PETROFACIES ANALYSIS AND DEPOSITIONAL ENVIRONMENT OF THE JAHRUM FORMATION (EOCENE), SOUTH-SOUTHWEST OF BURUJEN, IRAN

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ABSTRACT: A progressive carbonate environment from supratidal to near-shore, restricted to intertidal and restricted shallow marine environment existed during deposition of the Jahrum Formation. The main facies characteristics of the Jahrum Formation in the study area are: (1) a laminated, unfossiliferous dolomite and pelleted dolomitic mudstone with solution collapse breccias; (2) a pelleted laminated fossiliferous dolomitic mudstone; (3) reworked skeletal wackestone to packstone; (4) highly reworked biointraclastic grainstone; (5) fossiliferous wackestone to packstone. As a result, two major depositional systems tracts can be defined: (1) the lower portion, are transgressive systems tract; and (2) the upper portion, as highstand systems tract. Diagenetic processes involved in supratidal rocks of the Jahrum Formation reflect dolomitization of initial sediments, leaching of calcium sulfate and carbonate grains, replacement of dolomite and stylolitization. Voids are the most common pore type, and porosity was controlled by diagenesis that was influenced by primary depositional texture.

Depositional analysis and environmental interpretations suggest the occurrence of syngenetic euhedral dolomite in supratidal sediments of the Jahrum Formation in a mixing zone between meteoric waters and brines derived from sea water. Syngenetic dolomite is evidenced by fine euhedral crystal, pore shapes and the occurrence of pelletal fabric. Late dolomitization is most common as void-filling and replasive dolomites in rocks that were deposited in higher energy environments.

INTRODUCTION

The Tertiary deposits in the Zagros basin are divided into the lower Tertiary (Paleocene-lower Miocene) and upper Tertiary (lower Miocene-Pliocene and younger) Figure 1. The Jahrum Formation (Paleocene-Eocene) is part of the lower Tertiary deposits. The upper Tertiary deposits records a regression from lower Miocene to Pliocene (Fars Group, Motiei 1993).

The Jahrum Formation was deposited during early transgression from Hormuz Strait to wide areas of the Zagros basin, including, northeast-southeast part of this basin (Fig. 2). The Jahrum Formation is part of the shallow marine sedimentation of such a transgression. At the same time, the pelagic shales, marl and argillaceous limestones of the Pabdeh Formation deposited along the troughs of the basin (Wells 1967). The Jahrum Formation is exposed at the northeastern portion of the high Zagros mountains.

Lithologically, the Jahrum Formation is characterized by massive, grey to brown dolomite, dolomitic limestone (Stocklin 1977; Darvishzadeh 1992). Numerous shallow marine water benthonic microfauna are also present in the Jahrum Formation (Kalantary 1986; Jalali 1971). Most of the Jahrum studies are in connection with the subsurface, and are mainly associated with oil fields areas (Seyrafian and Hajhosseini 1983). The Jahrum Formation is mostly a gas producing reservoir in the coastal, interior and southeast of Zagros basin.

In this study the outcrops of the Jahrum Formation far beyond the oil field areas are examined (Fig. 3). Based on paleontological evidence observed in thin-sections, the Jahrum Formation in the study area is Eocene in age. The thickness of

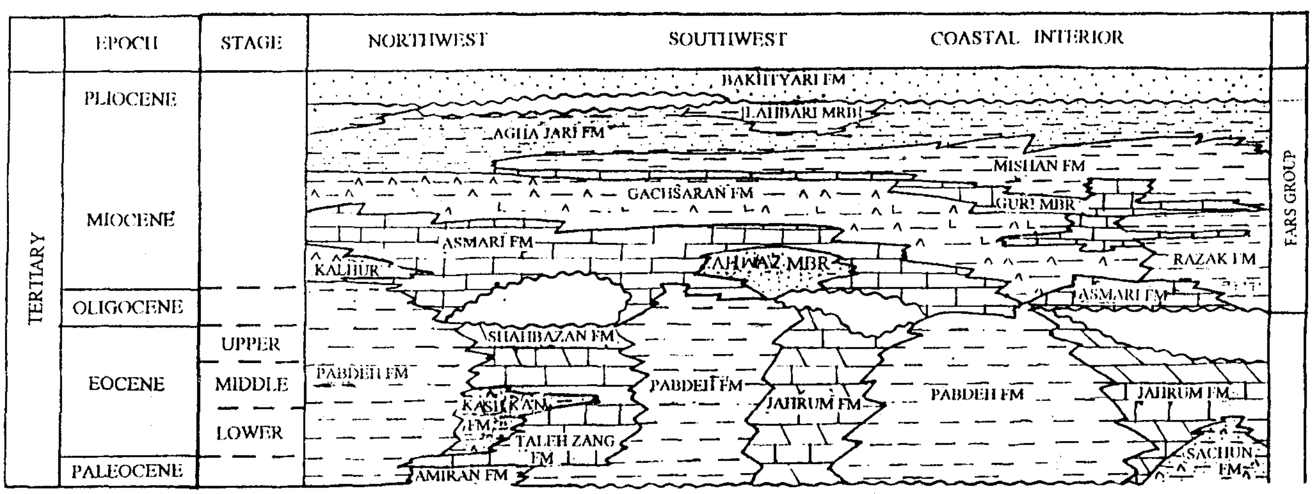

Figure 1. Tertiary lithostratigraphic correlation chart of southwest Iran (adapted from Ala 1982). Standard lithologic symbols used in lithology section (dots and circles for sandstones and conglomerates, dashes for siliclastic mudrocks, rectangles for limestones, parallelograms for dolomites, dashes and inverse V for evaporites, and wavy lines for unconformities).

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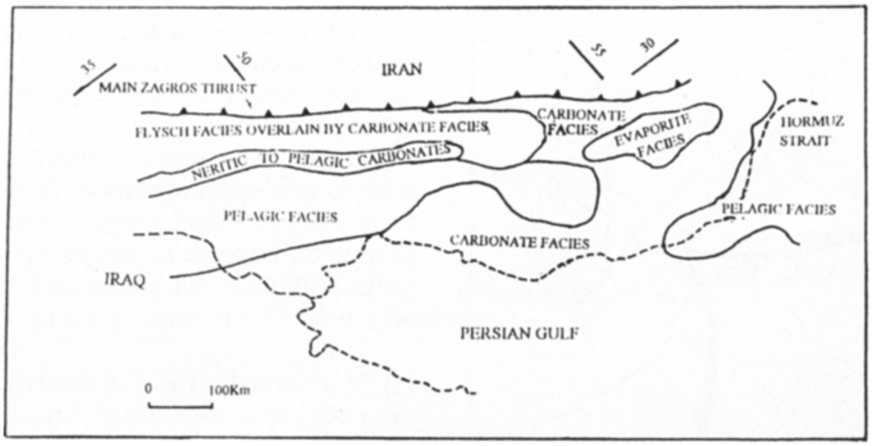

Figure 2. Regional distribution of the Paleocene-Eocene lithofacies through the Zagros basin. Carbonate facies including Jahrum Formation mainly deposited in a shallow marine sedimentation, where, pelagic sedimentation occurred in a deeper marine condition (adapted from Koop and Orbel 1977).

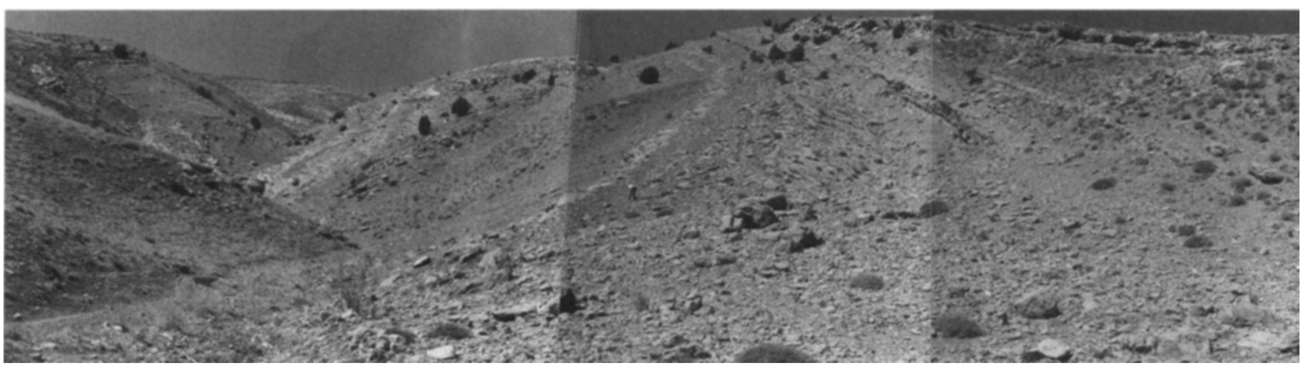

Figure 3. Outcrop panarama photograph of the Jahrum Formation (Eocene) west side of the Cheshmeh Ali village, 31 kilometers south of Gandoman, in Burujen area.

the Jahrum Formation in the study area (220 m) is relatively thinner than at its type section (467.5 m, N: 28°25',53", E: 53°44',47", James and Wynd 1965). The significance of thickness difference of the Jahrum Formation is due to lateral extension of the chocolate to purple shales (equivalent to the lower Pubdeh Formation) during Paleocene-Eocene at the study area. The Jahrum Formation in the study area overlies the red marls and chocolate shales of Eocene age.

REGIONAL ASPECTS

The Jahrum Formation is present throughout the interior and coastal parts of central Zagros basin. It is also present in the subsurface in the extreme southwestern part of the basin.

The Jahrum Formation is equivalent to the Taleh Zang and Shahbazan Formations (carbonates) and the red conglomerates and sandstones of the Kashkan Formation in northwestern part of the Zagros basin.

The Jahrum Formation is replaced by pelagic sedimentation of the Pabdeh Formation in deeper parts of the Zagros basin including west, southwest and central parts. The Jahrum Formation is disconformably overlain by Asmari Formation. However, in some localities of interior central part of the Zagros basin, the Razak Formation disconformably overlies the Jahrum Formation (Fig. 1). The Jahrum Formation is time equivalent of the Rad huma-Damman Formations of Saudi Arabia, Kuwait and southern Iraq (James and Wynd 1965).

STUDY AREA AND METHODOLOGY

The study area is located to the east of Cheshmeh Ali village, 31 km south of Gandoman in Burujen area (Fig. 4). This area is located at the southern margin of crushed zone of high Zagros mountains. Samples were taken almost every two meters, and sampling was based on facies variation of the outcrops. Approximately 100 thin-sections were studied.

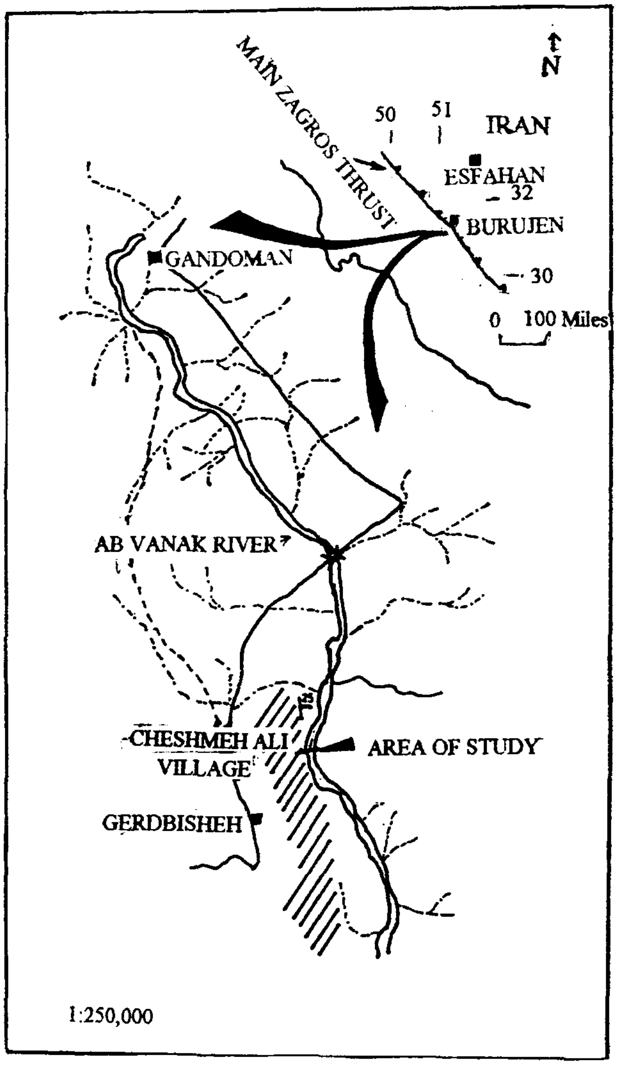

Figure 4. Location of the study area (for size convenient, original graph is 40% reduced).

PETROFACIES AND ENVIRONMENTS OF DEPOSITION

The following sedimentary sequence is recognized for the Jahrum Formation at the study area. From base upward (Fig. 7):

(1) This unit is a laminated unfossiliferous dolomite, dolomicrostone to dolomicrosparstone (Wright 1992), and pelleted dolomitic mudstone (Dunham 1962), and dolomicrosparstone, with evidence of slight solution collapse of dissolution of calcium sulfate and anhydrite remnants. It was deposited under supratidal conditions (microfacies standard no. 23 of the 8th facies belt, Wilson 1975); Figs. 5A and 5B. The thickness of this unit is 60 m.

(2) This unit consists of a pelleted laminated dolomitic biomicrite, skeletal wackestone to packstone, with minor miliolids, *Globorotalia* sp., globigerinid foraminifera and bioclastic limestone, bioclastic calcimudstone. Also reworked and bioturbated wackestone to packstone and fragments of miliolids, *Orbitolites* sp., *Nummulites* sp., *Rhapydionina* sp., are present. These were deposited under restricted to near-shore to inner-shelf environment (Boltz 1976). Occasional storm and higher water energy of environment textures such as bioclastic limestone are also present (microfacies standard no. 19, of 7th facies belt, Wilson 1975, and Flügel 1982); Figs. 5C and 5D. The thickness of this unit is 60 m.

(3) This interval contains a bioclastic grainstone, highly reworked with *Dictyoconus* sp., brachiopods, *Orbitolites* sp., miliolids, *Nummulites* sp., and, echinoid fragments, graded and finely cross-laminated dolomite layers, and inter and intragranular void filling, deposited under intertidal environment (microfacies standard no. 11, of 6th facies belt, Wilson 1975); Figs. 6A and 6B. The thickness of this unit is 30 m.

(4) The upper unit is a wackestone to packstone with *Orbitolites* sp., *Dictyoconus* sp., *Rhapydionina* sp., *Litunella* sp., and slightly pelleted, and dolomitic (as void filling). It displays intraclasts, deposited under restricted shallow marine environment associated with channels and lagoons (microfacies standard no. 16 and 17 of the 7th and 8th facies belts, Wilson 1975); Fig. 6C. The thickness of this unit is 70 m.

This sequence is interpreted to represent a progressive depositional environment from supratidal to semi-restricted near shore to intertidal and restricted shallow marine environment. However, occasional occurrence of intraclast breccias and traces of cross-laminated dolomite mudstone within supratidal rocks of the Jahrum Formation may represent periodic storm deposition on supratidal flats (Shinn 1983).

Interpreted lithofacies and microscopic visual characteristics of crystal size, porosity and dolomitization of the Jahrum Formation relative to its depositional environment is shown in figure 7.

Major dolomitization and voids occur in supratidal rocks, and to a lesser degree, in rocks of intertidal and restricted shallow marine strata, respectively.

Based on above explanation and field observations, two major depositional systems tract (Jacquin et al. 1991; Weimer 1992): (1) a transgressive system tract, and: (2) a high stand system tract for deposition of the Jahrum Formation at the study area is recognized. The sedimentary sequence of the Jahrum Formation deposited under supratidal to restricted near-shore conditions are part of the transgressive system tract, and the strata deposited under restricted to intertidal, also, in the restricted shallow marine conditions are part of the high stand system tract. Repetition of the lithological characteristics of

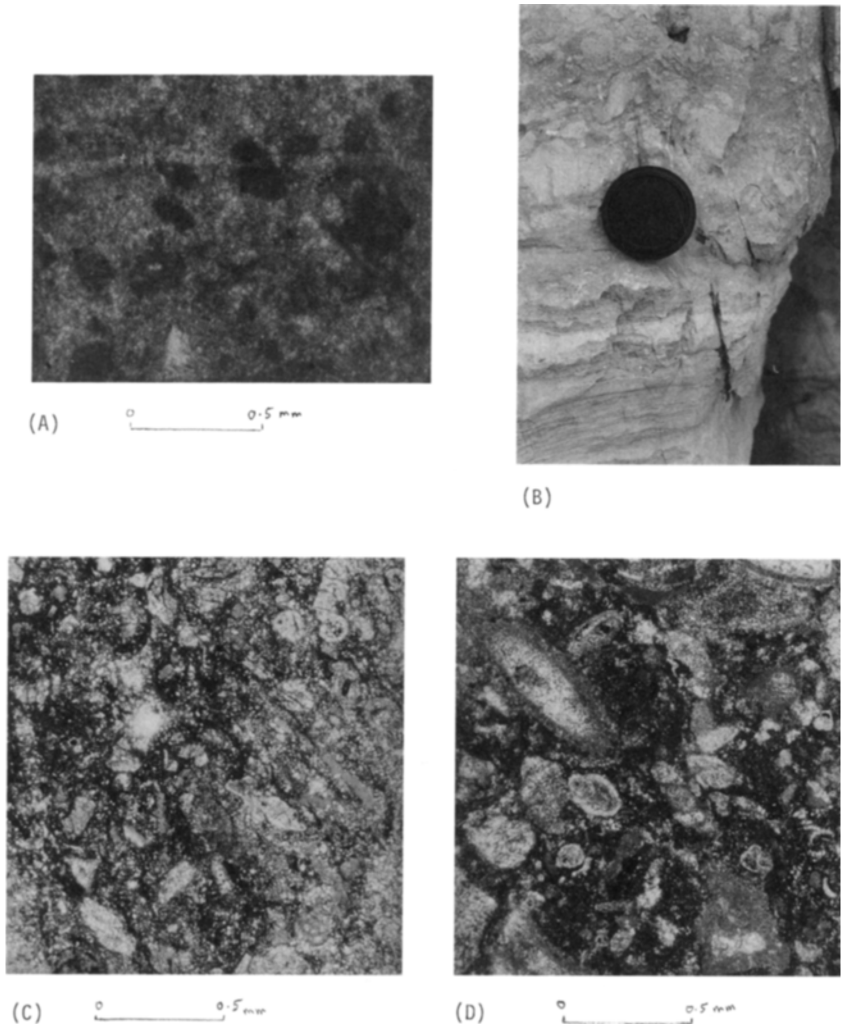

Figure 5. (A) Photomicrograph of pellets in finely crystalline dolomite wackestone, X50. (B) Poorly sorted intraclastic pelleted dolostone overlies wavy laminated micritic dolomite. Black circle equals camera cover lense. (C and D) Photomicrographs of bioclastic limestone, slightly dolomitic. Photograph C also, reflects an increase in water energy of deposition X50.

strata related to a high stand system tract may reflect prevailing sea level fluctuation (Sarg 1988).

Transgressive system tract sequence in the study area consists exclusively of carbonate facies ranging upward from laminated unfossiliferous dolomite, pelleted dolomitic mudstone, pelleted laminated dolomitic biomicrite, and, skeletal wackestone to packstone. Such a lithological characteristic suggests an increase in water depth (sea level rise) and also, a continuous increase of water depth and accommodation space of the platform.

During episodes of highstand the following sedimentary deposits, from base upward, are recognized: (1) A bioclastic calcimudstone, slightly dolomitic, with fragments of miliolid, *Orbitolites* sp., *Nummulites* sp., and *Rhapydionina* sp., (2) A biointraclastic grainstone with reworked *Dictyoconus* sp., brachiopod, *Orbitolites* sp., miliolid, *Nummulites* sp., and echinoid fragments. (3) A wackestone to packstone fossiliferous with *Orbitolites* sp., *Dictyoconus* sp., *Rhapydionina* sp., and *Litunella* sp., fragments. Such lithological characteristics suggest an occurrence of sea level fluctuation grading to slight increase in water and accommodation space over the platform (Fig. 7).

The transgressive system sequence is characterized by an incised lower boundary of carbonate overlying siliceous deposits (red marls and chocolate colored shales). TST and HST boundary is not clearly observable on outcrops. So, differentiating TST and HST deposits may be difficult. The dolomitic limestone layers (mostly identified in thin-sections) occurring in the middle part of the restricted to near-shore deposits were considered as a boundary. The upper boundary of high stand system tract sequence is placed at present erosional surface (upper-most layer of the Jahrum Formation).

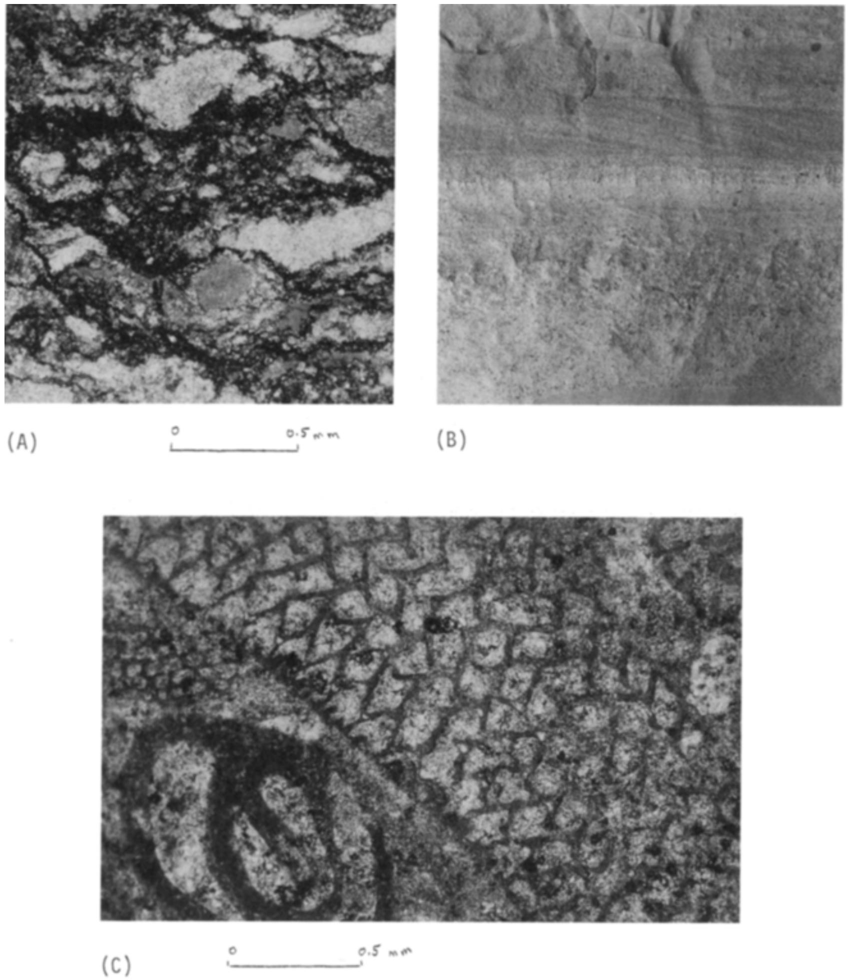

Figure 6. (A) Photomicrograph of unsorted intraclastic packstone to grainstone, X50. (B) Finely cross-laminated dolomite on outcrop. (C) Photomicrograph of biomicritic packstone. Miliolid and Orbitolite shells are laid down in a finely crystalline matrix, X50.

DIAGENESIS POROSITY

Porosity in the Jahrum Formation at the study area varies from nill to 25 percent (visual estimation from thin-sections). It increases in rocks deposited at supratidal and intertidal environments, with an average porosity of 15-25 percent (Fig. 8A). Nill to poor porosity is present in restricted and shallow marine rocks of the Jahrum Formation (Fig. 7).

Pores included molds of leached carbonate grains as pellets (Fig. 9A) and anhydrite and irregular fenestral vugs (Fig. 8A) in dolomite and dolomitic mudstone, and, intercrystalline voids (Fig. 9B) associated with dolomite rhombs. These are considered to be a fabric selective pores (Mazzullo and Harris 1992). Rare porosity associated with fractures and stylolites (pressure-solution phenomena, Milliman 1974) are also present, not fabric selective (Figs. 8C and 8D). Voids in rocks of the Jahrum Formation that are deposited in the higher energy of environment are partly filled or replaced by late dolomite (Fig. 6A). However, some intergranular and intragranular porosity already existed. Voids are the most frequent pore types. Preservation of leached molds is evidence of unavailable highly saturated solution with respect to dolomitization (Sibley and Gregg 1987).

Rims of pores consist of dolomites crystals (Fig. 9B). Dolomites which do not nucleate on grains may subsequently dissolve to form molds. Dolomite crystals do not progress into molds, reflecting, leaching of grains after dolomitization had occurred. Moldic pores are characteristics of rocks that have been exposed to meteoric waters (Mathews 1968). Leached voids are the most frequent type pores and porosity control by diagenesis is mainly influenced by primary depositional texture.

Intercrystalline pressure-solution features and stylolitization are commonly present in thin-sections of the Jahrum Formation (Fig. 8D). Stylolites cross-cut finely crystalline supratidal dolomites, indicating that, stylolitization was a very late diagenetic process. Rare porosity associated with

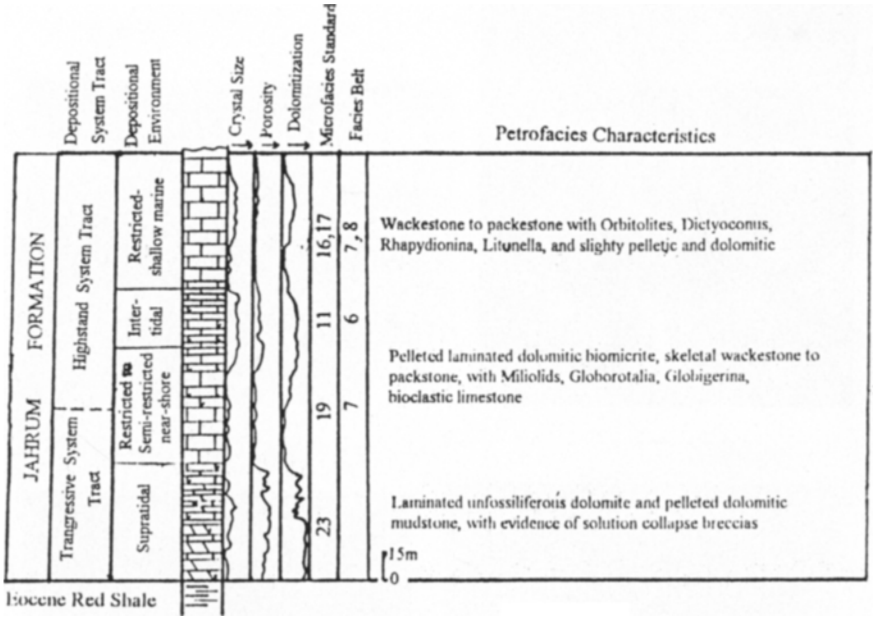

Figure 7. Interpreted lithofacies and microscopic visual characteristics of crystal size, porosity, and dolomitization of the Jahrum Formation relative to its depositional environment.

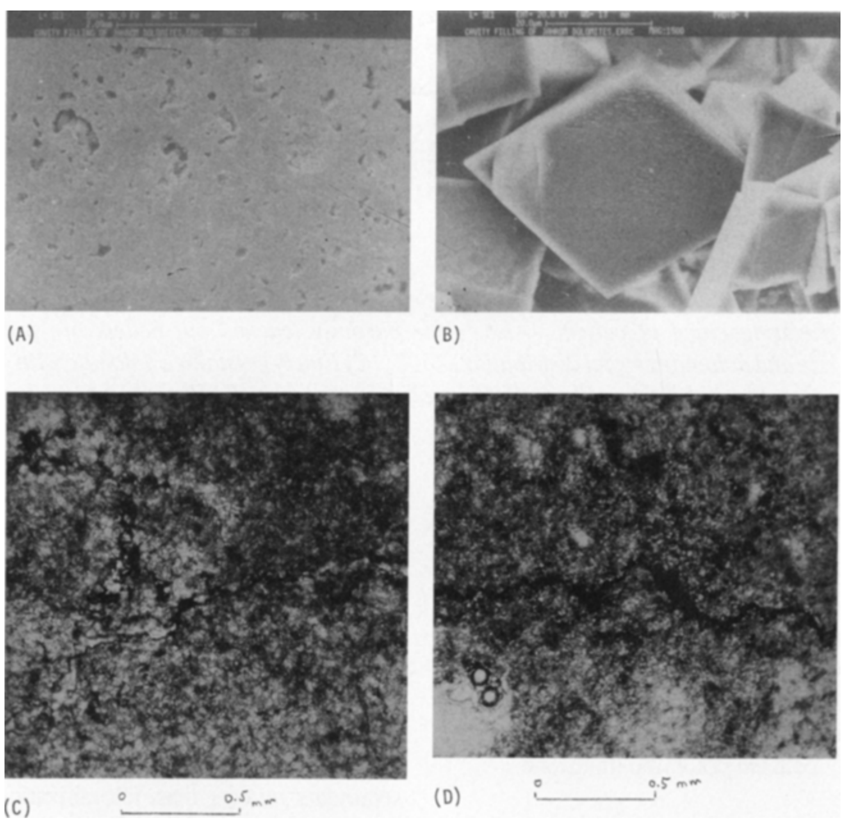

Figure 8. (A) SEM characteristics of pore size and their distribution under X20 magnification. Voids are 47 to 850 microns in diameters. (B) SEM characteristics of pore size and dolomite crystals under X1500 magnification. Attention a well developed dolomite rhombs, also, intercrystalline voids associated with dolomite rhombs. (C) and (D) rare porosity associated with fine fractures and stylolites X50.

fine fractures and stylolites may reveals mesogenetic type pores (Mazzullo and Harris 1992).

Diagenetic processes involved in development of porosity in the supratidal rocks of the Jahrum Formation may be

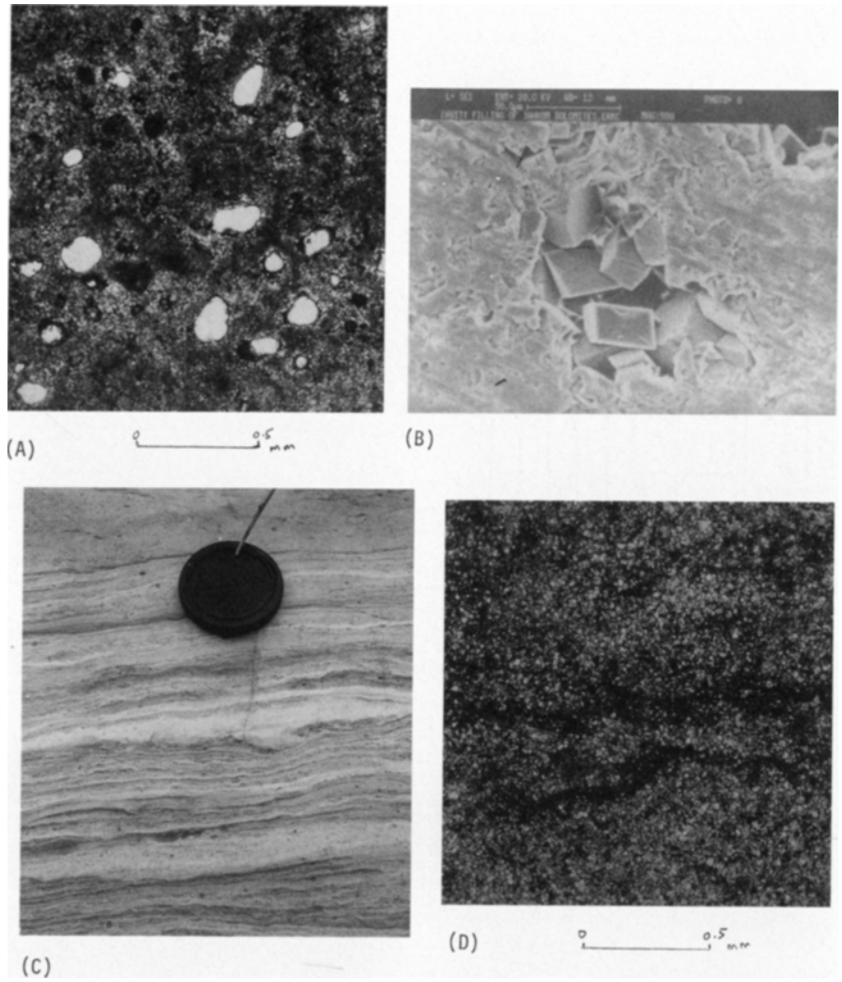

Figure 9. (A) Photomicrograph of unconnected voids in pelleted finely crystalline dolomitic limestone to dolomite. A well-rounded pore walls reflects leaching of pellets. Also, some partially leached out pellets are present, X50. (B) SEM characteristics of pore size and dolomite crystal distribution, X500. (C) Finely crystalline dolomite with wavy laminae. In some cases laminaes are associated with stylolites. Black circle equals camera lense. (D) Photomicrograph of mud laminated finely crystalline dolomite, X50.

summarized as:

Initial sediments, lime-mud, pellets, and calcium sulfate; Diagenesis, dolomitization of matrix, leaching calcium sulfate and carbonate grains as pellets, replacement of dolomite, and stylolitization; Present rock, vugs (primary controlled by depositional texture) in finely crystalline dolomite, and, in finely pelleted dolomitic mudstone.

DOLOMITIZATION

Depositional analysis and environmental conditions observed suggest the occurrence of syngenetic (early) dolomites in supratidal sediments of the Jahrum Formation in the study area.

Original supratidal sediments including pelletal lime-mud, have been dolomitized under hypersaline environments (Friedman and Sanders 1978). Hypersalinity is recognized by presence of anhydrite in a finely crystalline pelleted dolomite (Fig. 10D).

Criteria suggesting the occurrence of syngenetic dolomite in the supratidal sediments of the Jahrum Formation includes: (1) preservation of original pelletal fabric of the sediments (Fig. 9A). Availability of pelletal fabric in lime-mud sediments reflects that dolomitization occurred right after deposition, as well-preserved pellets in ancient carbonate sediments is evidence of synsedimentary sedimentation (Shinn et al. 1980). (2) The characteristic of pore shapes. The shapes of the pores formed due to leaching of anhydrite and pellets (Fig. 2A). In most cases, dolomite crystals do not progress into voids completely (Fig. 8B). It reflects, leaching of grains as anhydrite and pellets, after dolomitization was occurred (Fig. 9B). Preservation of molds is evidence of unavailable highly saturated solution with respect to

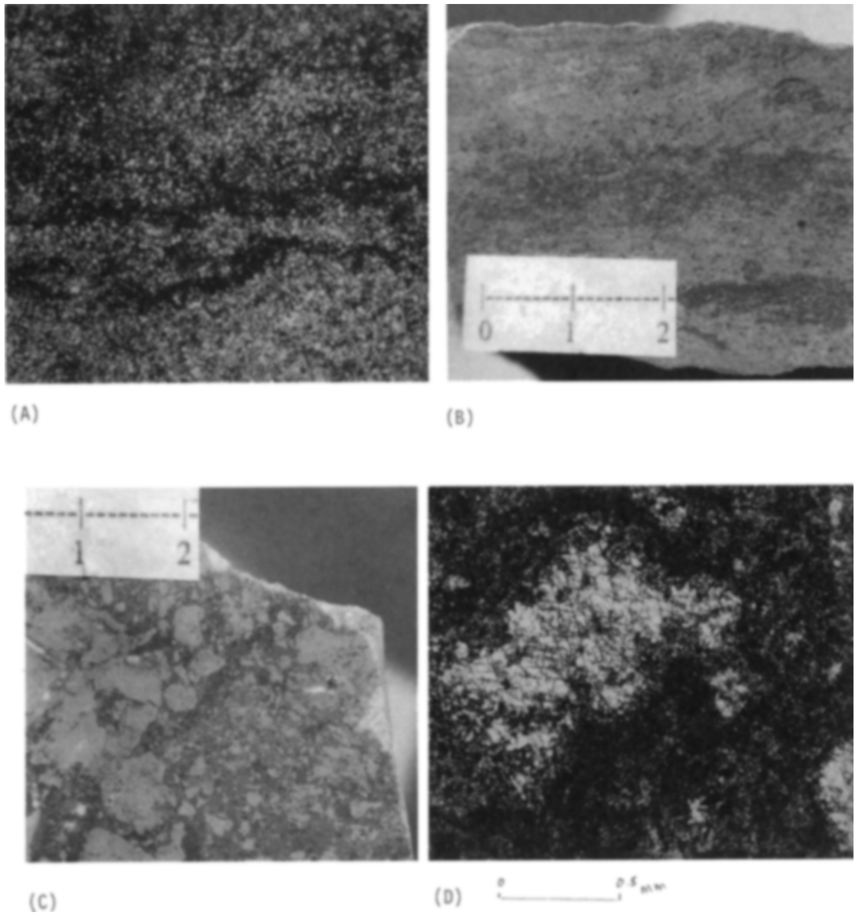

Figure 10. (A) Photomicrograph of laminated finely carbonate mud and coarser dolomite crystals, X50. (B) Polished photograph of finely crystalline mudstone (dark laminae), interbedded with finely crystalline dolomite, scale is on centimeter. (C) Clast-supported solution collapse. Secondly anhydrite fills fractures and and voids, scale is on centimeter. (D) Photomicrograph of anhydrite in finely crystalline pelleted dolomite. Partial replacement of anhydrite grains by euhedral dolomites, X50.

dolomitization (Sibley and Gregg 1987). Rims of pores consist of dolomite crystals (Fig. 9B). Dolomite which not nucleate on grains may subsequently dissolve to form molds. (3) Finely crystalline sizes (5 to 10 microns rhombs). Early dolomites are nonluminescent to dully luminescent, fine to medium in crystal size and are euhedral to subhedral (Gao et al. 1992). Early dolomites in supratidal rocks are unimodal and planar-euhedral (Sibley and Gregg 1987).

The occurrence of syngenetic dolomite, finely crystalline dolomite sizes and unavailable highly saturated solution may reveals the occurrence of near-surface dolomitization, in which, a mixing zone between meteoric waters and brines derived from sea water was existed (Dorag model, Badiozamani 1973).

Late dolomite as void-filling dolomites including cement (Bathrust 1975), and, dolomite that replaced previous cement are present in intertidal and subtidal rocks of the Jahrum Formation. Euhedral dolomite crystals partially replaced anhydrite grains. Crystal size varies from 30 to 60 microns, but coarse crystals have been also observed. Replacement by dolomite commonly starts at edges of anhydrite grains and extends inward (Fig. 10D). Replacement by dolomite to have been taken placed in a very late diagenetic process, as fractures and pressure-solution contacts are partially to completely replaced by dolomite crystals (Figs. 8C and 8D).

Euhedral dolomite crystals scatterly replaced pre-existing fine grained matrix, and partially replace intraclasts. Replacement of dolomite usually concentrates at the peripheral grains (Figs. 5C and 6A).

Some voids in rocks of the Jahrum Formation are mainly filled by late dolomite. Late dolomites are considered polymodal and planar-subhedral with mimically and nonmimically replaced allochems (Sibley and Gregg 1987). Late dolomites are brightly luminescent (Gao et al. 1992).

LAMINATION

Lamination is one of the most common feature associated with the supratidal and restricted near-shore strata of the Jahrum Formation (lower to lower-middle part of the section) in the study area. Lamination at the outcrops is characteristic of finely crystalline dolomite with wavy laminae (Fig. 9C).

Lamination in thin-sections is mostly intermittent in finely carbonate mud and dolomite crystals (Figs. 9D and 10A). Laminaes are also associated with stylolites. Microscopic lamination of original texture such as intercalation of finely carbonate mud and dolomite reflects different chemical processes included rate of crystallization and the effects of magnesium and other ions in environment of deposition during precipitation (Folk 1974). Lamination in tidal flat sediments are usually caused by storm tidal deposition (Ball et al. 1963), and, by algal growth (Logan et al. 1964). Also, microbial cyanophytes bacteria (algae) commonly create a stirky substrate on which repeated storm deposits may form to create laminations. No algal growth evidence was observed.

SOLUTION BRECCIAS

Several solution collapse breccias were observed in supratidal sediments of the Jahrum Formation. These are interpreted to have been formed by dissolution of calcium sulfate in a supratidal rocks (Fig. 10C). The solution collapse breccias are mostly composed of poorly sorted dolomite clasts in a dark brown mudstone matrix. Dolomite clasts range in size from a few millimeters to more than 5 centimeters. The distribution of the collapse zone versus preserved massive sulfates helps determine whether exposure or transgression is the cause of calcium sulfate dissolution. Based on degree of dissolution and the fact that no bedded sulfates are present, leads to belief in subaerial exposure. The solution collapse breccias, also, could have been caused by sea level rise or fall (Anderson 1992). Recognition of evaporitic solution breccia is described by Beals and Oldershaw (1969).

PETROLEUM APPLICATION

The Jahrum Formation at the type section (N 28°25' 53"; E 53°44' 47") is composed of basal massive brown-weathered dolomite, upward to medium-bedded dolomite to massive dolomitic limestone with abundant microfauna from Paleocene to upper Eocene in age (James and Wynd 1965). The Jahrum Formation is also erroneously called Jahrum dolomite, predominantly based on the presence of intensive dolomite layers.

Regional distribution of Paleocene-Eocene lithofacies through the Zagros basin reflects carbonate facies including Jahrum Formation mainly deposited in a shallow marine sedimentation, where, pelagic sedimentation occurred in a deeper marine conditions (Fig. 2). Paleocene-Eocene lithofacies through Zagros basin also includes a variety of transitional depositional areas, such as, neritic to pelagic, evaporitic to carbonate, and carbonate to pelagic sedimentation. Thus, lithological characteristics of the Jahrum Formation may range from supratidal to shallow marine and to deeper marine environment of deposition from area to area throughout the Zagros basin. Variation in sedimentological conditions leads to different porosity-permeability characteristics for the Jahrum Formation in that basin. For instance, the Jahrum Formation in Sarkhun Filed, Bandar Abass area, far north of Hormuz Strait, is mainly composed of argillaceous limestone, and to a lesser degree limestone and slighty dolomitic limestone (Seyrafian and Hajhosseini 1983). Effective porosity of the Jahrum Formation in that field ranges from nill (argillaceous limestones) to about 15 percent (dolomitic parts). Sarkhun Filed is a domed-anticline structure, and hydrocarbon trapping should be controlled by structural phenomena. Detailed analysis revealed porosity characteristic of the Jahrum Formation is severely affected by lateral and vertical lithological variations, and in turn, its hydrocarbon trapping. Gas trapping in Sarkhun Field is mostly concentrated in the dolomitic parts of the Jahrum Formation. Porosity increases in eastern and northern part of the field where, vertical and lateral alternating dolomitization has occurred. Based on above explanation, hydrocarbon accumulation in relation to the Jahrum Formation throughout the Zagros basin should be controlled by:

(1) present structural style of the basin;
(2) primary depositional control on lithology and related porosity;
(3) diagenesis such as dolomitization and leaching.

CONCLUSION

The following facies characteristics and depositional analysis is recognized for the Jahrum Formation (Eocene) at the Cheshmah Ali village, south-southwest of Burujen, Iran. (1) A laminated unfossiliferous dolomite and pelleted dolomitic mudstone with solution collapse breccia deposited under supratidal condition. (2) A pelleted laminated dolomitic biomicrite, skeletal wackestone to packstone with forams and periodic reworked bioturbated wackestone to packstone deposited under restricted to near-shore to inner-shelf environment, with occurrence of storm and higher energy of water conditions. (3) A highly reworked biointraclastic grainstone, deposited under intertidal environment. (4) And, a wackestone to packstone, fossiliferous, deposited under restricted shallow marine environment.

Based on above explanation, two major depositional system tracts; (1) transgressive system tract, and; (2) high stand system tract is suggested for deposition of the Jahrum Formation in the study area. Repetition of lithological characteristics of the strata related to a high stand system tract may reflect prevailing of sea level fluctuation. Diagenesis processes involved in development of porosity in supratidal rocks of the Jahrum Formation, reflects dolomitization of matrix and leaching of calcium sulfate and carbonate grains of initial sediments. Voids are the most common pore type, and primary depositional texture is influences porosity. Syngenetic dolomite is evidenced by finely crystalline sizes, nature of pore shapes and availability of pelletoidal fabric.

Criteria suggest that, early dolomitization could have been occurred under the mixing zone between meteoric water and brines derived from sea water. Void-filling and replaced dolomites are the most frequent late dolomite types.

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