Indian Journal of Geo Marine Sciences
Vol. 49 (05), May 2020, pp. 858-867

Paleoenvironmental reconstruction, sequence stratigraphy and diagenetic processes of the Asmari Formation in KabirKuh Anticline, North of the Zargos Basin, Iran

F Moradi[*,a], A Sadeghi[a], M H Adabi[b] & A Tahmasbi[a]

[a]Department of Geology, Faculty of Sciences, Shahid Beheshti University, Tehran, 198396311, Iran

[b]Exploration Directorate, National Iranian Oil Company, Tehran, 1994814695, Iran

*[E-mail: f_moradi@sbu.ac.ir]

Received 19 December 2018; revised 22 April 2019

Because of the importance of the Asmari Formation in Lurestan zone (north of the Zagros basin), Jahangirabad section with a total thickness of 179 meters consist of mixed limestone-evaporites have been studied in order to interpretfacies, paleoenvironment, sequence stratigraphy and diagenetic processes. Based on lithostratigraphic classification in Lurestan zone by Adams studies, the Asmari Formation **(**Late Oligocene – early Miocene deposits) in study area has been divided into 3 units (including 5 sub-units). According to the field studies and laboratory works, 13 microfacies in 5 facies association were recognized, which belong to open marine, shoal, lagoon, intertidal environments. By considering the Lower Kalhur evaporites (with observed micro-texture), which are located in the lower part of this formation, it seems that the precipitation of these evaporates has occurred in the restricted basin during fall of sea level in saline environments. The precipitation of limestone with pelagic fauna has occurred over basal anhydrite during the rise of sea level. The main recognized diagenetic processes are dissolution and dolomitization which has influence on Asmari formation in this region. Three depositional sequences were identified based on facies distribution and sequence boundary.

[**Keywords:** Asmari Formation, Diagenetic processes, Facies analysis, Jahangirabad section, KabirKuh Anticline, Sequence stratigraphy]

Introduction

The Asmari Formation with mainly carbonate sequences is an important hydrocarbon reservoir in the Zagros Basin, at Iran. The oil produced in the Asmari reservoir is basically controlled by the fractures[1]. This formation consists of limestone beds and has two members: Ahwas member (sandstone) and Kalhur member (evaporite deposits) which are located, respectively in Dezful Embayment and Lurestan zone[2]. The lower and upper boundaries with the Pabdeh and Gachsaran formations are gradual and sharp, receptively.

The Zagros Basin has been created by multiphase collision between the Arabian plate, the former southern margin of the Neo-Tethys Ocean and central Iran microplate[3]. The external part of Zagros orogenic Wedge is shaped by the zagros fold thrust belt. This part is identified as approx. 7 to 12 km sequence of heterogeneous latest Neoprotrozoic-Phanerozoic sedimentary. This part is identified as approx. 7 to 12 km sequence of heterogeneous latest Neoprotrozoic-Phanerozoic sedimentary[4] (Fig. 1a). The latest Neoproterozoic stratigraphy of the Zagros fold-thrust belt has been modified in 2004 as megasequences[6]. Megasequence XI (Oligocene ~ 33 Ma to present) consists of carbonate sequences. It includes the Razak, Asmari, Ahwaz, Kalhur, Gachsaran, Mishan, Agha Jari, Lahbari, and Bakhtiari stratigraphic units[5].

The Late Oligocene / Early Miocene sediments in Zagros Basin is relevant to the final part of progradational carbonate platform system[4]. The location of study area is in the northwestern part of the Zagros basin (Lurestan zone) in ~ 105 km of southwest of Ilam, near the Jahangirabad village north of the KabirKuh Anticline (~1km) at 33°06′45″ N, 47°21′19″ E (Fig. 1b). The aim of this research is to conduct comprehensive study of the evolution of facies, paleoenvironment, sequence stratigraphy and diagenetic processes of the Asmari Formation in Lurestan zone (Fig. 1).

Material and Methods

Samples of the Asmari Formation were collected systematically (~2 m) and 180 samples were prepared

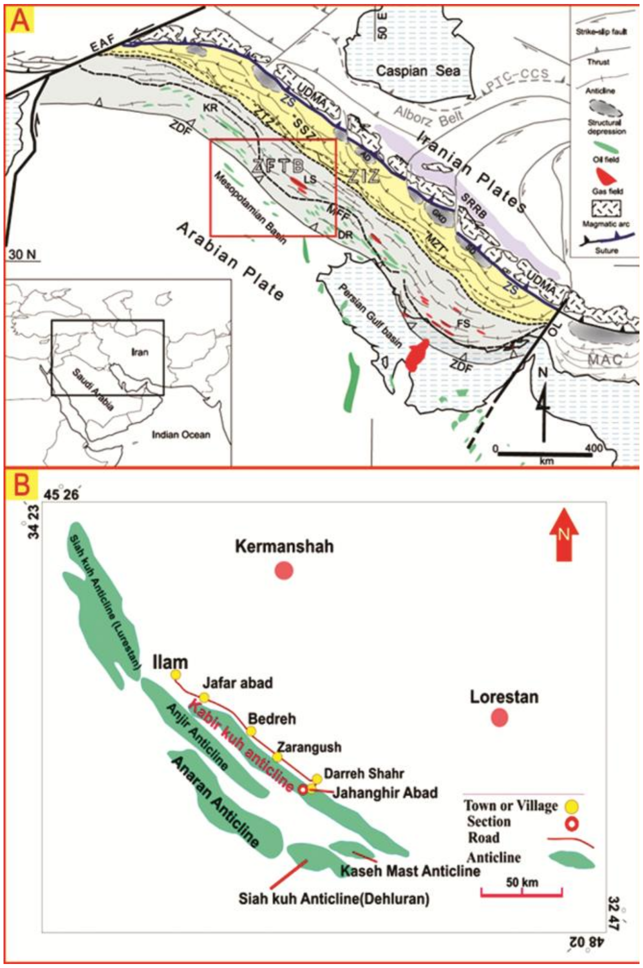

Fig. 1 — (a) Subdivision of the Zagros orogenic belt. Abbreviations: AD– Arak depression; DR– Dezful recess; EAF– East Anatolian Fault; FS– Fars salient; GKD– Gav Khooni depression; KR Karkuk recess; MFF– "Mountain front flexure"; "MZT"– "Main Zagros Thrust"; OL– Oman Line; PTC-CCS– Paleo-Tethyan continent-continent collisional suture; SD– Sirjan depression; SRRB– Saveh-Rafsanjanretroforeland basin; "SSZ" Sanandaj-Sirjan zone; "ZTZ"– Zagros thrust zone; UDMA– UrumiehDokhtar magmatic assemblage; ZDF– Zagros deformational front; ZFTB Zagros fold-thrust belt; ZIZ– Zagros imbricate zone; ZS– Zagros suture (modified from Alavi[4]). (b) Location of the study area in North of the KabirKuh Anticline (Jahangirabad section) (modified from Road Atlas of Iran 1995)

in the laboratory. Petrographic and microfacies analysis were described based on Dunhum[6], Embry and Klovan[7] classifications of sedimentary textures. Facies classification of this formation has been done and compared with standard facies of sedimentary environment[8]. The definition of this sequence stratigraphy model, identification of sequence boundary, maximum flooding surfaces and system tracts are based on Tucker[9] and Flügel[8].

Result and Discussion

Lithostratigraphy

The Asmari Formation **(**Late Oligocene – early Miocene deposits) in Lurestan zone is classified into 5 units including Lower Kalhurgypsum, Inter Kalhurbeds, Upper Kalhur gypsum and Middle and Upper Asmari limestone[10]. The thickness of this Formation in study area is about 179 meters. The upper contact of this formation with Gachsaran Formation and lower contact with the Pabdeh Formation are sharp.

According to the classification of Adams[1] the Jahangirabad section has been divided into 3 units (including 5 sub-units) as follows: 1) *Lower Kalhurgypsum* (9 meters): This unit consists of 9 meters anhydrite and gypsum which is located on the Pabdeh Formation and covered by limestone with planktonic fauna. 2) *Marl and Limestone beds* (35.5 meters): The dominant content of this unit is planktonic fauna and divided to 2 sub-units: Sub-unit 1: consist of 9.5 meters thick bedded limestone with gray color; and Sub-unit 2: 26 meters thin to medium gray marl. According to the Adams[1] classification, this unit equivalent with Inter Kalhur Beds and the dominant content of this unit is planktonic fauna. 3) *Middle and Upper Asmari Limestone* (134.5 meters): This unit composed of thin, medium to thick bedded limestone that is mainly with foraminifers representing a shallow water lagoon. This unit is divided to 3 sub-units. Sub-unit 1: 63 meters grey limestone with thick to medium bedded; Sub-unit 2: 22.5 meters thin, medium marly limestone with grey color; and Sub-unit 3: 49 meters medium to thick bedded grey limestone with marly limestone intervals.

Furthermore, Upper Kalhur beds and transition beds don't exist in the Asmari Formation in Kabirkuh Anticline (Fig. 2).

Microfacies and sedimentary environments

The thin sections study and laboratory works led to recognition of 13 microfacies. These microfacies were deposited in five depositional settings (tidal flat, lagoon, high energetic shoal and open marine) in a carbonate ramp. These microfacies including:

***Open marine facies*:**

Facies O1 Bioclast wackestone: The main components of this microfacies are species of the genus Globigerinoides, benthic foraminifera with silt size quartz grains. Shallow and deep water allochems together with silt size quartz grains show these

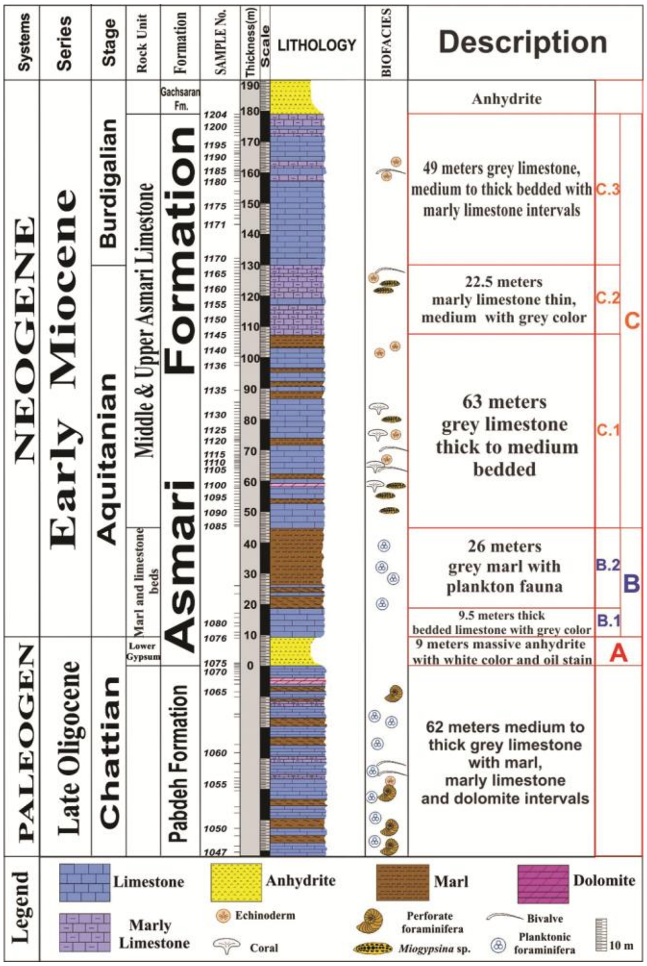

Fig. 2 — Sub-division of lithostratigraphic units of the Asmari Formation in the study area, with classified units according to Adams classification[10]

allochems were transported into the deep basin (Fig. 3a).

Facies O2 Planktonic foraminifera wackestone: This microfacies is characterized mainly by planktonic foraminifera such as *Globigerinoides* spp., and *Globorotalia* sp., with minor components of such as *Elphidium* sp.1, *Textularia* sp., echinoids and ostracods. According to the presence of planktonic foraminifera and matrix supported texture, this microfacies deposited in an open marine environment (outer ramp)[8,11]. The absence of LBF and other dependent light biota indicates the aphotic zone[14, 15] (Fig. 3b).

Facies O3 Bioclast perforate foraminifera wackestone to packstone: The species of Lepidocyclinidea family (*Eulepidina* sp. and *Nephrolepidina* sp.) and *Operculina complanata* from Nummulitidae family are the main components of this microfacies. Planktonic foraminifera and *Texularia* sp., *Heterolepa Mexicana*, *Neorotalia vienoti* and red algae (*lithophyllum* sp.) are the minor components of this microfacies.

Larger benthic Foraminifera (LBF) accompanied with planktonic foraminifera suggest deposition of this microfacies in a platform slope depositional setting between fair weather wave base (FWWB) and storm wave base (SWB)[14,15] (Fig. 3c).

***Shoal facies*:**

Facies S1 Coral boundstone: Coral and coralline algae boundstone are the main constituents. Other bioclasts include: miliolids, echinids and bryozoan.

Scattered coral indicated the patch-reef area, which apparently extended around FWWB in oligotrophic condition[16-18]. In other words, the existence of discontinuous coral in the form of patch reef along column with interbedded lagoon indicates their precipitation in a ramp environment[8,11] (Fig. 3d).

Facies S2 Bioclast pelloid/ ooid packstone/ grainstone: This facies is characterized by abundant ooid and pelloid. Coralline red alga, miliolida and imperforate foraminifera such as *Quinqueloculina* sp. and another porcelaneous benthic form are minor constituents. Abundant ooid and pelloid with grainstone texture represent shoal sub-environment with high energy condition[8] (Fig. 3e).

Lagoon facies:

Facies L1 Bioclas tpelloid ooid imperforate foraminifera grainstone: The main components of this microfacies are ooid, imperforate foraminifera such as *Quinqueloculina* sp., *Dendritinarangi*, *pyrgo* sp., *Triloculina* sp., and *Peneroplis* sp. Most ooids nucleuses are composed of porcelaneous foraminifera (miliolid forms). Abundance of ooid, imperforate foraminifera with grainstone texture show lagoon of environments near shoal sub-environment[15]. The presence of imperforate foraminifera supports lagoonal environment [14] (Fig. 3f).

Facies L2 Coralline red algae imperforate foraminifera packstone to grainstone: The dominant components of this microfacies are corallinacea red algae, porcelaneous foraminifera such as *Quinqueloculina* sp., *Pyrgo* sp., *Triloculina* sp., *Dendritinarangi*, *Peneroplis* sp., and *Textularia* sp. Bivalve is the minor bioclasts.

The presence of algae shows stable condition in the environment and low sedimentation rate[20]. Furthermore, the miliolids are good evidences which shows this facies deposited in the inner part of Lagoon[19] (Fig. 3g).

Facies L3 Bioclast imperforate foraminifera wackestone: The main components of this microfacies are porcelaneous foraminifera such as milliolids, *Dendrtinarangi*, *peneroplisevo lotus*, *Austrotrillina* sp., *Rupertina* sp., *Miogypsina* sp. Red algae is the minor component of this microfacies[8,11,20].

The presence of benthic foraminifera (Perforate and Imperforate) shows that this facies occurred in Lagoon[14]. Porcelaneous benthic foraminifera such as *Quinqueloculina* sp., *Penerolpisevo lotus*, *Dendritinarangi* in this facies are good evidences of Euphotic condition[21] (Fig. 3h).

Facies L4 Bioclast peloidal wackestone: The main components of this facies are peloid with porcelaneous foraminifera such as *Quinqueloculina* sp., echinoid and bivalve debris. The peloids are bahamite type (Fig. 3i).

Facies L5 Bioclast rudstone to floatstone: Shell fragments with sand to gravel-sized are the main allochems and porcelaneous foraminifera are the minor ones. This facies with rudstone and floatstone matrix show characteristic of the lagoonal environment[8,22] (Fig. 3j).

Facies L6 Bioclast echinoid wackestone: Echinoid is the main components of this microfacies. Echinoid and *Borelis melocurdia*, *Quinqueloculina* sp., *meandrospina iranica* are the minor components of this facies. By considering allochems of this microfacies occurred in low energy condition in lagoonal environment (Fig. 3k).

Facies E Evaporites: Petrographic study of the Lower Kalhur gypsum has been recognized as porphyloblastic microtexture. By considering: (1) the presence of evaporites sediment between deep succession, (2) high thickness of evaporites sediments (9 meter, as an aggradational pattern), (3) the observed microtexture, (4) vast lateral extension of Lower Kalhur gypsum in lurestan zone without external erosion surface, it seems Kalhur member might deposited in Salina setting (subaqueous condition)[23,24] (Fig. 3l).

Tidal flat facies:

Facies T1 Dolomudstone: The total allochem of this microfcies is less than 5 %. Dolomite in this facies is very early diagenetic dolomite and deposited in intertidal and is equal to MF9 of Wilson[11] (Fig. 3m).

Facies T2 Mudstone: This microfacies is characterized by mudstone texture with echinoid and bivalve debris (less than < 10 %). According to fenestral fabric this microfacies deposited in intertidal environment (Fig. 3n).

Depositional Environments

Based on facies architecture, bounding surface, presence of patch reef, abundant red algae in these facies, gradual transition facies, biofacies types and sedimentary carbonate analysis, depositional model of the Asmari Formation from late Oligocene (Chattian) to early Miocene (Aquitanian-Burdigalian) is homoclinal ramp[8,24-28].

Precipitation of Kalhur evaporites with lateral extension in the study area shows the hydrological stability condition and isolated basin. In addition, the presence of vast lateral extension of Lower Kalhur gypsum in lurestan zone without external erosion surface shows deposition of Kalhur member has occurred in subaqueous condition in saline environment[23,24].

Outer ramp

The appearance of planktonic foraminifera and shortage of bioclast and represents the deposition of facies O1 and O2 occur bellow SWB in deep water environment[15]. Terrigenous material, also suggests storm effect with periodic condition[8].

Middle ramp

Facies O3 belongs to open marine environments of middle ramp. The components of this facies are large benthic foraminifera (LBG) like *Operculina complanata*, *Heterostegina* sp., *Eulepidina* sp. and small benthic foraminifera, (SBF) like *Neorotalia vienoti* with red algae (*lithophyllum* sp.) and coral debris. According to presence of LBF and red algae together, oligotrophic to mesotrophic zone can be detected. The existence of LBG in lower part of study section shows the precipitation in subtropical to tropical environments[29].

Inner ramp

Facies associations consist of S, Land T respectively which are belongs to shoal, lagoon and intertidal environments. Rhodalgal facies occur in the recent shallow water carbonate sedimentary environment. Presence of rhodalgal facies in facies association Lsuggeste a photic zone with water depth about 35-45 m[21]. In the other words, coralline red algae with larger benthic foraminifera (*Quinqueloculina* sp., *Dendritinarangi*, *peneroplisevo lotus*), bryozoan and coral debris indicate a tropical to subtropical environment with oligotrophic condition

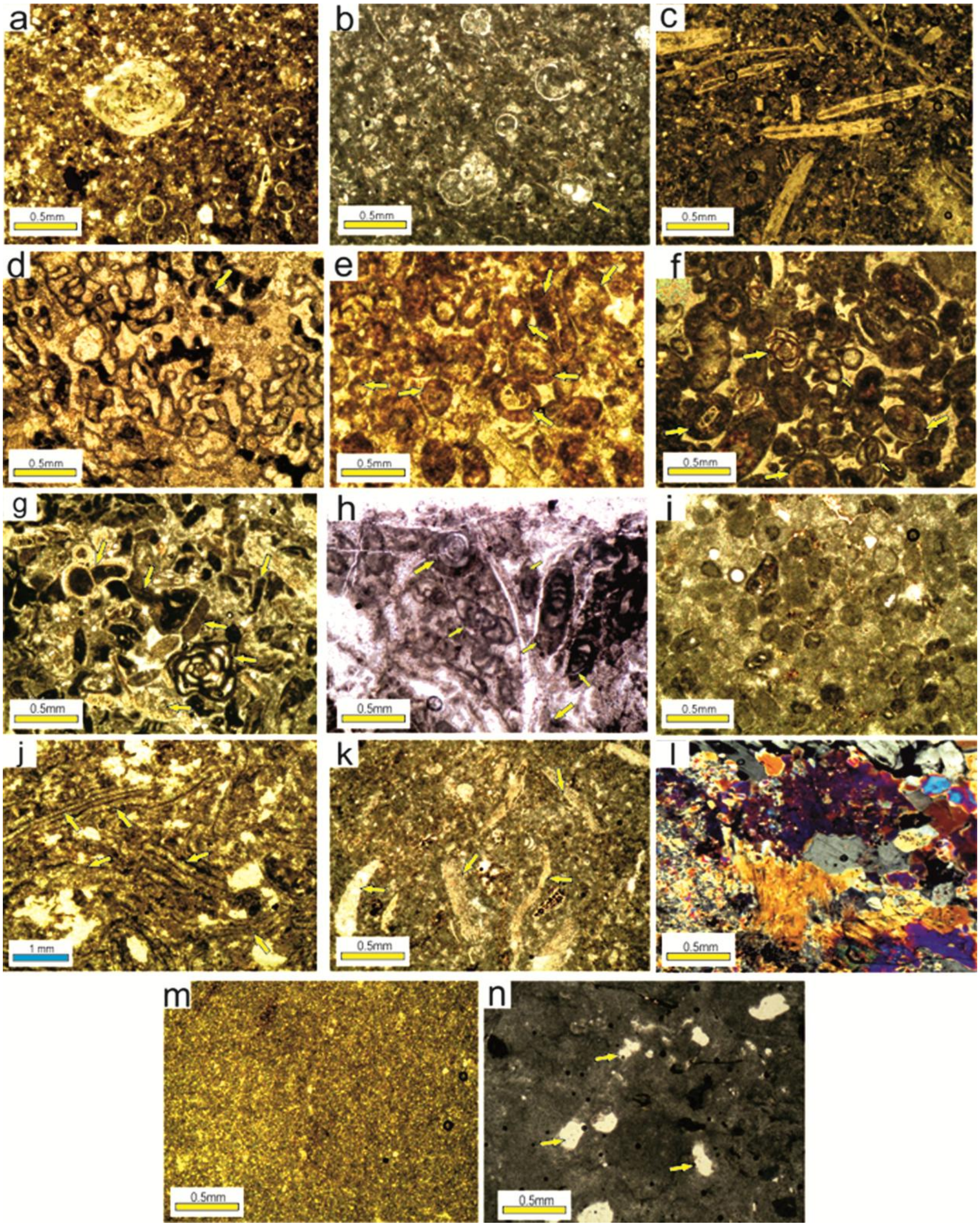

Fig. 3 — Micorfacies (a) MF O1, Hemipelagic bioclast wackestone; (b) MF O2, Planktonic foraminifera wackestone; (c) MF O3, Bioclast perforate foraminifera wackestone to packstone; (d) MF S1, Coral boundstone; (e) MF S2, Bioclast pelloidooid packstone to grainstone; (f) MF L1, Bioclast pelloid imperforate foraminifera ooid grainstone; (g) MF L2, Coralline algae imperforate foraminifera packstone to grainstone; (h) MF L3, Bioclast imperforate foraminifera wackestone; (i) MF L4, Bioclast pelloidal wackestone; (j) MF L5, Bioclast rudstone to floatstone; (k) MF L6, Bioclast echinoid wackestone; (l) porphyloblastic microtexture (evaporate microtexture); (m) MF T1 Dolomudstone; and (n) MF T2 Mudstone

during deposition of the Asmari Formation[21]. The main components of shoal are ooid and coral boundstone with well sorted fabric suggest deposition of shoal facies in high energetic condition. Presence of limestone with evaporites in our study area indicates the fluctuation of sea level of this part of the Zagros basin as a result of tectonic activities like block faulting or paleohigh (Fig. 4).

Sequence stratigraphy

The facies succession of the Asmari formation in the study area, stacking patterns and sequence boundary are the key points to third-order depositional sequence. According to the facies distribution and component of the facies in succession of the Asmari formation, sequence boundaries, three third-order sequences have been identified The beginning of the maximum flooding surface (MFS) depicts the maximum water depth and it is coincident with the end of transgressive system tract (TST). The influences of long term accommodation spaces caused highstand systems tract (HST) which finishes at the sequence boundaries[30,31] (Figs. 5, 6).

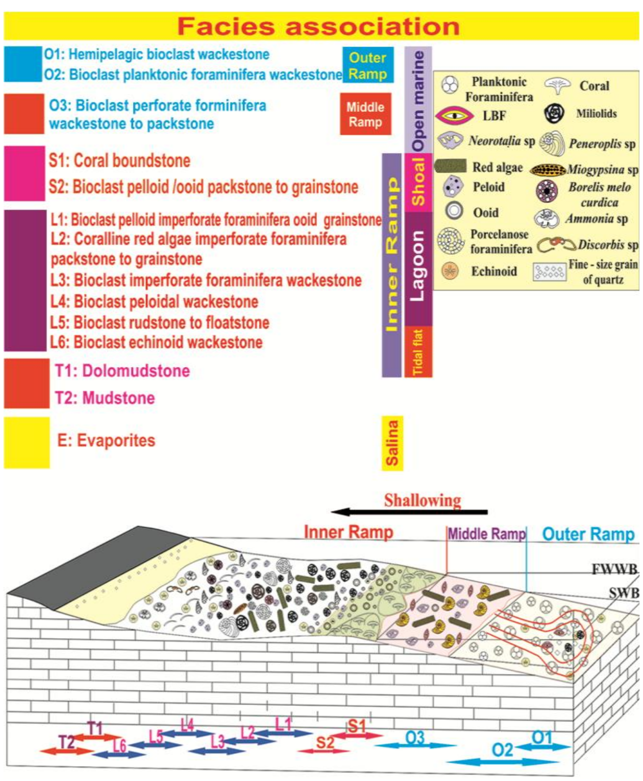

Fig. 4 — Paleoenvironmental model with identified facies

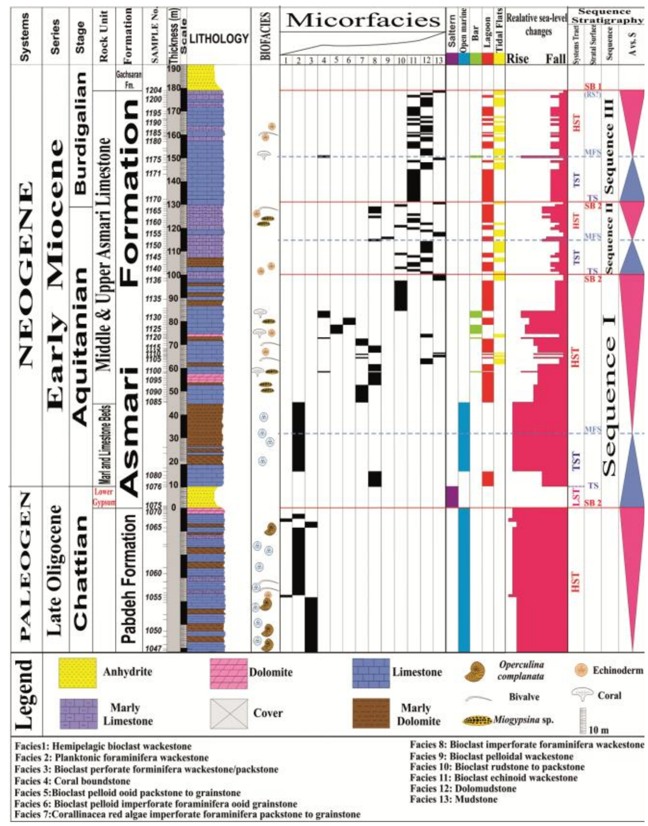

Fig. 5 — Vertical facies distribution, showing paleoenvironments, relative sea level changes and sequence stratigraphic characteristic of the Asmari Formation in Jahangirabad section

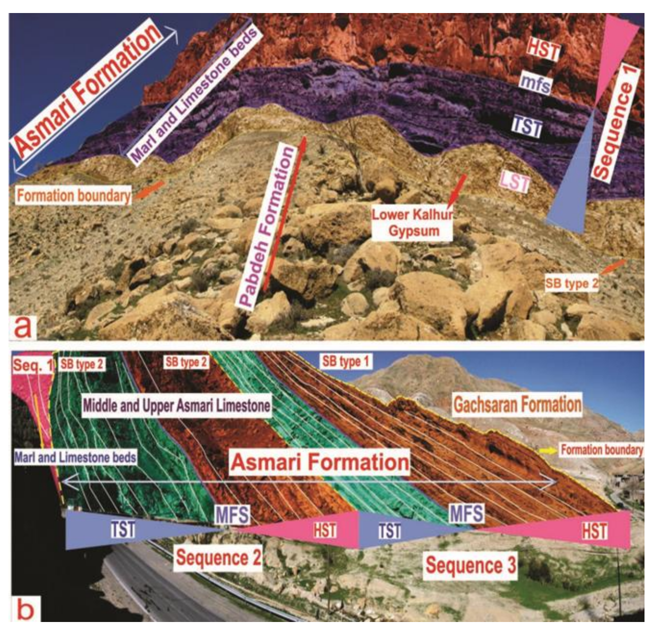

Fig. 6 — (a) General view of the Asmari Formation (Lower Kalhur Gypsum and Inter kalhur beds) and sequence stratigraphy one in Jahangirabad section. (b) Close-up view of the Asmari Formation and interpretation of sequence stratigraphy 2 and 3 in Jahangirabad section

Sequence 1

This sequence is 100 m thick begins with LST. It's related to the deposition of evaporites in saline environment (9 m). Above this evaporites sediments, marl and limestone unit corroborate the sudden rise of sea level which is related to TST with thickness of 23 m. These sediments consist of marl with planktonic foraminifera and large hyaline foraminifera. MFS of this sequence is in depth of 32 m. Shallow water component such as porcealneous foraminifera and coral debris were deposited in highstand systems tract (HST) with thickness of 68 m. The boundary between sequence 1 and 2 is characterized by fenestrate mudstone (SB type-2).

Sequence 2

The thickness of sequence 2 is approximately 48 m and consists of medium to thick bedded limestone successions. TST related to ramp lagoonal deposits with thickness of 16 m that are distinguished by the happening of imperforate foraminifera and separated from HST with thickness of 15 m by maximum flooding surface. MFS contains ferigenious and hard ground surface in the depth of 116 m. The boundary between sequence 2 and sequence 3 is characterized by fenestrate mudstone (SB type-2).

Sequence 3

Sequence 3 is mostly composed of thick limestone of about 48 m which belongs to middle and upper Asmari Formation. The beginning of this sequence is accompanied with facies L6 with echinoid and porcelaneous foraminiferas (TST). The final part of sequence 3 is HST and which is separated from TST by maximum flooding surface in depth of 151 m (MFS). The thicknesses of TST and HST are subsequently 20 and 28 m. According to sea level changes, sequence 3 shows upward decrease in accommodation space. In other words, shallowing the final part of the Asmari Formation is related to sequential closure of the Zagros proforeland basin (SB type-1)[3].

Diagenetic Processes

Diagenetic history of the Asmari Formation in the study area is influenced by series of diagenetic processes including micritization, fenestral, physical compaction, cementation, pressure dissolution, dolomitization, dissolution and tectonic fracture (Figs. 7a, b). The relationships between dolomitization and porosity are very important[32-34]. The main diagenetic processes which have affected the Asmari Formation are dolomitization and dissolution.

Dolomitization

Dolomitization is the most important diagenetic event and influence on porosity and permeability in the Asmari Formation. Based on classification of dolomite[35], 3 types of dolomites have been identified.

Type-1: Dolomicrite (very fine to finely crystalline dolomite) varying in size from 4 to 16 μ (~4 μ) is identified as planar-s crystal subhedral and unimodal mosaic shapes. This dolomite was formed in lower temperature and is identified as early depositional texture and lack of fossil[35] (Fig. 7c).

Type -2: Dolomicrosparite (fine to medium crystalline dolomite) ranging in size from 16 t0 62 μ in size (~36 μ) is formed of planar-s (subhedral to anhedral) crystal shape. This type of dolomite is formed in the late diagenetic replacement of limestone or recrystallization of early dolomite under critical roughening temperature (< 60 ˚C)[35] (Figs. 7d, e).

Type -3: Dolosprite (medium crystalline dolomite) varying from 62 to 256 μ in size (~ 135 μ), is distinguished as planar-s to non-planar–a and unimodal mosaic[34]. These dolosprite were formed by recrystallization of type 1 and 2 dolomites and developed when dolomitizing fluids were under saturated with respect to calcite[35] (Fig. 7f).

Dissolution and Cementation

One of the important diagenetic processes affected the porosity is dissolution. Interparticle and intraparticle porosity, which belong to fabric selective, are the dominant porosity in the Asmari Formation. Secondary porosity as solution enlarged, vuggy types have been observed (Figs. 7g - j).

Cement is a chemical precipitation from solution in pores, and its occurrence needs supersaturation of the pore fluid with cement mineral[20]. According to cementation types, four types of cements including blocky calcite, isopachous fibrous, poikilotopic and vein filling cements have been identified in the Asmari Formation (Figs. 7k - n).

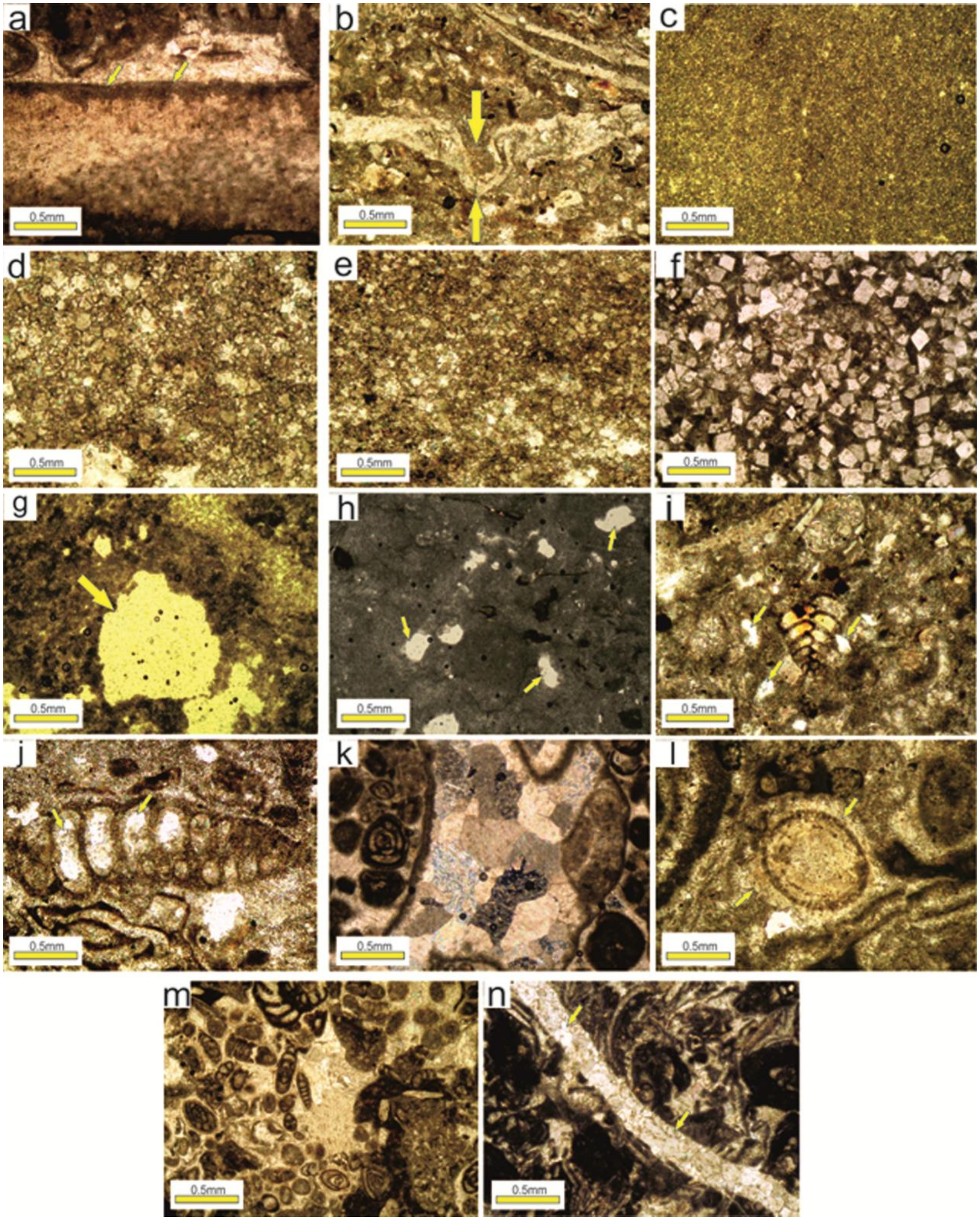

Fig. 7 — Diagenetic processes: (a) Micritization; (b) Physical compaction; (c) Dolomicrite, type 1 dolomicrite, very fine crystalline, anhedral, Xenotopic; (d–e) Dolomicrosparite, type 2 dolomite, fine to medium crystalline, anhedral to subhedral, Hypidiotopic; (f) Dolosparite, type 3 dolomite, medium crystalline, subhedral to euhedral clear rim; (g) Vugy porosity; (h) fenestral porosity; (i) Interparticle porosity; (j) Intraparticle porosity; (k) Blocky calcite cement; (l) Isopachous fibrous cement; (m) Poikilotopic cement; and (n) Vein filling calcite cement

Conclusion

The Asmari Formation in the KabirKuh Anticline (Jahangirabad section) in Lurestan zone of Zagros basin has been studied. By considering the Adams Lithostratigraphic classification in Lurestan zone, study formation was divided into 3 units (including 5 sub-units). According to field study, facies analysis and laboratory observation, paleoenvironment and sequence stratigraphy of the Asmari Foramtion have been identified. Presence of evaporites with porphyroblastic microtexture in Lower Kalhur member indicates the precipitation of evaporates as a result of paleotectonic activity and restriction condition. 13 microfacies with gradual shallowing upward trend were recognized, which belong to intertidal, lagoon, shoal and open marine. Gradual transition of facies with lack of reef barrier and broke slop show the deposition occurred in homoclinal ramp setting and consequently three-third-order depositional sequence were identified. According of vast lateral extension of evaporite sediments with high thickness and lack of external erosion surface in lower kalhur gypsum implied deposition of these evaporates occurred in saline environment.

Diagenetic processes and evolution of the Asmari Formation in study area was affected by micritization, physical compaction, cementation, dissolution and dolomitization. Dolomitization and dissolution are important diagenetic processes. Based on classification of dolomites Adabi[35], three types of dolomites were identified in the Asmari Formation at the studied area.

Acknowledgments

The experimental works of this research study were supported by University of Shahid Beheshti, University of Innsbruck and N.I.O.C Exploration Directorate of Iran. Special thanks are extended to Dr. Karl Krainer, Dr. Parvin Mohtat-Aghai from University of Innsbruck Austria, for giving valuable advices and consideration.

Conflict of Interest

The authors declare no conflict of interests.

Author Contributions

FM and AS: wrote the main manuscript text; FM drawn the Figures with CorelDRAW X5; and MHA and ATS helped in interpretation of the microscopic pictures.

References

1 Ahr W M, *Geology of Carbonate Reservoirs: The Identification, Description, and Characterization of Hydrocarbon Reservoirs in Carbonate Rocks*, (John Wiley & Sons, Inc., New Jersey) 2008, pp. 296.

2 Motiei H, *Stratigraphy of Zagros: Treatise on the geology of Iran*, (Geological Survey of Iran Publication) 1993, pp. 583.

3 Van Buchem F S P, Allan T L, Laursen, G V, Lotfpour M, Moallemi, *et al*., Regional stratigraphic architecture and reservoir types of the Oligo-Miocene deposits in the Dezful Embayment (Asmari and Pabdeh Formations) SW Iran, *J Geol Soc London*, 329 (2010) 219–263.

4 Alavi M, Structures of the Zagros Fold-Thrust Belt in Iran, *Am J Sci*, 307 (2007) 1064–1095.

5 Alavi M, Regional stratigraphy of the Zagros fold-thrust belt of Iran and its proforeland evolution, *Am J Sci*, 304 (2004) 1–20.

6 Dunham R J, Classification of carbonate rocks according to depositional texture. In: Classification of Carbonate Rocks, edited by Ham W E, *Aapg Bull*, 1 (1962) 108–121.

7 Emery D & Myers K J, *Sequence Stratigraphy*, (Blackwell Science Ltd) 1996, pp. 297.

8 Flügel E, *Microfacies of Carbonate Rocks: Analysis, Interpretation and Application*, (Springer, Berlin–Heidelberg, New York) 2010, pp. 976.

9 Tucker M E, Calvet F & Hunt D, Sequence Stratigraphy of Carbonate Ramps: System Tracts, Models and Application to the Muschelkalk carbonate Platforms of eastern Spain. Sequence stratigraphy and Facies Association, edited by Posamentier H W, Summerhayes C P, Haq B U & Allen G P, *Int As Sed*, 18 (1993) 397–415.

10 Adams C G & Bourgeois E, *Asmari Biostratigraphy*, Iranian Oil Offshore Company, Geological and Exploration Division, Report No. 1074, (1967) 1-37.

11 Wilson J L, *Carbonate facies in Geological History*, (Springer, Berlin– Heidelberg, New York) 1975, pp. 168.

12 Pomar L, Ecological control of sedimentary accomodation: evolution from a carbonate ramp to rimmed shelf, Upper Miocene, Balearic Islands, *Palaeogeogr Palaeocl*, 175 (2001) 249–272.

13 Pomar L, Types of carbonate platforms: a genetic approach, *Basin Res*, 13 (2001) 313–334.

14 Romero J, Caus E & Rossel J, A model for the palaeoenvironmental distribution of larger foraminifera based on Late Middle Eocene deposits on the margin of the south Pyrenean basin (SE Spain), *Palaeogeogr Palaeocl*, 179 (2002) 43–56.

15 Corda L & Brandano M, Aphotic zone carbonate production on a Miocene ramp Central Apennines, Italy, *J Sediment Petrol*, 61 (2003) 55–70.

16 Brasier M D, An outline history of sea-grass communities, *Paleontol J*, 18 (1975) 81–702.

17 Hallock P & Glenn E C, Larger foraminifera: A tool for paleoenvironmental analysis of Cenozoic carbonate depositional facies, *Palaios*, (1986) 55–64.

18 Buxton M W N & Pedley H M, A standardized model for Tethyan Tertiary carbonates ramps, *J Geol Soc London*, 146 (1989) 746–748.

19 Fournier F, Montaggioni L & Borgomano J, Paleoenvironments and high-frequency cyclicity from

Cenozoic South-East Asian shallow-water carbonates: a case study from the Oligo-Miocene buildups of Malampaya, Offshore Palawan, Philippines, *Mar Petrol Geol*, 21 (2004) 1–21.

20 Brandano M, Frezza V, Tomassetti L & Peley M, Facies analysis and paleoenvironmental interpretation of the Late Oligocene Attard Member (Lower Coralline Limstone Formation), Malta, *Sedimentology*, 56 (2008) 1–21.

21 Brandano M, Frezza V, Tomassetti L, Marco L & Cuffaro M, Heterozoan carbonates in oligotrophic tropical waters: The Attard member of the lower coralline limestone formation (Upper Oligocene, Malta), *Palaeogeogr Palaeocl*, 274 (2009) 54–63.

22 Embry A F & Klovan J, A Late Devonian reef tract on Northeastern Banks Island, *NWT Bull Can Pet Geol*, 19 (1971) 730–781.

23 Warren J K, Lock D & Granger P, Coorong Dolomites (South Australia) and models of ancient Coorong-style dolomites, *AAPG Bull*, 68 (1984) 537–538.

24 Warren J K, *Evaporites: sediments, resources and hydrocarbon*, (Springer, Berlin) 2006, pp. 373.

25 Tucker M E, Sequence stratigraphy of carbonate–evaporate basins: models and application to the Upper Permian (Zechstein) of northeast England and adjoining North Sea, *J Geol Soc*, 148 (1991) 1019–1036.

26 Burchette T P & Wright V P, Carbonate ramp depositional systems, *Sedimentary Geol*, 79 (1992) 3–57.

27 Pomar L, Ecological control of sedimentary accomodation: evolution from a carbonate ramp to rimmed shelf, Upper Miocene, Balearic Islands, *Palaeogeogr Palaeocl*, 175 (2001) 249–272.

28 Pomar L, Types of carbonate platforms: a genetic approach, *Basin Res*, 13 (2001) 313–334.

29 Brandano M & Corda L, Nutrients, sea level and tectonics: constrains for the facies architecture of a Miocene carbonate ramp in central Italy, *Terra Nova*, 14 (2002) 257–262.

30 Emery D & Myers K J, *Sequence Stratigraphy*, (Blackwell Science Ltd., Oxford) 1996, pp. 297.

31 Nichols G, *Sedimentology and stratigraphy*, (Wiley-Blackwell, New York) 1999 pp. 432.

32 Choquette P W, Cox A & Meyer W J, Characteristics, distribution and origin of porosity in shelf dolostones, Burlington-Keokuk Formation (Mississippian), U.S. mid-continent, *J Sediment Petrol*, 62 (1992) 167–189.

33 Ehrenberg S N, Eberli G P, Keramati M & Moallemi S A, Porosity and permeability relationships in interlayered limestone-dolomite reservoir, *AAPG Bull*, 90 (2006) 91–114.

34 Lucia F J, *Carbonate reservoir characterization*, (Springer-Verlag Heidelberg Berlin) 2007, pp. 179.

35 Adabi M H, Multistage dolomitization of Upper Jurassic Mozduran Formation, Kopet-Dagh Basin, N.E. Iran, *Carbonate Evaporite*, 24 (2009) 16–32.