MICROFACIAS E GEOQUÍMICA DA FORMAÇÃO DA RUTEH NA ÁREA DE RUTEH, ALBORZ CENTRAL, IRAN**GEOCHEMISTRY AND MICROFACIES OF THE RUTEH FORMATION IN THE RUTEH AREA, CENTRAL ALBORZ, IRAN**

ژئوشیمی و میکروفاسیس سازند روته در منطقه روته، البرز مرکزی، ایران

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RESUMO

Para compreender as microfacias, o ambiente deposicional e a geoquímica das rochas do Permiano Superior na região de Alborz, foram estudadas as seções de tipo da Formação Ruteh. Durante o Permiano, a região de Alborz era parte do mar de Paleotethys, de tendência leste-oeste. Estudos estratigráficos indicam que a Formação Ruteh na seção de Ruteh é composta de calcário fino a massivo, calcário argiloso intercalado com xisto, é coberto por um distinto horizonte laterítico da Formação Eliká e é sustentado pela desconformidade da Formação Dorud. Análise de fácies e estudos petrográficos levaram ao reconhecimento de 11 microfacias na seção de Ruteh. Estas fácies foram depositadas em cintos de 4 fácies, como planícies de maré, lagoa, cardume e sub-ambiente marinho aberto. As algas calcárias Permianas na Formação Ruteh são amplamente difundidas e bem documentadas para determinar o ambiente e microfilamentos dos depósitos permianos. Cimentação e dolomitização são os principais processos diagenéticos na Formação Ruteh. Com base em estudos petrográficos (tamanho e tecido), foram reconhecidos 4 tipos de dolomita, como dolomicrita, dolomicrospar, dolospar e cimento de dolomita. A água do mar foi a principal fonte de Mg para dolomita diagenética precoce (tipo 1), enquanto o Mg para dolomita tardia diagenética (tipos 2, 3, 4) foi provavelmente originado por processos de pressão de xisto e solução de pressão. Estudos de elementos maiores e menores levaram ao reconhecimento da mineralogia da aragonita. O estudo geoquímico mostra que esses carbonatos foram afetados principalmente pela diagênese meteórica, que ocorre em um sistema semipróximo ao diagenético aberto.

Palavras-chave: *Mineralogia original, Estudo geoquímico, Ambiente deposicional, Permiano, Biofácies.*

ABSTRACT

To understand microfacies, depositional environment and geochemistry of Upper Permian rocks in Alborz region, the type sections of Ruteh Formation were studied. During the Permian, the Alborz region was a part of the east-west trending Paleotethys sea. Stratigraphic studies indicate that the Ruteh Formation in Ruteh section is composed of thin to massive limestone, argillaceous limestone interbedded with shale, is overlain by distinct laterite horizon of the Eliká Formation and is underlain by the unconformity by the Dorud Formation. Facies analysis and petrographic studies led to the recognition of 11 microfacies in Ruteh section. These facies were deposited in 4 facies belts such as tidal flat, lagoon, shoal and open marine sub-environment. The Permian calcareous algae in the Ruteh Formation are widespread and well documented to determine the environment and microfacies of Permian deposits. Cementation and dolomitization are the main diagenetic processes in Ruteh Formation. Based on petrographic (size and fabric) studies, 4 dolomite types such as dolomicrite, dolomicrospar, dolospar, and dolomite cement were recognized. Seawater was the main source of Mg for early diagenetic dolomite (type 1), while Mg for late diagenetic dolomite (types 2,3,4) probably were sourced by shale pressing processes and pressure solution. Major and minor element studies led to the

recognition of aragonite mineralogy. The geochemical study illustrates that these carbonates were affected mostly by meteoric diagenesis, which is occurred in a semi-close to open diagenetic system.

Keywords: *Original mineralogy, Geochemical study, Depositional environment, Permian, Biofacies*

چکیده

به منظور تعیین میکروفاسیس، محیط رسوبگذاری و ژئوشیمی سنگ های پرمین بالایی در منطقه البرز، برش الگوی سازند روته مورد مطالعه قرار گرفت. در طول پرمین، منطقه البرز بخشی از حوضه تتیس قدیمی بوده و با روند امروزی شرقی - غربی گسترش داشته است. بر اساس مطالعات استراتیگرافی سازند روته در منطقه روته از تناوب آهک نازک لایه تا توده ای، آهک مارنی همراه با میان لایه های شیلی تشکیل شده است که به واسطه افق لاتریتی در زیر سازند الیکا قرار دارد و با ناپیوستگی فرسایشی روی سازند درود قرار گرفته است. مطالعات پتروگرافی و بررسی رخساره ها منجر به شناسایی 11 رخساره در برش روته شد. این رخساره ها در محیط های جزرومدی، لاگون، سد و دریای باز نهشته شده اند. جلبک های آهکی پرمین در سازند روته گسترش بسیاری داشته است و راهنمای خوبی جهت تعیین میکروفاسیس ها و محیط رسوبگذاری نهشته های پرمین می باشند. سیمانی شدن و دولومیتی شدن مهمترین فرایندهای دیاژنتیکی در سازند روته می باشد. بر اساس مطالعات پتروگرافی (اندازه و فابریک) 4 نوع دولومیت شامل: دولومیکریت، دولومیکرواسپار، دولواسپار و سیمان دولومیتی شناسایی شد. آب دریا منبع اصلی تامین Mg برای دولومیت های دیاژنتیکی اولیه (نوع 1) میباشد در حالی که Mg برای دولومیت های دیاژنتیکی تاخیری (نوع 2، 3 و 4) توسط انحلال فشاری و فرایند تراکم شیل ها تامین میشود. مطالعه عناصر اصلی و فرعی منجر به شناخت کانی شناسی آراگونیتی شده است. مطالعات ژئوشیمیایی نشان می دهد که این کربنات ها اساسا تحت تاثیر دیاژنز متئوریکی قرار گرفته اند که در یک سیستم دیاژنتیکی نیمه بسته تا باز اتفاق افتاده است.

کلید واژه ها: کانی شناسی اولیه، مطالعات ژئوشیمیایی، محیط رسوبگذاری، پرمین، بیوفاسیس

1. INTRODUCTION

At the present time, Iran is a part of the Alpine-Himalayan orogenic belt, which is bordered by the Arabian Shield to the south-west and the Turan Plate to the north-east. However, a large part of Iran (central-east Iranian microcontinent, north-west Iran, and the Alborz Mountain) rifted from the northern margin of Gondwana in the Early Permian (Aghaei *et al.*, 2013).

Lower to Upper Permian rocks are widely distributed throughout North Iran (Alborz Range). These rocks consist mainly of clastic in the lower part and fossiliferous carbonate rocks in the upper part. The clastic rocks were deposited in the continental (meandering rivers) and transitional (deltaic and littoral) environments (Mokhtarpour, 1997) whereas carbonate rocks were deposited in a shallow marine environment of the continental margin in the Paleo Tethys. These sedimentary rocks have been named as the Dorud and Ruteh formations by Assereto (1963) and the Nesen Formation by Glaus (1964). The type section of the Ruteh Formation (study area) is located in Central Alborz near the village of Ruteh (North of Tehran).

The Ruteh Formation, as a second sedimentary cycle in Permian in Alborz - Azerbaijan can be observed in vast areas in eastern Alborz (Khoshyeilagh, Tillabad, east of Gorgan), Central Alborz (Ruteh, Delichai, Darbandsar, Amol, Gaduk). On the contrary evidence, Aserto (1963) belief that the lower boundary of the Ruteh Formation is discontinuous, but conformable in other locality.

Besides erosional surfaces, between Dorud and Ruteh formations, there is a lateritic layer which Stampfli (1978) has related that to the gap of Artinskian. In most areas of southern Alborz, the upper surface of the Ruteh Formation is the Elika Formation (Triassic) or the Shemshak Formation (Triassic - Jurassic), but in northern Alborz, limestones of Ruteh Formation have a discontinuous contact with a younger sequence of Permian (Nessen Fm.). As paleontology viewpoint, the Ruteh Formation is one of the lithostratigraphic units which contains abundant fossils in Alborz - Azerbaijan. So, corals, brachiopods, algae and foraminifera in this formation have been studied and are representative of the lower part of Upper Permian (Morphabian). The aim of this study is to understand the original carbonate mineralogy of the Ruteh Formation based on the geochemical study. Also, reconstruct the depositional environment of the Late Permian (located in the North of Iran) and recognize the most dominant biofacies and their distribution on the Permian carbonate platform.

2. MATERIALS AND METHODS

Samples were collected near significant lithological changes. One hundred and twenty uncovered thin section for petrographic, and facies analysis were studied. These thin sections were stained with Potassium Ferricyanide and Alizarin-Red S solutions (Dickson, 1965).

The key to environmental interpretation is to analyze all of the facies together, that is, to

study the entire stratigraphic successions in which facies occurred. The vertical succession and lateral variation in facies can contribute environmental information as much as the characteristics of the facies themselves (Boggs 2001). Therefore, facies association was utilized for interpretation of depositional environments.

Geochemical interpretation has been done based on geochemical analysis of outcrop samples. For this, micritic part of samples (mudstone to wackestone) were drilled and micritic powders were analyzed for major and minor elements. Thirty powdered micritic samples were analyzed by Atomic Absorption Spectrometer for Ca, Mg, Sr, Na, Mn and Fe at the Geology Department of the Shahid Beheshti University, Tehran, Iran. Test Precision were $\pm 0.5\%$ for Ca and Mg and ± 5 ppm for Sr, Na, Mn, and Fe (Robinson, 1980).

3. RESULTS AND DISCUSSION:

3.1. GEOLOGICAL SETTING

Iran is composed of several continental blocks separated by complex suture zones representing the remnants of the Tethyan oceans, called Paleo- and Neo-Tethys. The geological evolution of Iran was mainly governed by these two main phases of Tethyan evolution that partly overlapped in time. Paleo-Tethyan evolution took place mainly in Early Silurian to Late Triassic times, while Neo-Tethyan evolution occurred mainly from Permian to Miocene (Golonka, 2004; Ghasemi and Talbot, 2005; Horton *et al.*, 2008).

The slightly modified tectonic scheme of Iran suggested by Alavi (1991) is in Figure 1A, where the location of the study area is shown. The Alborz belt is a 1500 km- long mountain system extending from Azerbaijan to Afghanistan, flanking in its central part the southern coast of the Caspian Sea. The belt was affected by several successive tectonic events, from Eo-Cimmerian orogeny to the late Tertiary-Quaternary intracontinental transgression (Allen *et al.*, 2003), and is still strongly seismically active (Ritz *et al.*, 2006). The uppermost Precambrian- Middle Triassic sedimentary succession was deposited along the passive margin affected by the opening of the Paleotethys Ocean during the early Paleozoic time and, successively, by the opening of the Neotethys Ocean in the late Paleozoic (Stampfli *et al.*, 1991). Marine platform conditions prevailed in the

Alborz region during the Palaeozoic. A basement block containing the Alborz and Central Iran separated from Gondwana in the Ordovician-Silurian, as a part of the Paleo-Tethyan rifting that was followed by renewed continental shelf deposition from the Middle Devonian to the Middle Triassic when the Alborz-Central Iran block collided with Eurasia. The collisional suture is assumed to lie in the north (Gorgan), north-east (Mashhad), and north-west (NE Talesh) of the current Alborz mountain belt (Stocklin, 1974; Clark *et al.*, 1975; Berberian and King, 1981; Alavi, 1996; Stampfli *et al.*, 2001). One of the most active of this province is Central Alborz. During the Permian time, the Alborz region was a part of the east-west trending Paleotethys Sea. The Ruteh Formation is one of the upper Permian (Murgabian) rock units in the North of Iran.

The study area is a type section of the Ruteh Formation and is located in central Alborz near the village of Ruteh (North Tehran) (Figure 1B) at longitude of $51^{\circ} 29' 57''$ east and latitude of $36^{\circ} 01' 53''$ north, where it has a thickness of about 229 meters and consists of dark gray, medium-bedded to massive fossiliferous limestones (Figure 2A). This formation is underlain by the Elika Formation with a bauxite-laterite horizon (Figure 2B) and unconformably overlies the Dorud Formation (Figure 2C).

3.2. PETROGRAPHY

The Ruteh Formation consists of a large variety of skeletal and non- skeletal grains, calcite cement, micrite, and early and late diagenetic dolomites.

3.2.1 Skeletal grains

Skeletal grains are mostly bivalves, brachiopods, crinoids, gastropods, benthic foraminifera, and abundant calcareous algae. The assemblage of skeletal calcareous algae in Upper Permian carbonate facies is characterized by three distinct groups, such as calcareous red algae (Gymnocodiacean), calcareous green algae (Dasycladacean) and Tubiphytes algae. Gymnocodiacean family is abundant in the Ruteh Formation. The record of this group range from the Middle Devonian (Mamet *et al.*, 1994) to the late Tertiary, with the most abundant occurrences at the Upper Permian and common occurrences in some Cretaceous carbonates (Elliot, 1958; Bucur, 1994). Gymnocodiacean algae are common in the Middle and Upper Permian carbonate of the Tethys. During the Upper

Permian, gymnocodiaceans were important sediment producers in shallow, low to moderate energetic shelf seas. Common geographically widespread taxa are *Gymnocodium* (Figure 3A) and *Permocalculus* (Figure 3B). Genus *Permocalculus* has a variable form, spheroidal, ovoid or barrel - shape segment, or elongate-irregular, finger-like. *Permocalculus* is similar to *Gymnocodium*, but pores are finer than those of *Gymnocodium*.

Dasycladacea is the most important fossil calcareous algae used in microfacies analyses. These algae are abundant from Carboniferous to Pliocene and show the most diversity in Permian, Lower Cretaceous, and Paleocene. *Dasycladacea* are a major group of benthic marine chlorophytes in which the external part of the thallus can be heavily calcified. As a result of this calcification, dasyclads have a better fossil record than any other marine green algae. Overall, dasycladacean algae are the most diverse organisms, when warm water, shallow seas were extensive. Therefore, long-term patterns of dasycladacean diversity are linked to the global fluctuation in temperature and sea level. *Vermiporella* (Figure 3C) and *Mizzia* (Figure 3D) are two genera of the dasycladacean family that was identified in this section. Wray (1977) believes that dasycladacean and gymnocodiacean are living in shelf environment, and they spread in shallow and warm seas. Expansion of these algae was reported in subtidal to a depth of 30 meters and rarely to 90 meters, so the best place to live is lagoon and front of the barrier. These algae reduced in the deeper basin because the amount of light, temperature, and other physicochemical conditions are not suitable for life. Other genera are *Tubiphytes* with dark clot forms and cortical mechanisms. *Tubiphytes* algae are common in Carboniferous and Cretaceous and are abundant in Permian. These organisms found in barrier and front of the barrier environment. Some of the skeletal grains are micritized due to algal boring.

3.2.2 Non- skeletal grains

Non- skeletal grains have consisted mainly of ooid, intraclast and peloids. The studied ooids in the limestone have been partially or completely micritized due to algal borings. In some samples, the nuclei of ooids are commonly quartz fragment. Peloids are also abundant. Peloids in all samples range from 0.05 to 0.3 mm (average 0.175 mm). Intraclasts occur in some samples. They are generally polymodal in size ranging from 0.3 to 2.5 mm. All intraclasts are internally

homogeneous and consist of micrite.

3.3. FACIES ANALYSIS AND DEPOSITIONAL ENVIRONMENT

Facies analysis and petrographic studies have led to the recognition of 11 microfacies in Ruteh section. These facies were deposited in 4 facies belts such as tidal flats, lagoon, bar and open marine.

3.3.1 Tidal flat

The flat tidal sediments are composed of dolomicrite with ostracods and echinoderms (less than 10%) (Figure 4A). Lack of biological variation in this microfacies points to the lack of appropriate ecological conditions for marine life (Amalain and Adabi, 2015). Dolomicrite facies contain windblown, silt-size quartz grains. Dolomicrite forms during very early diagenesis in supratidal to intertidal environments (Adabi, 2009; Bustillo *et al.*, 2002).

3.3.2 Lagoon

From the shoreline towards the sea, this facies consists of gastropod bioclast wackestone/packstone, pelloid bioclast wackestone, mudstone with bioturbation and *Dasycladaceae* bioclast wackestone, (Figure 4B-E). Restricted conditions are suggested by bioturbation, micrite matrix, the lack of normal - marine biota and abundant skeletal components of restricted biota such as porcelaneous test benthic foraminifers, gastropods, and green algae (*Dasycladaceae*). *Dasycladaceae* are widespread in low energy and shallow restricted environment (Flügel, 2010). Therefore, long-term patterns of dasycladacean diversity are linked to the global fluctuation in temperature and sea level.

3.3.3 Shoal

Shoal or barrier sediments are composed of peloid grainstone and ooid bioclast intraclast grainstone (Figure 4F and G). The abundance of ooids, intraclast and marine biota (bryozoan, echinoderm, brachiopod, and red algae), presence of fully cement matrix and the mud-free nature of this facies indicate high energy conditions (Betzler *et al.*, 2006; Katibi and Adabi, 2013).

3.3.4 Open marine

The open marine facies includes bioclast red algal packstone, bioclast wackestone/packstone, echinoid wackestone, and bioclast mudstone (Figure 4H-K). The abundance of red algae (Thomas *et al.*, 2008; Flügel, 2010) in shallow marine and barrier, a hyaline test of benthic foraminifera, echinoderm, bryozoan, brachiopod and also the presence of mud-supported facies indicate low energy conditions such as open marine. These facies are underlain by Barrier or Shoal sediments in depositional sequences. During the late Permian, gymnocodiaceans were important sediment producers in shallow, low to moderate energetic shelf seas. Common geographically widespread taxa are *Gymnocodium* and *Permocalculus*.

This formation is interpreted to be a carbonate ramp with a very gentle slope (Figure 5). The lack of any marginal reef development, absence of major break of slope, absence of slump structure, calciturbidite and oncoids and widespread tidal flat deposits, indicate deposition on a carbonate ramp system.

3.4. DIAGENESIS

3.4.1 Cementation

Micrite and sparry calcite are the cementing materials of the rocks of the Ruteh Formation. In this study, sparry calcite cements are more abundant than micrite. Sparry calcite cement consists of three major types of morphology, namely, fibrous, syntaxial rim, and equant. Cementation in this formation took place in all the diagenetic zones but with variable form, mineralogy, and abundance that are detailed herein. Cementation at the earliest stage of diagenesis in the Ruteh Formation is represented by acicular to fibrous isopachous cement (Figure 6A). These fibrous cements indicating a marine aragonitic origin (Machel, 1985; Adabi and Rao, 1991) and are the first generation cements which predate other cements. They commonly form isopachous fringes around the grains or cavity wall. These are succeeded by meteoric equant to mosaic sparry calcite cement and later by drusy to platy phreatic to burial cements.

Syntaxial rim cements were produced at burial zone and found around the fragments of echinoderms that do not have a micritic coating (Figure 6B). Thus, it is inferred that the presence/absence of micrite and micritic coating acted as strong control over the nucleation of

syntaxial rim cements. In the Ruteh limestone, equant cement is present (Figure 6C). The coarse equant cements are mostly of meteoric origin. CL study confirms these interpretations.

3.4.2 Dolomitization

Dolomitization is the main diagenetic processes in the Ruteh Formation. Based on petrographic (size and fabric) studies, 4 dolomite types were recognized (Adabi, 2009).

Type 1, very fine to finely crystalline dolomite ($< 4 \mu\text{m}$): Unimodal mosaics, planar (subhedral) (Figure 6D). These dolomites are dense and dark in color, non-porous, unfossiliferous, preserve traces of depositional textures, such as laminations and intraclasts, and are commonly associated with scattered detrital quartz grains. They possibly resulted from penecontemporaneous or early replacement of a carbonate precursor soon after deposition, in a supratidal to the upper intertidal setting (Adabi, 2009). Seawater (e.g., Saller, 1984; Land, 1985; Mitchell *et al.*, 1987; Adabi, 2009) or interstitial solutions enriched in Mg might be responsible for dolomitization.

Type 2, fine to medium crystalline dolomite (generally between 4 to 16 μm): This type forms euhedral dolomite rhombs mainly floating within the lime mud matrix. Isolated rhombs are polymodal in size. Dolomite rhombs are not widespread throughout Ruteh limestones and occur mainly in lime mud lithofacies (Figure 6E), but also occur in other lithofacies. Fossil fragments are least affected by this type of dolomitization, suggesting that dolomitization began preferentially in the fine-grained matrix.

Type 3, medium crystalline dolomite (16-64 μm): Is composed mainly of dense unimodal mosaics of subhedral to anhedral planar crystals (Figure 6F). In many of the dolomite crystals, straight compromise boundaries are well developed, and some crystals have preserved crystal-face junctions (Adabi, 2009). Dolomite type 3 is texturally destructive and largely modifies or obliterates earlier diagenetic features.

Type 4, coarsely crystalline planar (cement) dolomite (> 64 to 250 μm): This type consists of clear, coarsely crystalline, planar (cement), often euhedral dolomite crystals, lining voids, vugs, and fractures, and occurs as major void-filling dolomite (Figure 6G) planar-c dolomites are partly responsible for occlusion of open spaces and fractures and considered to be relative late-stage diagenetic products.

3.5. GEOCHEMISTRY

Modern abiotic aragonitic sediments in tropical warm shallow- marine waters have low Mn and Fe (~ 20 ppm), moderate Na (~ 2,500 ppm) and high Sr (~ 10,000 ppm) concentration (Milliman, 1974). Modern temperate shallow-marine biotic calcite sediments on average have low Sr (~ 1000 ppm) and high Na (~ 5,000 ppm), Mn (~ 150 ppm) and Fe (~ 1000 ppm) concentration (1990a). Concentration of Sr (363-992 ppm; mean 615 ppm), Na (223-328 ppm; mean 260 ppm), Mn (77-542 ppm; mean 215 ppm) and Fe (910- 3290 ppm; mean 2384 ppm) in the Ruteh limestone suggest appreciable loss of Sr and Na, and gain of Mn and Fe during diagenesis when compared with modern tropical aragonite and temperate calcite carbonates. The plot of Sr–Mn values shows that most limestone samples fall within or close to the warm-water sub-tropical aragonite fields of the Mozduran Formation (Adabi and Rao, 1991), Cretaceous of the Ilam Formation (Adabi and Asadi-Mehmandosti, 2008) and Lower Cretaceous of the Fahliyan Formation (Adabi *et al.*, 2010) (Figure 7A).

3.5.1 Diagenetic trends

The concentration of Sr and Na in diagenetic calcite depend mostly on their partition coefficients and their concentration in diagenetic solutions. Because Sr and Na have partition coefficients of 1 and low concentration in meteoric waters, thus their diagenetic imprint will show the low concentration of Sr and Na. On the other hand, Mn concentration increase with the increasing influence of meteoric diagenesis (Brand and Veizer, 1980; Rao, 1990b) because the partition coefficients of Mn is ~ 15 and it occurs in high concentration in meteoric waters (Pingitore, 1978). Calcite under oxidizing conditions carries little Mn, but if formed in reducing condition, it may have a few percent Mn (Pingitore, 1978; Shanmugam and Benedict, 1983). In the Ruteh Formation, Mn is interpreted to reflect alteration and the increasing influence of meteoric diagenesis. Fe values increase with increasing Mn concentration during reducing condition. Sr and Na variation with Mn concentration (Figures 7A and 7B) indicate two diagenetic stages. The first stage coincides with a significant decrease of Sr and Na, with no appreciable increase of Mn, and is interpreted inversion of aragonite to calcite. The second stage coincides with an appreciable increase in

Mn with no significant change in Sr and Na concentrations, attributed mainly to meteoric diagenesis involving calcite recrystallization and sparry calcite cementation.

The bivariate plot of Sr/Ca versus Mn shows that the limestones have been stabilized by fluids in semi-closed to open diagenetic system (Figure 7C).

3.5.2 Original aragonite mineralogy

Modern and ancient tropical carbonates are differentiated from non-tropical counterparts by their Sr/Na ratio and Mn content (Rao, 1991; Adabi and Asadi-Mehmandosti, 2008; Asadi-Mehmandosti and Adabi, 2013). Modern tropical aragonite carbonates have low Mn and high Sr/Na ratio from 3 to ~ 5, in contrast to modern temperate calcite, which has high Mn and low Sr/Na ratios, ~1 (Adabi and Rao, 1991; Rao, 1991, 1996; Rao and Amini, 1995; Winefield *et al.*, 1996; Adabi and Asadi-Mehmandosti, 2008, Adabi *et al.*, 2010). Sr/Na ratio in limestone of the Ruteh Formation ranges from 1.2 to 3.5 (average 2.1) are similar to the aragonite fields of the Mozduran Formation (Adabi and Rao, 1991), the Upper Cretaceous of the Ilam Formation (Adabi and Asadi-Mehmandosti, 2008), Lower Cretaceous of the Fahliyan Formation (Adabi *et al.*, 2010) and Recent tropical aragonite (Milliman, 1974; Winefield *et al.*, 1996) (Figure 7D). The similarity of trace-element data with modern and ancient carbonates supports the interpretation that the original carbonate mineralogy of the Ruteh limestone was aragonite. Petrographic studies such as acicular to fibrous isopachous cement, dissolution of aragonitic skeletal grains also support the above conclusions.

3.6. INTERPRETATION

Based on petrographic and geochemical studies, 11 microfacies belong to 4 facies belt such as tidal flat, lagoon, shoal and open marine sub-environment have been recognized. Dolomicrite facies due to the presence of very fine to finely crystalline dolomite belongs to the tidal flat sub-environment. They were possibly formed during very early diagenesis in supertidal to intertidal sub-environments. This facies also contains wind-blown, silt-size quartz grains and calcite pseudomorph after evaporites. Based on geochemical studies, in very early diagenetic fine-grain dolomite (dolomicrite), Sr and Na values are higher, and Fe and Mn are lower than

late diagenetic coarse grain dolomite (Adabi, 2009).

In general, coarse grain dolomites are affected more by diagenetic alteration in the burial environment. Thus Mn and Fe increase and Sr and Na decrease. Pelloid bioclast wackestone, dasycladasean bioclast wackestone and mudstone with bioturbation belong to the lagoonal sub-environment. Some common characteristic of this microfacies is the presence of mud between main grains and the abundant of bioclasts capable of living in the restricted lagoonal conditions. Small and large green algae (dasycladasea) and porselaneous test of benthic foraminifers are present in this facies.

The fundamental characteristic of some lagoonal facies is the presence of a large amount of pelloids, gastropods, and benthic foraminifera. Lagoonal facies in the Ruteh Formation shows the higher concentration of Sr, average amounts of Na and the lower values of Fe and Mn in comparison to the open marine sub-environment, due to the presence of aragonitic components such as green algae, gastropods, and bivalves that have higher Sr values. Shoal or bar facies are composed of ooid bioclast intraclast grainstone and pelloid grainstone. The common characteristic of this facies is the lack of lime mud matrix between the grains.

The presence of sparry calcite cement, intraclast, and particularly the abundance of ooids in this facies confirm the higher energy environment. This facies also shows the low concentration of Mn and Fe in comparison to the lagoon and open marine sub-environments, due to more oxidizing conditions. In reducing environment, more Fe and Mn can enter into the carbonate lattices. The open marine microfacies composed of bioclast red algal packstone, bioclast wackestone/packstone, echinoid wackestone and bioclast mudstone. The presence of intergranular muddy matrix, the abundance of red algae, echinoids, bryozoans as well as a hyaline test of benthic foraminifera, indicate the formation of this microfacies in a low-energy environment. Open marine sediments in the Ruteh Formation shows the higher concentration of Mn and Fe, indicating anoxic to a sub-oxic condition in this environment. According to the result of microscopic studies and field observation, due to the lack of any major marginal reef development, calciturbidite or slump structures, and presence of wide spread tidal flat facies, this formation has been formed in a homocline carbonate ramp system.

Petrographic evidences such as acicular to fibrous isopachous cement, dissolution of abundant aragonite skeletons filled with sparry calcite cement and the presence of oomold along with geochemical evidences such as high Sr value, Sr/Na more than one and high Na value support original aragonite mineralogy. Major and minor elements shows that most of the data fall within the aragonite fields of the Mozduran limestone (Adabi and Rao, 1991), Cretaceous of the Ilam Formation (Adabi and Asadi-Mehmandosti, 2008) and Lower Cretaceous of the Fahliyan Formation (Adabi *et al.*, 2010), due to similar aragonite mineralogy. Decrease in Sr and Na concentration and an increase in Mn values suggest that Ruteh carbonates were affected by meteoric diagenesis. Variation of Sr/Ca values versus Mn suggest that the Ruteh Formation were stabilized in a semi-close to open diagenetic system.

4. CONCLUSIONS:

The present study indicates that the Ruteh Formation was deposited on a carbonate ramp system with 11 microfacies, which occurred in four facies belts: tidal flat, lagoon, shoal, and open marine.

Bivariate plots of minor and major elements along with petrographic studies indicate that the original carbonate mineralogy was dominantly aragonite in Ruteh Formation. The decrease in Sr and Na concentration and increase of Mn values suggest that the Ruteh carbonates were affected by meteoric diagenesis. Mn is interpreted to reflect the original mineralogy of predominantly calcite and the increasing influence of meteoric diagenesis. The bivariate plot of Sr/Ca versus Mn shows that the limestones have been stabilized by fluids in semi-closed to open diagenetic system.

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Figure1. (A) Tectonic zonation of Iran (Alavi, 1991), (B) Location map of the study area in Ruteh area

Figure 2. (A) Stratigraphic column of the Ruteh Formation in the study area. (B) the Ruteh Formation is underlain by the Elika Formation with a bauxite- laterite horizon. (C) Disconformity boundary between the Ruteh and Dorud formation

Figure 3. Skeletal grains in the Ruteh Formation: (A) *Gymnocodium* algae . (B) *Permocalculus* algae. (C) *Vermiporella* algae and (D) *Mizzia* algae

Figure 4. Tidal flat facies: (A) Dolomudstone with silt- size quartz grains; lagoon facies: (B) Gastropod bioclast wackestone/ packstone, (C) pelloid bioclast wackestone, (D) Mudstone with bioturbation, (E) Dasycladaceae bioclast wackestone; Shoal facies: (F) peloid grainstone, (G) ooid bioclast intraclast grainstone; open marine facies: (H) bioclast red algal packstone, (I) bioclast wackestone/ packstone, (J) echinoid wackestone, (K) bioclast mudstone

Figure 5. Schematic diagram of ramp platform environment in the Ruteh Formation

Figure 6. (A) fibrous isopachous cement around a ostracod, (B) syntaxial cement around an echinoderm, (C) equant cement, (D) type 1 very fine to finely crystalline dolomite, (E) type 2 fine to medium crystalline dolomite, (F) type 3 medium crystalline dolomite (G) type 4 coarsely crystalline dolomite cement.

Figure 7. (A) Comparison of the Sr and Mn field of Rutuh limestones with warm-water sub-tropical aragonite fields of the Mozduran Formation (Adabi and Rao, 1991), Cretaceous of the Ilam Formation (Adabi and Asadi-Mehmandosti, 2008) and Lower Cretaceous of the Fahliyan Formation (Adabi et al., 2010).

Figure 7.(B) Comparison of the Na and Mn field of Rutuh limestones with warm-water sub-tropical aragonite fields of the Mozduran Formation (Adabi and Rao, 1991), Cretaceous of the Ilam Formation (Adabi and Asadi-Mehmandosti, 2008) and Lower Cretaceous of the Fahliyan Formation (Adabi et al., 2010). Note that the Rutuh pattern is similar to that of the Mozduran limestone and near the Fahliyan and Ilam limestone

Figure 7.(C) Mn and Sr/Ca variation in the Ruteh carbonates . This trend show that these carbonate have been stabilized by fluids in semi-closed to open diagenetic system

Figure 7.(D) Mn and Sr/Na variation in Ruteh limestones. Note that the Sr/Na ratio of most samples are > 1, indicating original aragonitic mineralogy