Facies Characterization, Diagenetic Processes, and Reservoir Quality of the Asmari Formation in the Lorestan Region, Zagros Basin (Iran): A Case Study from a Subsurface Well

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ABSTRACT

The Asmari Formation, with Oligo-Miocene age, one of the most important hydrocarbon reservoirs for production and extraction in Iran, in the Zagros Basin. In the Lorestan region, this formation displays a mixed carbonate–evaporite nature, within early Miocene deposits. In this study, a subsurface well from the Lorestan sector was analyzed in detail to reconstruct the sedimentary environment, identify microfacies, and assess the reservoir quality based on sedimentary and diagenetic controls. A total of 17 sedimentary microfacies were identified, deposited in a homoclinal ramp-type carbonate platform. The facies distribution and depositional conditions experienced substantial changes across the formation's vertical profile, with a distinct transition from common coral red algae in the lower sequence to rare aragonitic-walled red algae (Peyssonellia-type) in the upper sequence.

Porosity assessment revealed that facies such as packstone to grainstone dominated by aragonitic red algae exhibit the highest average porosity (9.2%), attributed to extensive moldic porosity resulting from algae dissolution. In contrast, low-energy lagoonal and deeper open marine facies typically showed limited reservoir potential due to micritization and cementation. Diagenetic processes, including marine cementation, mechanical compaction, dolomitization, neomorphism, and selective dissolution, significantly controlled the evolution and spatial distribution of porosity. A sequence stratigraphic framework highlights the major influence of sea-level fluctuations on facies transitions and diagenetic overprints, with evaporite intervals acting as potential sealing units.

Overall, this study introduces a unique facies model for the Asmari Formation in Lorestan, documenting the replacement of coral red algae with aragonitic red algae, and emphasizes the critical role of diagenesis in enhancing or diminishing reservoir properties in carbonate–evaporite systems.

Keywords: Asmari Formation; Zagros Basin; Microfacies; Diagenesis; Porosity Distribution; Sequence Stratigraphy; Homoclinal Ramp; Aragonitic Red Algae; Reservoir Quality

1. *INTRODUCTION*

The Asmari Formation represents one of the most significant petroleum reservoir units in Iran and the wider Zagros fold-thrust belt, owing to its extensive hydrocarbon production and widespread distribution across multiple oil fields. While this formation has been extensively studied in provinces such as Khuzestan and Fars, its facies development, diagenetic evolution, and reservoir characteristics remain underexplored in the Lorestan region—despite its complex interplay of carbonate and evaporitic sedimentation during the Oligo-Miocene (Figure 1).

In the subsurface sequences of Lorestan, the Asmari Formation exhibits a distinctive mixed carbonate–evaporite nature. This variation reflects significant changes in sea level, basin restriction, and paleoenvironmental conditions, particularly during the Aquitanian and Burdigalian stages. The presence of evaporites such as anhydrite and gypsum within the lower Asmari, and the emergence of unique red algae with aragonitic walls (Peyssonellia-type) in the upper part, points to a dynamic depositional system that differs markedly from the conventional facies models developed in Khuzestan and central Zagros, Furthermore, benthic foraminifera assemblages in similar Oligo-Miocene intervals have been used to infer salinity and energy fluctuations in the Zagros Basin (Bahrami & Moussavi-Harami, 2019).

Previous works (e.g., James & Wynd, 1965; Vaziri-Moghaddam et al., 2006; Amirshahkarami et al., 2007) have classified the Asmari ramp as a rimmed to homoclinal carbonate platform. However, these models do not adequately explain the peculiar diagenetic patterns and facies successions observed in Lorestan. Furthermore, the vertical transition from coral red algae to aragonitic red algae, coupled with evidence of sea-level oscillations, strongly suggests a need for revising the regional facies and reservoir models.

This study aims to fill this gap by presenting a comprehensive facies analysis, diagenetic interpretation, and porosity distribution assessment of the Asmari Formation in a representative well from Lorestan. Emphasis is placed on the unique stratigraphic organization, sedimentological processes, and post-depositional alterations that control the reservoir properties in this part of the basin.

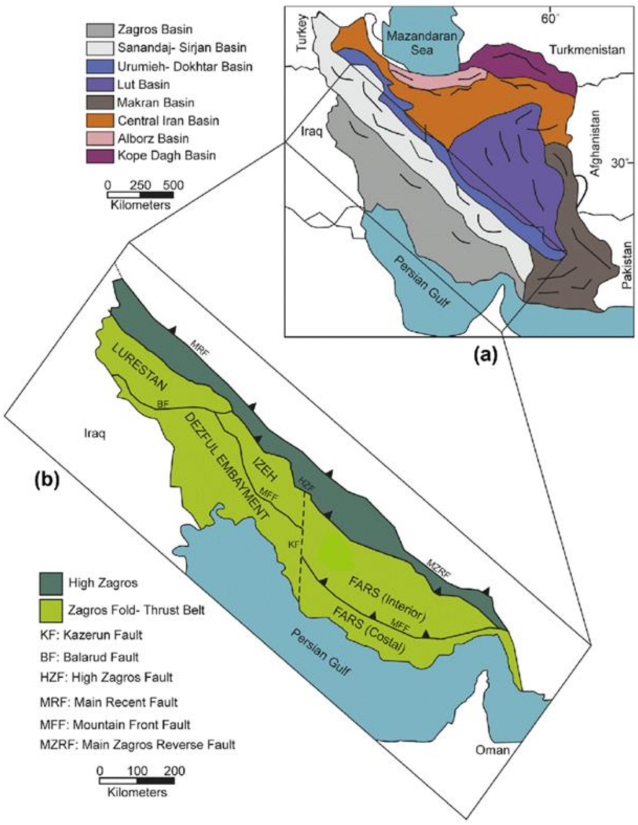

Fig. 1. *Geological location of the study area in the Lorestan zone, northern Zagros Basin, Iran.*

2. Geological Setting

The study area is located within the northern part of the Zagros Fold–Thrust Belt, specifically in the Lorestan sub-basin. This region lies between the Main Zagros Thrust and the High Zagros Fault and is characterized by an elongated and structurally complex geometry due to active compressional tectonics during the Cenozoic. The Asmari Formation in Lorestan rests conformably on the Pabdeh Formation and is overlain by the evaporitic Gachsaran Formation, forming a prominent stratigraphic succession from the Oligocene to early Miocene.

The stratigraphy of the region indicates that the Oligocene–Miocene transgression deposited a shallowening-upward carbonate sequence on a homoclinal ramp, transitioning from deeper, open-marine facies at the base to high-energy shoal and restricted lagoonal environments upward. The absence of significant slope-related deposits such as slumps, turbidites, or breccias suggests the dominance of a gentle ramp setting over a rimmed shelf platform. Evaporitic intercalations within the lower Asmari, specifically in the Kalhor Member, reflect semi-restricted conditions under arid climatic regimes during the Aquitanian. These evaporites are dominantly composed of anhydrite and gypsum and are interpreted as excellent regional seals for underlying hydrocarbon-bearing units.

Vertical and lateral facies changes within the formation are attributed to eustatic sea-level changes, synsedimentary faulting, and variations in accommodation space. The occurrence of middle Miocene uplift and regional erosion is evidenced by local truncation of the upper Asmari in some parts of the Lorestan Basin. Notably, the transition from coral-dominated shoals to facies rich in aragonitic-walled red algae marks a unique paleoenvironmental condition rarely observed in other sectors of the Zagros Basin(Figure 2).

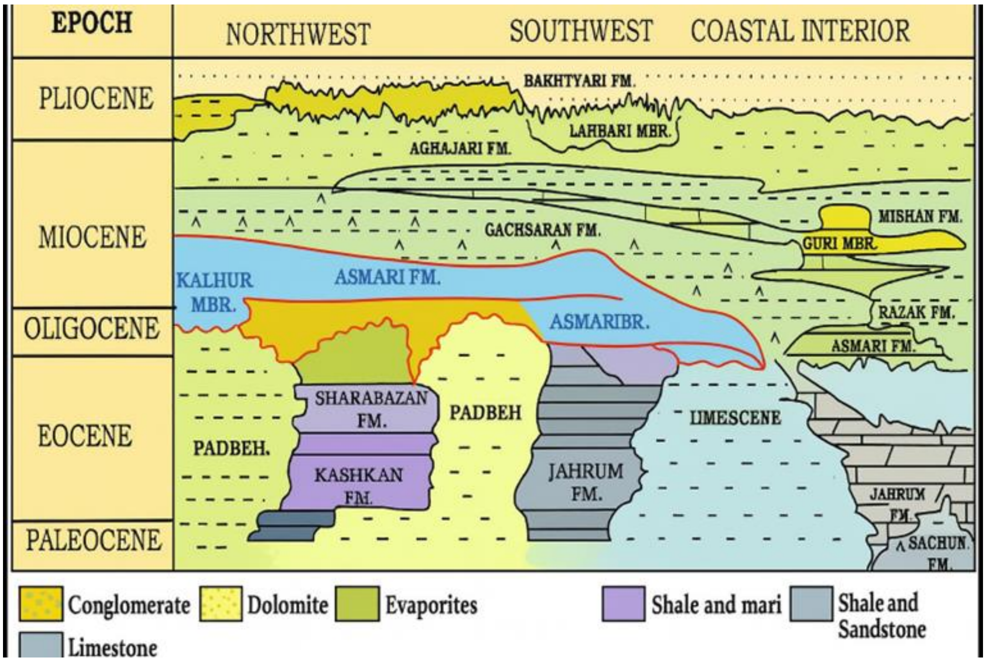

Fig. 2. *schematic illustration of the spatial and temporal distribution of depositional facies in the Zagros Basin from the Late Eocene to Early Miocene. Modified from Ala (1982).*

3. Materials and Methods

This study is based on the detailed petrographic analysis of 150 thin sections prepared from a cored interval of the Asmari Formation in one subsurface well drilled in the Lorestan region. The core interval covers the entire thickness of the Asmari Formation, from its contact with the underlying Pabdeh Formation to the overlying Gachsaran Formation.

The methodology involved:

- **Facies analysis** using the standard microfacies classification of Wilson (1975) and Flügel (2010), supported by field analogs and core descriptions.
- **Diagenetic interpretation** based on the identification of cement types, dissolution textures, compaction features, dolomitization patterns, and neomorphic alterations.
- **Porosity assessment** through visual estimation and point-counting methods, distinguishing between interparticle, intraparticle, moldic, vuggy, and fracture porosity.
- **Environmental reconstruction** using facies stacking patterns and vertical sequences to define depositional settings.
- **Stratigraphic correlation** was performed using the vertical distribution of microfacies and their bounding surfaces to interpret transgressive–regressive cycles.

4. Results

4.1. Microfacies Types

Seventeen distinct microfacies (Mf1–Mf17) were identified within the Asmari Formation based on petrographic analysis of thin sections. These microfacies are classified into four main depositional environments: tidal flat, lagoon, shoal, and open marine settings.

Among the most prominent are:

- **Mf10: Bioclastic Coraline Red Algae Rudstone-Packstone**
  This is a highly fossiliferous facies composed predominantly of encrusting coralline red algae and benthic foraminifera with porcelaneous walls (e.g., Miliolids and Peneroplis). Rhodoliths and red algae clasts are common, and dissolution features in these components have produced significant moldic porosity.
  Reservoir Quality: High, with average porosity of 9.2%.

  Mf11: Peyssoneliacean Algae Boundstone
  This facies is entirely constructed by aragonitic red algae of the Peyssoneliacean group. The framework exhibits high moldic porosity due to the selective dissolution of algal skeletons. Micritization and later cementation are common. These aragonitic walls were highly susceptible to meteoric dissolution, leading to significant moldic porosity that contributes positively to reservoir quality.
  Reservoir Quality: up to 9.3% as confirmed in image analysis
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  Mf7: Oolitic Bioclastic Grainstone–Packstone
  This high-energy shoal facies contains ooids with bioclast-rich nuclei, including echinoids, bivalves, and miliolids. Good grain sorting and presence of sparry cement are typical.
  Reservoir Quality: Moderate to high depending on cementation intensity.

- **Mf6 & Mf9: Peyssoneliacean–Coralline Red Algae Grainstones**
  Found in shallow ramp crest zones, these facies show high-energy indicators and abundant red algae clasts, sometimes forming rudstones with minor dolomitization.

The full descriptions of all 17 microfacies, including texture, allochem composition, depositional energy, and reservoir significance, are detailed and correspond to facies Mf1 to Mf17 as described in the core analysis (Table ۱).

Table 1. *Key microfacies of the Asmari Formation with their environment, texture, porosity, and reservoir quality.*

Facies Code	Depositional Environment	Dominant Components	Texture	Energy Level	Avg. Porosity (%)	Reservoir Quality
Mf3	Lagoon	Miliolids, micrite	Wackestone–Packstone	Low	3.6	Poor
Mf6	Shoal	Red algae, ooids	Grainstone–Packstone	High	8.8	Good
Mf7	Shoal	Ooids, echinoids, forams	Grainstone	High	7.6	Good
Mf10	Shoal	Coralline red algae, benthic forams	Rudstone–Packstone	Moderate–High	9.2	Excellent
Mf11	Shoal	Aragonitic red algae (Peyssonellia)	Boundstone	Moderate	9.3	Excellent
Mf12	Lagoon	Miliolids, micrite	Packstone	Low–Moderate	6.9	Moderate

4.2. Porosity Distribution

Porosity within the Asmari Formation varies significantly depending on microfacies type, energy level, and diagenetic overprints. The most porous facies are those dominated by red algae (Mf10, Mf11), where extensive moldic pores developed due to early meteoric dissolution. In contrast, micritic lagoonal facies (e.g., Mf3, Mf12) exhibit very low porosity due to micritization and mechanical compaction.

The average porosity values for selected facies are as follows:

Table 2. *Porosity estimation was conducted using both visual point counting and image analysis in JMicroVision software.*

Microfacies	Average Porosity (%)
Mf10	9.2
Mf11	9.3
Mf7	7.6
Mf6	8.8
Mf3	3.6
Mf12	6.9

Porosity values were obtained using both visual estimation and quantitative image analysis based on JMicroVision software, with results derived from multiple thin sections representing various microfacies types. Detailed sample-specific data were compiled and analyzed to determine average porosity for each facies (Figure 3).

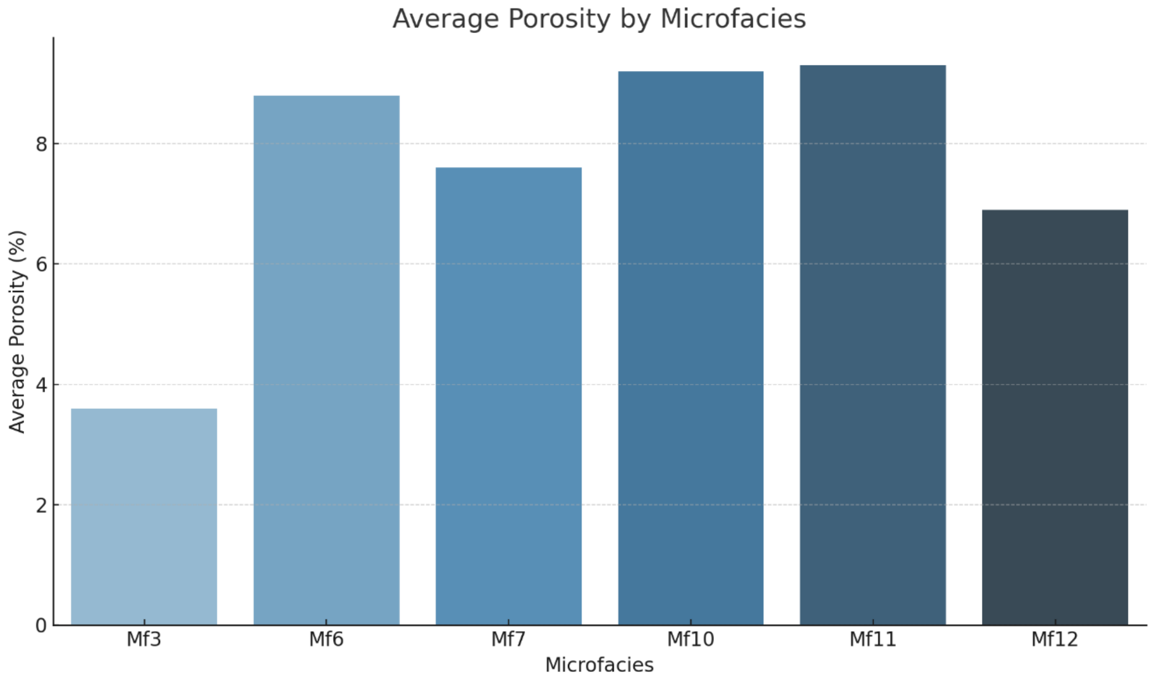

Fig. 3. *Bar chart showing the average porosity values for selected microfacies within the Asmari Formation. Highest porosities are associated with red algae-dominated shoal facies, particularly Mf10 and Mf11.*

5. Discussion

5.1. Facies Evolution and Environmental Interpretation

The vertical succession of microfacies within the Asmari Formation in the Lorestan well reveals a progressive upward shallowing trend from deeper open marine facies to high-energy shoals and restricted lagoonal settings. This facies evolution supports deposition on a homoclinal carbonate ramp with limited bathymetric relief and gradual lateral facies transitions, which is in agreement with updated facies models for the Asmari Formation in the southwestern Zagros Basin (Tavakoli & Khanehbad, 2020). The absence of reefal or slope-derived facies such as breccias or turbidites further confirms the gentle ramp nature of the depositional profile.

A key observation is the transition from coralline red algae-dominated facies (lower Asmari) to Peyssoneliacean aragonitic red algae-dominated facies (upper Asmari). This shift may reflect increased restriction, higher salinity, or changing water chemistry that favored the proliferation of aragonitic algae. Such facies are rare or absent in most Khuzestan and Fars sections, indicating a unique paleoenvironmental signature for Lorestan.

5.2. Diagenetic Controls on Reservoir Quality

Diagenetic processes have played a decisive role in shaping the reservoir properties of the Asmari Formation in the study area. Early marine cementation, evidenced by syntaxial overgrowth and fibrous rims, stabilized framework grains in high-energy facies (e.g., Mf7). In contrast, meteoric dissolution during early exposure led to moldic porosity, particularly in algae-rich facies (Mf10, Mf11).

Mechanical compaction significantly reduced interparticle porosity in deeper facies (e.g., Mf2, Mf3), while dolomitization—observed in select samples from the mid-Asmarian interval—enhanced secondary intercrystalline porosity, consistent with dolomite-related porosity enhancement reported in other Miocene carbonate reservoirs (Al-Aasm et al., 2022). These porosity modifications align with recent observations from Miocene carbonates, where early meteoric dissolution and progressive burial compaction were shown to play a critical role in controlling moldic and interparticle porosity (Zhang et al., 2023). Neomorphism, transforming aragonite to calcite, further modified skeletal textures and often reduced effective porosity by occluding existing molds.

Based on stratigraphic and petrographic evidence, a diagenetic sequence was inferred comprising early marine cementation, meteoric dissolution during subaerial exposure, and subsequent burial compaction and neomorphism. This sequence reflects at least two exposure surfaces corresponding to sequence boundaries identified in the Asmari stratigraphy (Figure 4).

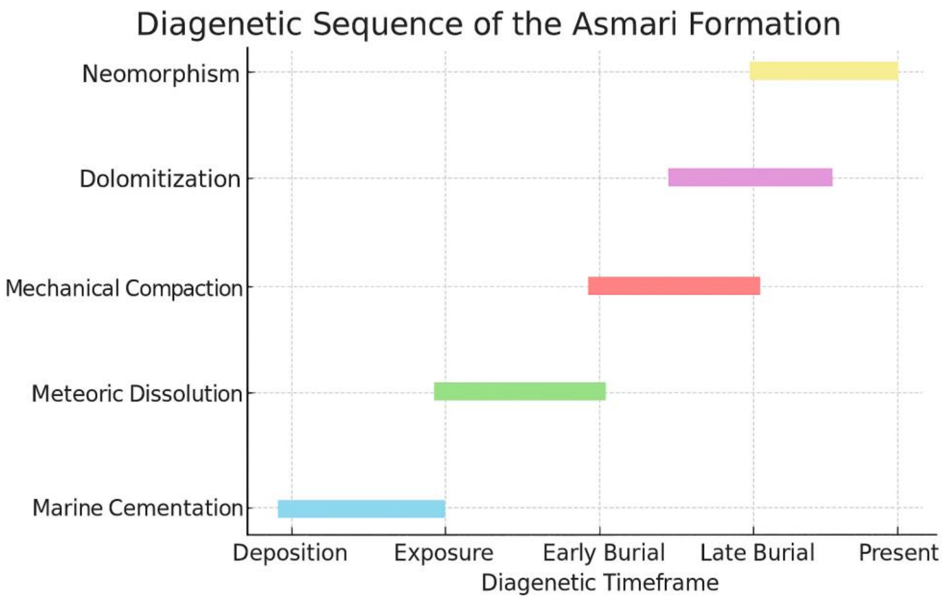

Fig. 4. *Diagenetic sequence illustrating the primary post-depositional processes in the Asmari Formation*.

5.3. Comparison with Previous Studies

Compared to classical Asmari facies models from Khuzestan (James & Wynd, 1965; Vaziri-Moghaddam et al., 2006), the Lorestan section exhibits a higher frequency of red algae-rich facies and greater evaporite content in the lower Asmari (Kalhor Member). These differences likely reflect more restricted and isolated ramp conditions under semi-arid climatic regimes.

Moreover, the presence of Peyssoneliacean algae, as confirmed in this study, has rarely been documented in other Zagros sections, representing a significant addition to the facies inventory of the Asmari Formation. This finding may necessitate a revision of the regional depositional models for northern Zagros.

5.4. Implications for Reservoir Modeling

Understanding the distribution and evolution of red algae-rich facies, coupled with their diagenetic overprints, is essential for reservoir quality prediction in the Asmari Formation. Moldic porosity associated with algae dissolution offers good storage capacity but may suffer from poor permeability unless preserved from subsequent cementation. This highlights the importance of microfacies-level modeling in carbonate reservoirs, as emphasized by Ahr (2021), where textural attributes and early diagenesis define reservoir flow units.

The presence of evaporitic barriers (especially in the Kalhor Member) also suggests favorable conditions for stratigraphic trapping of hydrocarbons. These evaporites could serve as intraformational seals, enhancing the petroleum system potential of the region (Figure 5).

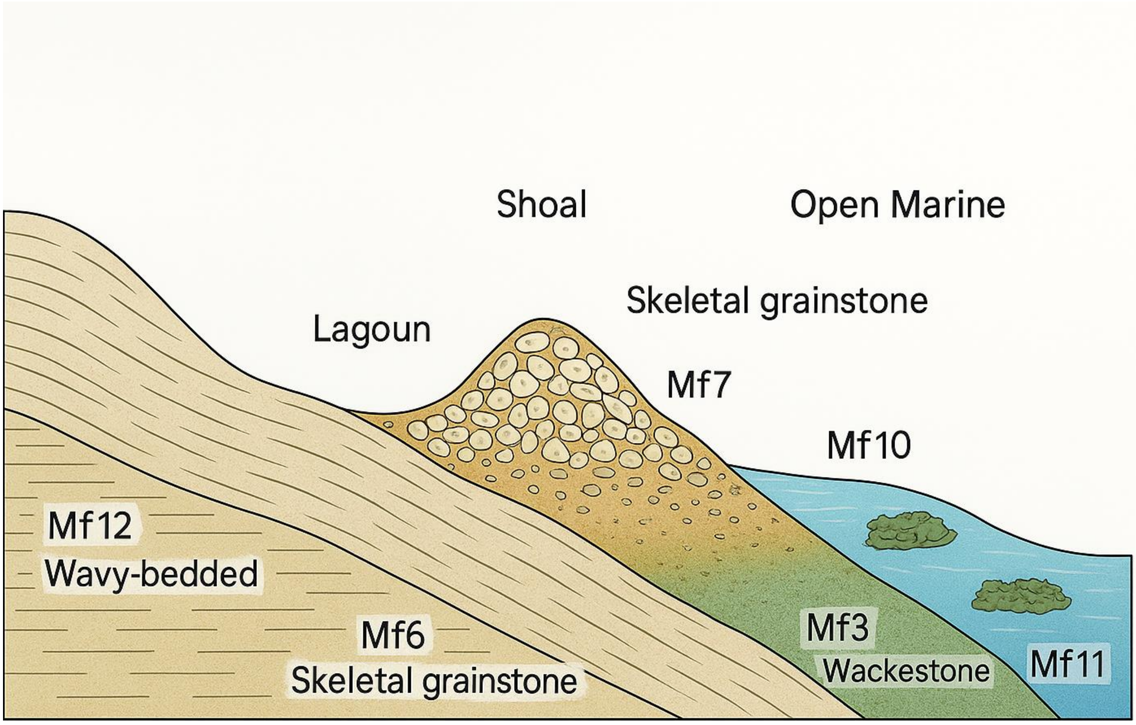

Fig. 5. *Depositional model of the Asmari Formation showing microfacies distribution along a homoclinal carbonate ramp.*

6. Conclusion

This study offers a detailed facies and diagenetic evaluation of the Asmari Formation in a subsurface well in the Lorestan region, northern Zagros Basin. Seventeen microfacies were identified and grouped into four depositional environments representing a homoclinal carbonate ramp system. The Asmari Formation in this area exhibits a distinctive transition from coralline to aragonitic red algae, marking a paleoenvironmental shift not commonly observed in other Zagros sectors.

Reservoir quality is highly facies-controlled, with the best porosity found in high-energy shoal and red algae-rich facies, especially where early meteoric diagenesis induced moldic dissolution. Diagenetic processes such as marine cementation, compaction, dolomitization, and neomorphism critically influenced the pore system evolution. Importantly, the presence of evaporitic intervals in the lower Asmari (Kalhor Member) points to their potential role as sealing units in the petroleum system.

In conclusion, this research highlights the unique sedimentological and diagenetic signatures of the Asmari Formation in Lorestan, suggesting that regional reservoir models should be updated to incorporate red algae-dominated facies and their associated diagenetic histories. These findings contribute to a more refined understanding of facies heterogeneity and reservoir potential in the northern Zagros.

Sea-level fluctuations, particularly relative sea-level fall at the end of depositional sequences, played a crucial role in enhancing secondary porosity, especially through moldic dissolution of aragonitic components in the upper Asmari interval.

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