

# Bio-Sequence Stratigraphy of Asmari Formation in the Southeast of Norabad (Zagros Basin, SW Iran)

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## Research Article

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# Abstract

Asmari Formation is the thick sequence of carbonate sediment in the range of Oligocene-Miocene which is deposited in the foreland basins of the Zagros and is considered as the original and most famous reservoir rock of Zagros basin. To study of lithostratigraphic units and sequence stratigraphy of this Formation, the section in the southeast of Norabad was selected. Field study indicated that Asmari Formation possessed the thickness of 401.5m and included 9 lithostratigraphic units. According to the study of microfacies, Stacking pattern and identification of main sequence level, three depositional sequences including two-second order and one-third order sequence were recognized. The sea-level curve in the studied section indicated that it was correspondence to the global sea level curve. These facies deposited in five environmental sedimentations as follow Open Sea Shelf (Fore Barrier), Bar, Lagoon, Back bar shelf, and Shoal. The environment is part of a carbonate platform that has been formed on an open shelf. In addition, according to the Study of foraminifer dispersion pattern the range of Asmari Formation in Norabad was suggested to be Oligocene (Rupelian- Chattian) to lower Miocene (Aquitania-Burdigalian).

## Introduction:

The hydrocarbon reserves and very young tectonic activities of the Zagros Basin attract many researchers. The deposits of the carbonate platform of the Asmari Formation include some of the important oil reservoirs in the world. The Asmari Formation is the youngest reservoir of Zagros reservoir and therefore extensive studies have been performed on this Formation. In the past, this unit of stone was named the calcareous jerib Formations, the Kalhor limestone Formation, and the khamir limestone. But the abovementioned formations are only as part of the Asmari Formation cut-off and does not include all of the formations. The name of this formation is adapted from the Asmari Mountains (southeast of Masjed Soleiman) and the cutting of its type section was measured in the tang-e gel torsh in Asmari Mountain. (Aghanabati, 2004).

In the type section, the Asmari Formation is 314 m thickness and includes resistant limestone with cream to brown color that is a little intermediate between the Chilean layer and abundant joints. In the type section, Asmari Formation is in Miocene and its lower part is not seen due to the change of facies in Pabdeh Formation. But the complementary part of this formation in Tang-e-Takab Mount Khavir, in the 30 km from Behbahan, indicates the full features of this formation (Aghanabati, 2004).

The Asmari Formation starts from the Oligocene (Rupelian) and continues to the lower Miocene (Burdigalian) (Motiei, 2004), along with the mountain front and its southern fields, the lower part of the Asmari is in Oligocene. In the northern oilfields of Dezful embayment, this area is characterized by Lower Asmari Anhydrite with the Age of Aquitanian. The upper boundary of the Asmari Formation in the north of the hypothesized line extending from the northern Kharg to the north of the Darkhovin which is consistent with the Gachsaran Formation and in the south it has a gradual elevation of carbonate sands to evaporation and sandy limestone deposits that is almost marginal and lateral facies of the Gachsaran

Formation (Motiei, 2004). On the northern border of Asmari sedimentary basin, including in the southwest of Sisaket, only the lower part of Asmari is seen and its upper limit is the Razak Formation. In the northern part of the Gurpi Mountain anticline, the upper boundary of Asmari Formation is the Razak Formation and similarly to this phenomenon can be seen in the North of the Anticline of Oil in Lorestan (Motiei, 2004).

In this study the stratigraphic section was selected in the southeast of the Norabad to study the lithostratigraphy and Sequence stratigraphy of Asmari Formation.

## **Method And Materials:**

To study the sequence stratigraphy of Asmari Formation in the Norabad section, 152 samples with a total thickness of 401.5m were collected. Then, some thin microscopic sections were prepared from these samples for performing laboratory examinations, identifying the sedimentary facies, and determining the depth changes of the sedimentary basin. In the present research, investigation, identification, and nomination of the sedimentary facies were conducted based on (Dunham's 1962) ranking.

## **Geographical and Geological Setting:**

The studied stratigraphic sections in southwestern Iran were located in Fars Province and territory (in Tethys and folded Zagros structural zone) (Fig. 1). The study area, located in the southeast of Norabad and the access to this section was possible through the Norabad-Sepidan Road. Asmari Formation of this section is placed above the Pabdeh Formation under the Gachsaran Formation. (Fig. 2).

## **Description of the lithostratigraphic units**

This stratigraphic section has 9 lithostratigraphic units as follows:

1- This unit was the first and smallest lithostratigraphic unit of this section and consists of thick-bedded limestone that is located on the sediments of Pabdeh Formation. This unit is 4.4 m thick and starts with the packstone facies and then turns into a wackestone and ends.

2- This unit was 14.9 m thick and consists of medium bedded of limestone. This unit begins with packstone facies and ends with the conversion of wackestone.

3- The sedimentary thickness of this limestone unit was 21.6 m and consists of thick-bedded limestone. This lithostratigraphic unit begins with packstone and then converted to grainstone, wackestone and again packstone, and eventually ends with mudstone. Due to the not very high thickness of this unit, we see the variation and successive variations of sedimentary facies, which indicates the instability of the sedimentary basin during the formation of this unit.

- 4- The thickness of sediments in this unit was 18.8 m and consists of medium-bedded limestone. The sedimentary facies of this unit began with the wackestone and then turned to grainstone and again into wackestone and ended up as the unit 3 with the mudstone. The instability of the sedimentary basin is also present in this section.
- 5- The unit consists of a thin-bedded of limestone with a thickness of 62.6 m, the beginning of this unit is with the wackestone and ends with grainstone, and alternatively, mudstone facies are also observed.
- 6- The thickness of sediments in this unit was 30 m and consists of medium-bedded of limestone. The first facies in this unit are mudstone which ends with the wackestone facies, but in this unit, grainstone and packstone facies are also observed. This unit is also one of the units that show the change in the successive conditions in the sedimentary basin.
- 7- This lithostratigraphic unit was 20.1 m thick and consists of thick-bedded limestone. The facies of this unit begin with the continuation of the previous wackestone unit and then converted to mudstone and grainstone, respectively, and eventually ended like the previous one with the wackestone.
- 8- This unit consists of thin-bedded limestone and the thickness was 36.2 m. It starts with wackestone, which is the continuation of the facies of the former unit and end in wackestone except one case that the facies are converted to grainstone. This unit is the most stable section unit in present study.
- 9- The last and thickest lithostratigraphic unit includes 192.9 m thick-bedded limestone which began with the continuation of the wackestone of the previous unit and ended with grainstone and alternately the facies of wackestone, mudstone and grainstone were observed in sediments of this unit. The sequential conversion of facies to each other is a control and volatility index of the sedimentary basin, which has turned this unit into the most unstable unit in terms of changing sedimentary basin conditions. At the end of this unit, the limestone sediments of the Asmari Formation gradually become evaporated sediments of the Gachsaran Formation.

## **Sequence Stratigraphy:**

Sequence stratigraphy is an important method to analyze the change of the sedimentary environment and regional correlation of sedimentary basin. Sequence stratigraphy is the study of periodic change in Stacking pattern layers in response to accommodation and the rate of sediment supply (Catuneanu 2012). The sequence is formed of somewhat continuously and connectively sequences in terms of the source which in up and down part surrounded by unconformity or equivalent conformity. Sequence boundaries (SB) are the important key to determine the sedimentary sequences which describe by unconformity and conformity adaptive to unconformity (Catuneanu et al. 2009). Preserved sediment between sequence boundaries indicates regression and retrogression which reflected the variation of sea level. The sedimentary package is interpreted according to the sedimentation layer's pattern, sequence position, and type of limiting surfaces (Catuneanu et al. 2010). Each sequence can be categorized into

sedimentary packages based on the accumulation patterns (Regression and Retrogression) and type of limitation sequence surface. LST, HST, and TST are the recognizable sedimentary packages in the sequence (Catuneanu et al. 2010, 2011). The sequences are deposited during a full cycle of variations of accommodation, but the formation of boundaries of the sequence depends on the periods when accommodation is negative (Mitchum 1977). Identifying the depositional sequences in the uniform carbonate facies seems to be difficult; however, the use of large benthic foraminifera, due to their sensitivity to depth changes, is a good index for determining the sequences (Sarg 1988). Some other studies that have been conducted in recent years on the sequence stratigraphy, depositional environments and facies analysis of Asmari formation are as follows: Wakefield (2003), Dehghanian et al. 2011; Dehghanian et al. 2012; Dehghanian et al. 2013, Habibi (2014); Sadeghi et al. 2017; Dehghanian and Asgari-Pirbalouti 2018; Naseri-Karimvand et al. (2019); Dehghanian 2012, 2017, 2019, 2022.

## Description of Bio-sequence Stratigraphy:

The sequence stratigraphy studies showed three bio-sequences for Asmari Formation which consists of two bio-sequences second-order and one bio-sequence third-order based on sedimentation time requirement in accordance to Vali 1991 study (Fig. 3).

### Bio-sequence 1 (Rupelian to Chattian):

The sediment thickness of this sequence is 122.3 m and includes the lower part of the Asmari as the Oligocene (Rupelian to Chattian). This sequence consists of lithostratigraphic units 1 to 5. The lower boundary of this bio-sequence to Pabdeh Formation and its upper boundary with sedimentation sequence 2 is mfs and the boundary between HST facies with TST was SB2-type. The thickness of the HST in this sequence was 40.9 m and the thickness of the TEST was 81.4 m. Meanwhile, the end sediments of Pabdeh Formation before converting to Asmari Formation was of the TST type. The sedimentary facies of bio- sequence 1 were mudstone, wackestone, grainstone, and packstone, respectively. The diversity of facies shows the instability of the sedimentary basin during the formation of this sedimentary sequence. Due to the abundance of foraminifera such as: *Nummulitesvascus* Joly and Leymeri, 1848, *Nummulitesfichteli* (Michelotti, 1841), *Operculinacomplanata* (Defrance, 1822), *Amphistegina* sp. and also presence of Bivalvia fragments, Gasteropoda, Crinoidea, Echinoderm fragments, Ostracoda and Ostracoda determined the TST system tract consists of open marine and the HST system tract, including bar to lagoon facies. In terms of the parasequence Stacking pattern, the TST facies are retrograde and the HST facies are of the Aggradational type (Fig. 3). The deposition of this sequence requires about 12.6 million years, so, according to Vail et al. (1991), this sequence was a second-order.

### Bio-sequence 2 (Lower Aquitanian):

The thickness of this sequence was 89.6 m and consists of 6 to 8 lithostratigraphic units, and it consists of medium-bedded limestone, thick-bedded limestone, and thin-bedded limestone. This sequence consists of the lower part of the middle Asmari Formation of the lower Aquitanian (lower Miocene). The lower boundary of this sequence was with sedimentation sequence 1 and its upper boundary with sedimentation sequence 3 of the type mfs and consists of two the HST and TST system tract, respectively. The thickness of the HST and TST sediments was 43.3 and 46.3 m respectively, and the boundary between these two systems was SB2. The sedimentary facies of this sequence are wackestone, grainstone, mudstone, and packstone, respectively. The presence of Bivalvia fragments, Gastropoda, Echinoderm fragments, Ostracoda, Coral, and also the presence of microfossils such as: *Austrotrilina asmariensis* Adams, 1968, *Austrotrilina paucialveolata* Grimsdale, 1952, *Eulepidina discus*, Eames, 1962 □ *Milliolid* which Shows that the sediment of the TST was related to the lagoon facies to the open marine, and the HST system tract is more related to the lagoon to the back bar shelf (Fig. 3). The deposition of this sequence requires about 1.4 million years, so, according to Vail et al. (1991), this sequence was a third-order.

## Bio-sequence 3 (Upper Aquitanian to Burdigalian):

The Bio-sequence 3 has a thickness of 184.1 m and only includes lithostratigraphic unit 9 and consists of thick-bedded limestone and includes HST. This sequence consists of the end of the middle Asmari and total upper Asmari (Upper Aquitanian to Burdigalian). The lower boundary of this sequence is with sequence 2 of mfs and the upper boundary to the Gachsaran Formation was SB2. Meanwhile, studying 5.5 m of the sediments of Gachsaran Formation in this section indicates that the sedimentary facies of the Gachsaran Formation continue to the Asmari formations of grainstone facies, and its system tract was of TST type. In sequence 3 sedimentary facies are frequent in the wackestone, mudstone, and grainstone facies, respectively, and there were no packstone facies in this sequence. Regarding the frequency of foraminifera in this section, such as: *Austrotrilina howchini* (Schlumberger, 1893), *Austrotrilina asmariensis* Adams, 1968, *Peneroplis glynnjonesi* Henson, 1950, *Peneroplis evolus* Henson, 1950, *Peneroplisthomasi* Henson, 1950, *Borelismelo* (Fichtel and Moll) *curdica* Reichel, 1937, *Archiashensoni* Smout and Eames, 1958, *Archiasperculiniformis* Henson, 1950, *pyrgo* sp. And according to the paleoecology of these organisms, the sediments of this system tract can be attributed to the Shoal to Lagoon (Fig. 3). The deposition of this sequence required about 5.9 million years, so, according to Vail et al. (1991), this sequence was a second-order.

## Discussion:

1- Based on studies of microscopic facies, stacking patterns and identification of the principal sequence levels, three sedimentary sequences (including two second-order sequences and a third-order sequence) are identified as follows:

A. Bio-sequence 1 (Rupelian to Chattian): It includes the open marine facies and the barrier facies of the lower Asmari Formation. This sequence requires 12.6 million years for precipitation and was a second-order sequence.

B. Bio-sequence 2 (Aquitanian): In this sequence, the TST facies belong to the lagoon to open marine and the HST facies were lagoon to back bar shelf. This sequence is related to the lower part of the Asmari, and has been deposited over 1.4 million years and was a third-order sequence.

C. Bio-sequence 3 (Upper Aquitanian to Burdigalian): It includes Shoal to lagoon and the upper part of the middle Asmari and total of the upper Asmari formation. The sedimentation time is about 5.9 million years old and is considered as the second-order sequencing.

2- Investigating the vertical and adjacent facies variations and comparing them with the present and the ancient environments showed that Asmari Formation in the studied section was formed on a carbonate ramp platform on an open shelf.

3- The lower boundary of Asmari Formation in this section is gradual with Pabdeh Formation and the upper boundary with Gachsaran Formation.

4- According to the study of foraminifera dispersion, the age of sediments of this section was determined as Oligocene (Rupelian to Chattian) to the Lower Miocene (Aquitanian to Burdigalian).

5- Due to the up-rise of Zagros during young Alpine phases and Tethys closure sedimentary basin has changed from the marine (Asmari Formation) to the lagoon-evaporation (Razak Formation).

## **Conclusion:**

During the Oligocene-Miocene, sedimentation has progressed inside the Tethys Basin and in the interior of the Fars area from the open sea to the shallow marine to Lagoon. Therefore, according to the study of microfacies and field studies in the region, it is concluded that the sedimentation regime in the basin has a direct relationship with the basin tectonic, the geometric shape of the basin and orogeny phases. As a result of the tectonic pressures caused by the collapse of the Arabic plate, the Tethys was closing and during the operation of the young Alpine orogeny phases, uplifting tectonic of Zagros occurred. On the other hand, the operation of the faults in the region was not affected by this fact and it facilitates the uplifts so that the basin gradually becomes less deep during Asmari sedimentation and then becomes lagoon-evaporative and deposits of Gachsaran formation are deposited therein.

## **Declarations**

## **Acknowledgment:**

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## Figures

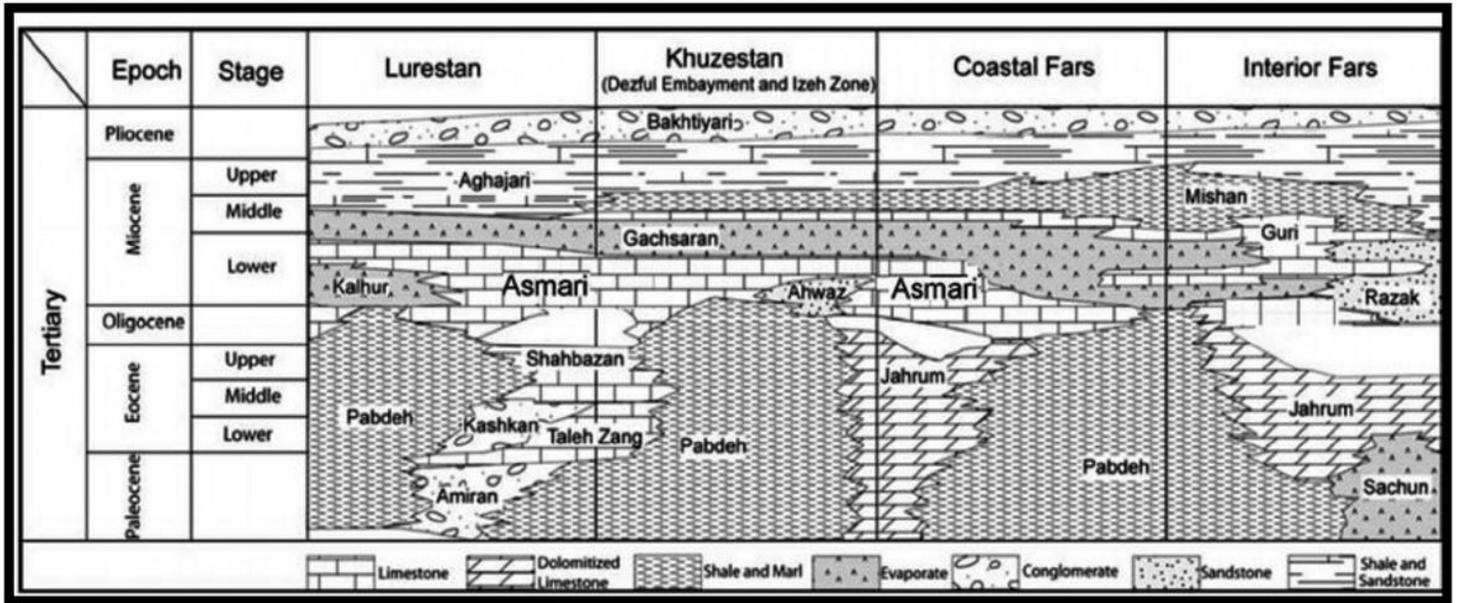


Figure 1

Cenozoic stratigraphic correlation chart of the Iranian sector of the Zagros basin, James and Wynd (1965)



**Figure 2**

Location map of the studied area in Zagros region, Southwest of Iran. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

## Sequence Stratigraphy Chart

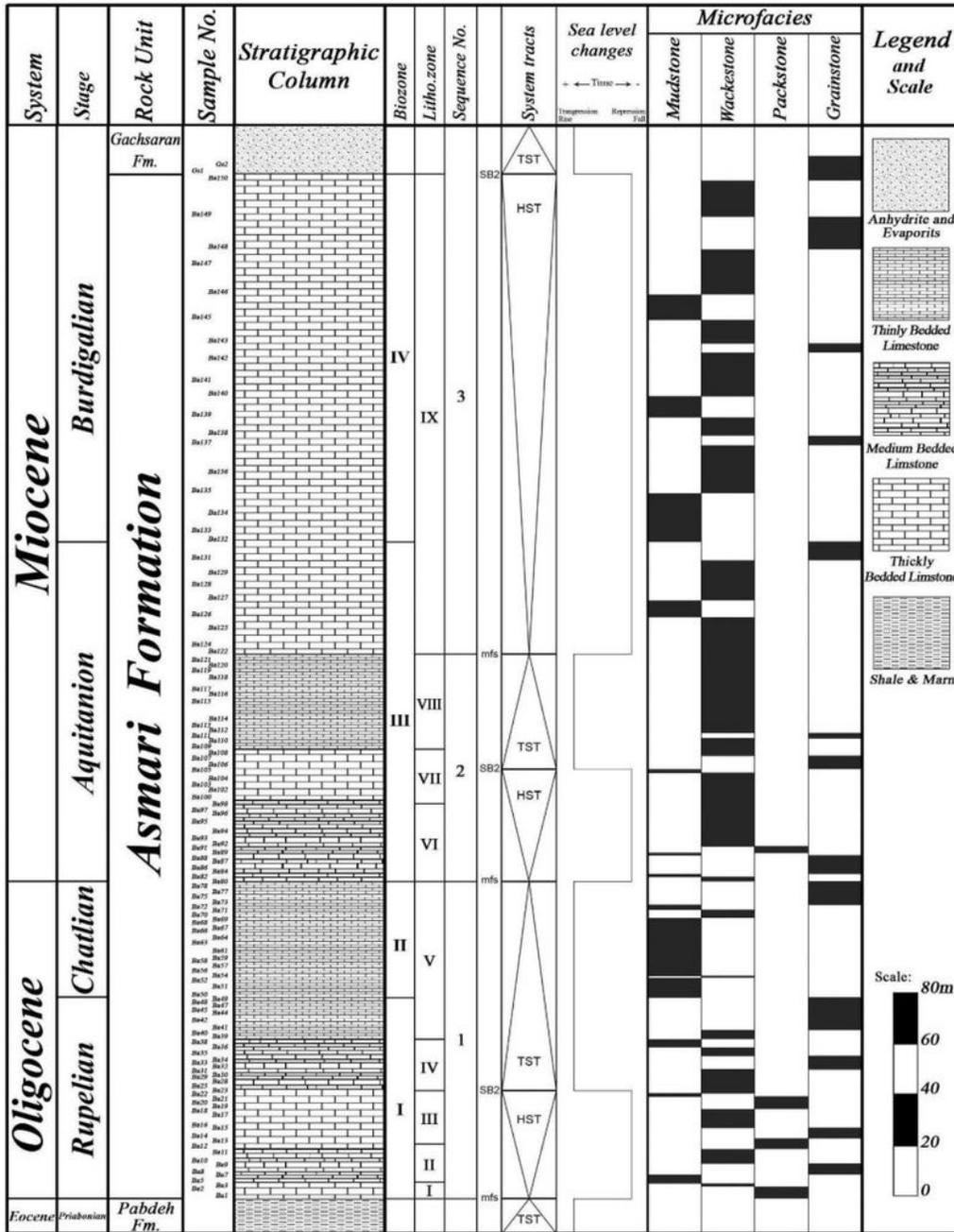
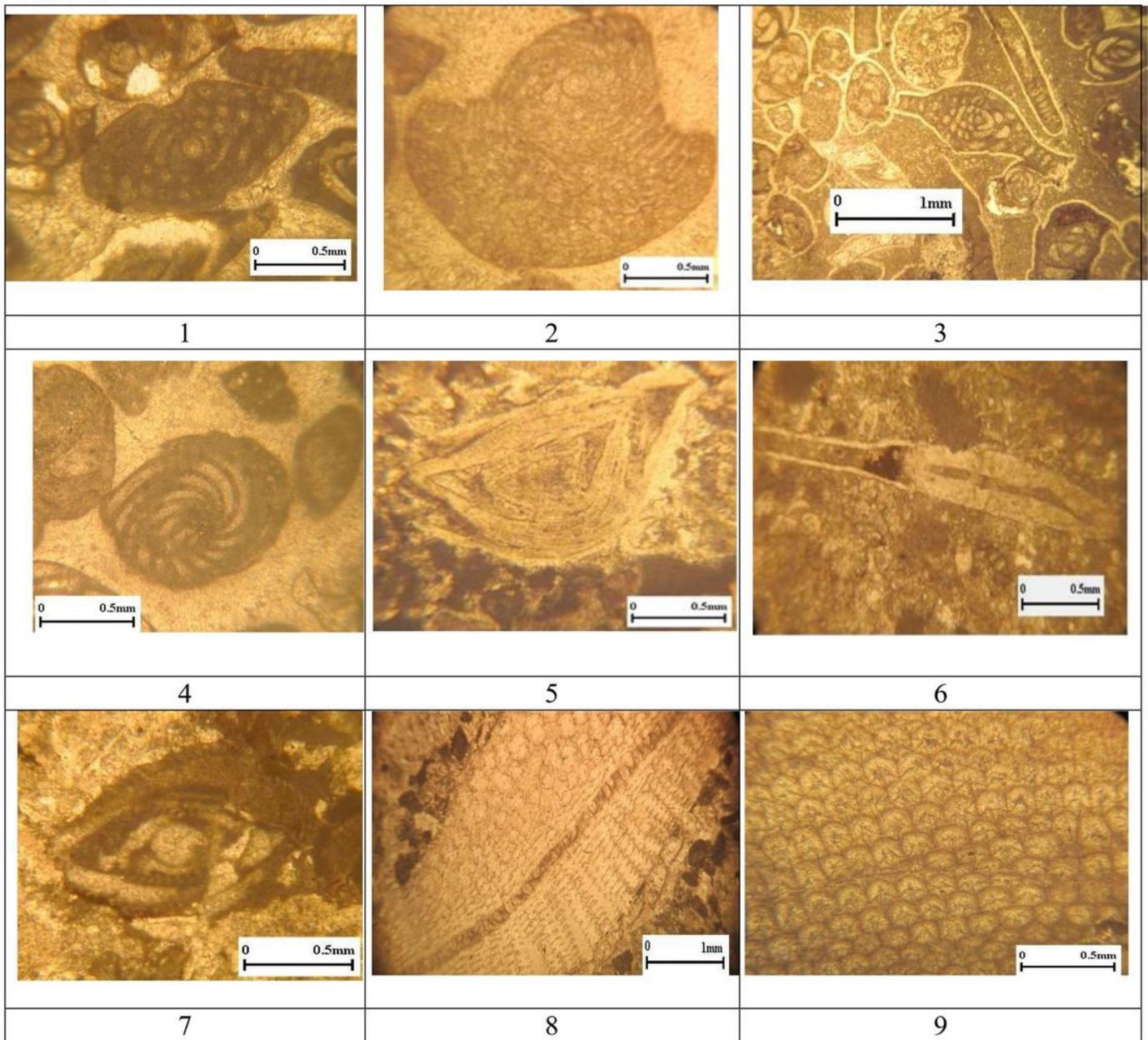


Figure 3

Shows the distribution of stratigraphy and carbonate microfacies and its elements in Norabad section.

Plate 1:



**Figure 4**

1. *Archaias operculiniformis* Henson, 1950, Section: Axial, Aquitanian, X 100, 2. *Peneroplis evolutus* Henson, 1950. Section: Subequatorial, Aquitanian, X 100, 3. *Peneroplis thomasi* Henson, 1950, Section: Axial, Aquitanian, X 40, 4. *Peneroplis glynnjonesi* Henson, 1950, Section: Subequatorial, Aquitanian, X 100, 5. *Amphistegina* sp., Section: Axial, Rupelian, X 100, 6. *Operculina complanata* (Defrance, 1822), Section: Subaxial, Rupelian, X 100, 7. *Austerotrillina asmariensis* Adams, 1968, Section: Axial, Rupelian, X 100, 8. *Eulepidina* sp., Section: Subaxial, Chattian, X 40, 9. *Eulepidina* sp., Section: Equatorial, Chattian, X 100,