Bandar Dayyer event (Salaree *et al.* 2018) confirms the region's susceptibility to such phenomena. The *Crassostrea* coquina bed thus represents both a significant paleoenvironmental archive and a potential benchmark for identifying Plio-Pleistocene seismic events in shallow marine sequences.

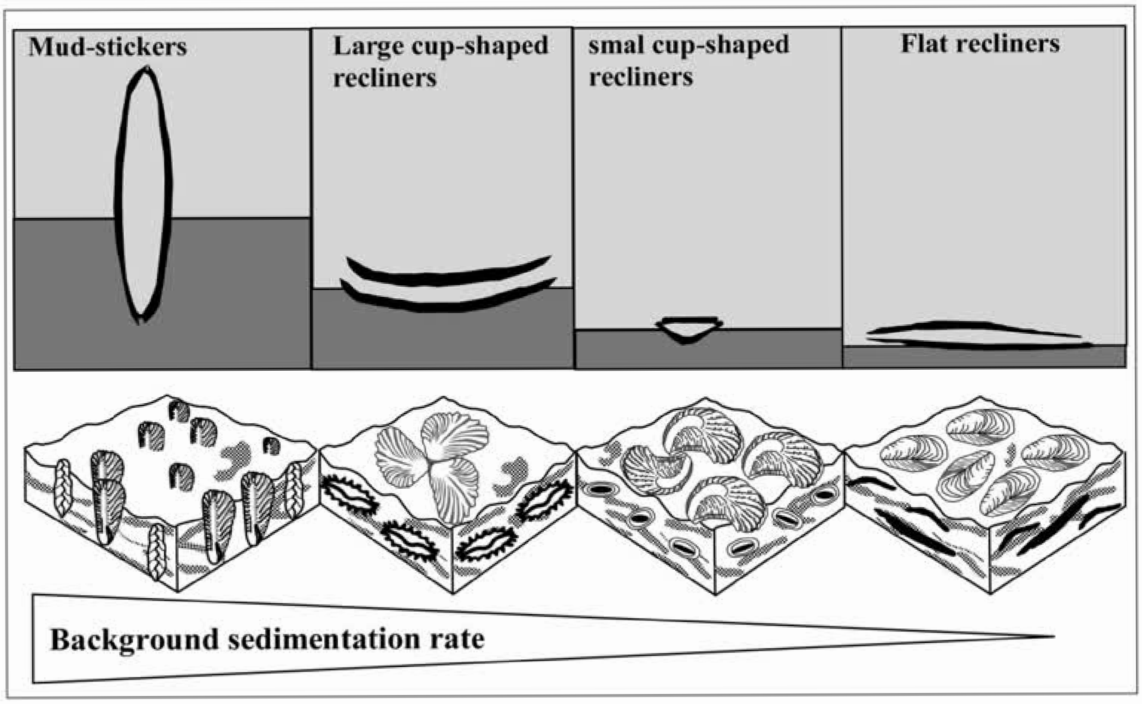

Figure 11. Schematic diagram showing changes in shell morphology in response to water depth and depositional rate in oyster communities (Hosseinipour et al. 2014).

Geotourism and Research Value

The bed's exceptional exposure and diverse fossil assemblages warrant designation as a new geosite within the Qeshm Geopark. The geometry and high-density accumulation of bivalve shells exhibit significant geotouristic appeal due to their visual and educational prominence. Furthermore, the unique co-occurrence of in situ and reworked oyster communities, along with their taphonomic signatures and paleoecological implications, enhances the site's scientific value, making it particularly compelling for research-oriented visitors and geoheritage enthusiasts.

These geosites must be effectively protected, requiring a multidisciplinary approach integrating physical barriers, visitor management strategies, and ecological monitoring. Protective measures may include the installation of non-invasive fencing, designating pathways to minimize trampling, and interpretive signage to educate visitors on fragile geological features. For erosion-prone sites, geoengineering techniques can mitigate natural degradation. Regular geotechnical assessments and 3D documentation (e.g., LiDAR, photogrammetry) enable damage tracking, while regulated access policies balance tourism with preservation. Collaboration with local communities ensures sustainable stewardship, aligning geotourism goals with long-term geoheritage integrity.

Conclusion

The *Crassostrea* coquina bed of Qeshm Island is a stratigraphically constrained and taphonomically distinctive Plio-Pleistocene deposit that provides critical insights into marginal marine paleoenvironments of the Persian Gulf. The bed's position within the uppermost Aghajari Formation, coupled with the co-occurrence of *Pecten vasselii* (LAD: 1.8 Ma) and *Crassostrea virginica*, precisely con-

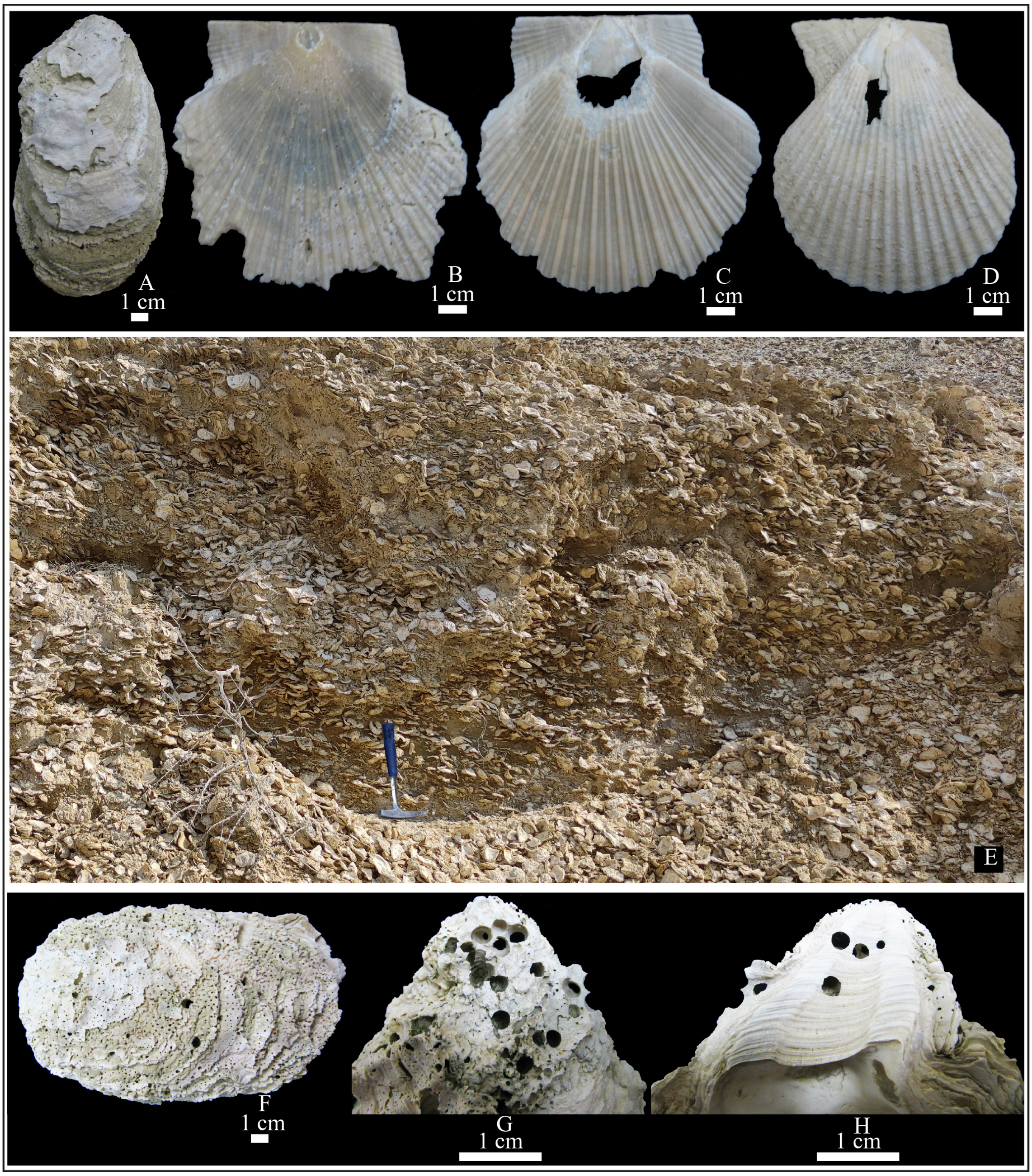

Figure 12. Taphonomy of the shell bed fossils. A-D) signs of mechanical abrasion and physical erosion on the collected fossil shells; E) a photograph showing the hydraulic sorting in the *Crassostrea* coquina bed; F–H) signs of bioerosion on collected fossil shells.

strains its age to 2.0–1.8 Ma, resolving prior ambiguities in regional correlations.

The shift from reclining to mud-sticker oyster morphotypes records escalating sediment flux during the island's uplift, with pectinid extirpation marking ecological turnover. The dominance of thick-shelled, eurytopic taxa (*C. virginica*) reflects adaptation to turbid, nutrient-rich deltaic conditions, consistent with modern analogs (Galtsoff 1964; Powell *et al.* 2016). Tsunami origin is strongly supported by hydraulic sorting and shell abrasion indices (3–4 *sensu* Brett & Baird 1986) matching global tsunami deposits (Massari *et al.* 2009, Razzhigaeva *et al.* 2006). Bioerosion signatures (*Oichnus* traces) confirm post-event marine submersion. Also, molar-tooth structures in underlying strata (Pratt 1998), suggesting seismic triggering.

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Authors' Contribution

Both authors participated in all stages of the article preparation, including fieldwork, laboratory studies, and text editing.

Conflict of interest statement

The authors declare that there are no conflicts of interest associated with this study.

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