Microfacies, sedimentary environment and geochemistry of the Badamu Formation (Lower-Middle Jurassic) in Lut Block, east of Iran

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Abstract

The Badamu Formation (Upper Toarcian-Middle Bajocian) mainly consists of limestone and shale and has is cropped out in east of Iran. The Badamu Formation conformably overlays Shemshak Formation and is underlaid sharply by Hojedk Formation in Kerman area and is underlaid gradually by Baghamshah Formation in Tabas and Southern Khorasan areas. The aim of this work is petrographical study of rocks and recognition of various microfacies that finally result in reconstruction and presenting depositional model and determine the paleoenvironment. Therefore, Southwest Esfak section with limestone lithology in Southern Khorasan province has been studied. Petrographical study of 50 thin sections of this formation revealed totally six carbonate microfacies within four microfacies belt including shallow marine, shoal, semi-closed lagoon and tidal channel. Comparison of these facies with standard ones indicates that Badamu Formation has been deposited in a homoclinal ramp including inner ramp, middle ramp and outer ramp sub-environments. Geochemical analysis of the limestone samples revealed high calcium and low magnesium content. Also, study of major and minor elements values determined that aragonite has been the original carbonate mineral of Badamu Formation limestones and these rocks have stabilized within a meteoric-pheratic and burial diagenetic environment. In addition, variations of Sr/Ca values versus Mn suggest that diagenetic alteration has occurred in a geochemically-opened system.

Keywords: Badamu Formation, Shotori Range, Lower-Middle Jurassic, Sedimentary environment, Petrography, Geochemistry.

1– Introduction

The Jurassic system, lasting for about 60 million years, is one of the most important systems in the geology of Iran (Motiei, 2003). Jurassic paleogeography of Iran has revealed that in this period, Iran had two independent zones that were separate from each other along the main Zagros drift (Motiei, 2003). Since the rocks and microfacies in these zones are totally different, the Jurassic studies of Iran can reveal the stratigraphic structures in reach of these structural zones. The Jurassic facies are mainly detrital and partially carbonate. Distinguishing upper Triassic from Lower and Middle Jurassic deposits is a challenging task. The detrital and carbonate deposits between Early Cimmerian and Lutian (Seyed-Emami and Alavi-Naini, 1990) or Middle Cimmerian (Aghanabati, 1992) in central Iran have been introduced as Shemshak Group which entails four formations of Nayband, Ab-e-Haji, Badamu, and Hojedk (Aghanabati, 1975).

The present study is an attempt to carry out petrographical and geochemical studies (analysis of major and minor elements) in carbonate deposits of Badamu Formation to identify microfacies, reconstruct of the environment, and identify the original mineralogy of the deposits.

2– Methodology

A section of Badamu Formation of Lower-Middle Jurassic located in Shotori range (Eastern Iran) is selected in the present study.

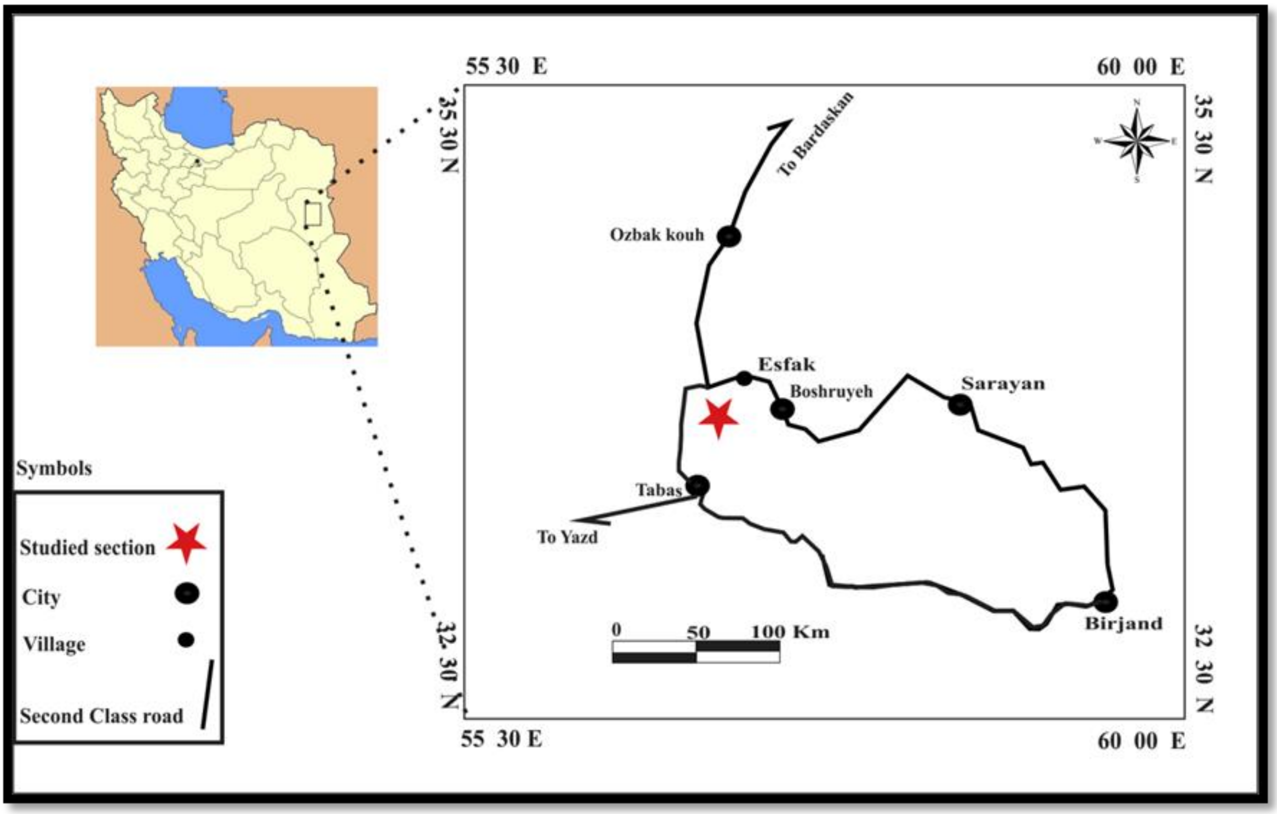

Figure 1) Location map of the studied section in south west of Esfak, north of Tabas city (retrieved from Atlas of roads of Iran (2005), with modifications).

The location of southwest Esfak section in north of Tabas (the east of Shotori range) is E 57° 09´ 45.89˝ and N 33° 44´ 26.52˝. The best access way to the mentioned section is by Birjand-Bashruyeh asphalt road and then by using gravel road from Bashruyeh to the given section (Fig. 1).

The studied section is about 101 m thick composed of limestone. The limestone layers are mainly in light grey to dark grey with medium or thick layers (Fig. 2). Badamu Formation is conformably located on Shemshak Formation. The upper boundary of the formation is conformable with Baghamshah Formation and is gradual (Fig. 3).

The study used 50 microscopic thin sections of Badamu Formation. The deposits were prepared and investigated through detailed Petrographical analysis.

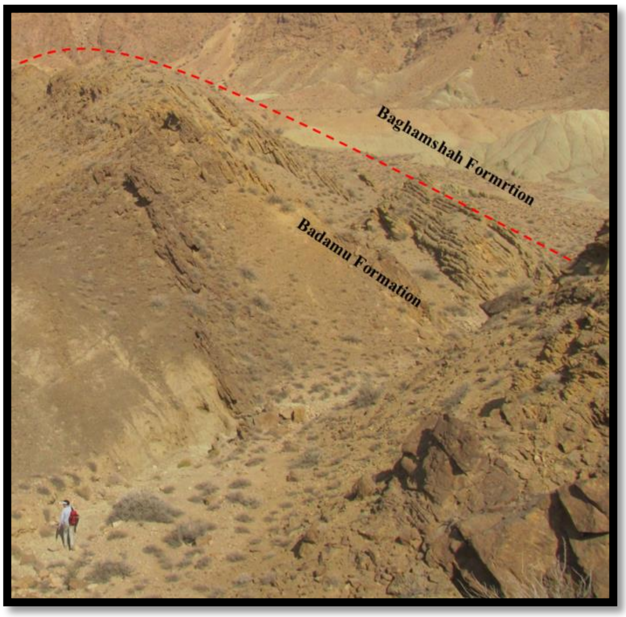

Figure 2) The overall outcrop of Badamu Formation in the south west of Esfak located north of Tabas (looking northward).

The classification systems of Flügel (2010) and Dunham (1962) were used for the purpose of determination and nomenclature of microfacies. Also, totally 16 samples were selected and prepared for geochemical analysis. The major and minor element analyses were carried out by Shimadzo-AAS 670 Atomic Absorption Spectrophotometer in the Laboratory of Analytical Chemistry, Department of Chemistry at Ferdowsi University of Mashad/Iran.

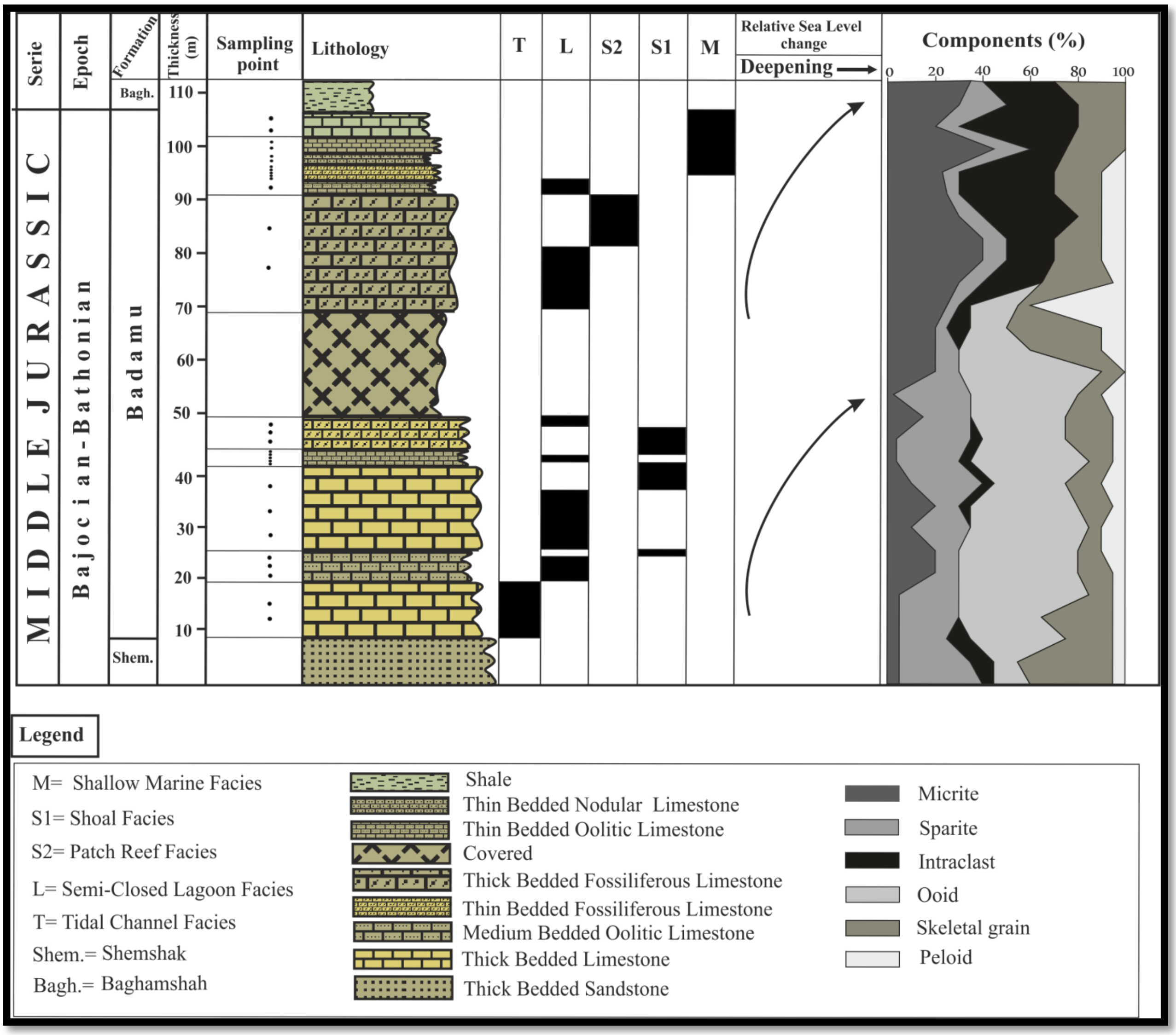

Figure 3) Stratigraphical sequence of the microfacies belts, relative fluctuations of water levels, and the diagram of the composing elements of the carbonates in the stratigraphy of the carbonate deposits in Badamu Formation in the south east of Esfak section.

3– Results and Discussion

3.1- The microfacies and the environment

Based on the petrographic analysis of the carbonate rocks in Badamu Formation in the given zone, six carbonate microfacies which represent shallow carbonate environments were identified. Based on Walter's law, these microfacies were formed beside each other and are classified as four microfacies belts of shallow marine, shoal, semi-closed lagoon, and tidal channel (Mohammadi Ghiasabadi, 2012).

3.1.1- Shallow Marine Facies Belt (M)

3.1.1.a- M_1: Bioclastic/Intraclastic wackestone Microfacies

This microfacies contains different allochems, mainly non-skeletal grains such as intraclast and partially peloid and oncoids and skeletal components including bivalves, ostracods, gastropods, echinoderms, and to a much lower extent detrital grains in a micrite matrix. Intraclasts of this facies are of different sizes. Abundant presence of allochems along with micrite reflects a low-energy shallow marine environment.

The composing elements of this microscopic facies include intraclast for 15-50%, skeletrainsal grains for 20-30% (including ostracod, bivalve, gastropod, and echinoderms from the most frequent to the least), detrital quartz for up to 3%, and micritic matrix for about 30-45% (Fig. 4-A). This facies located in the upper part of Badamu Formation composed an alternation of dark limestone (in fresh parts) and light shale.

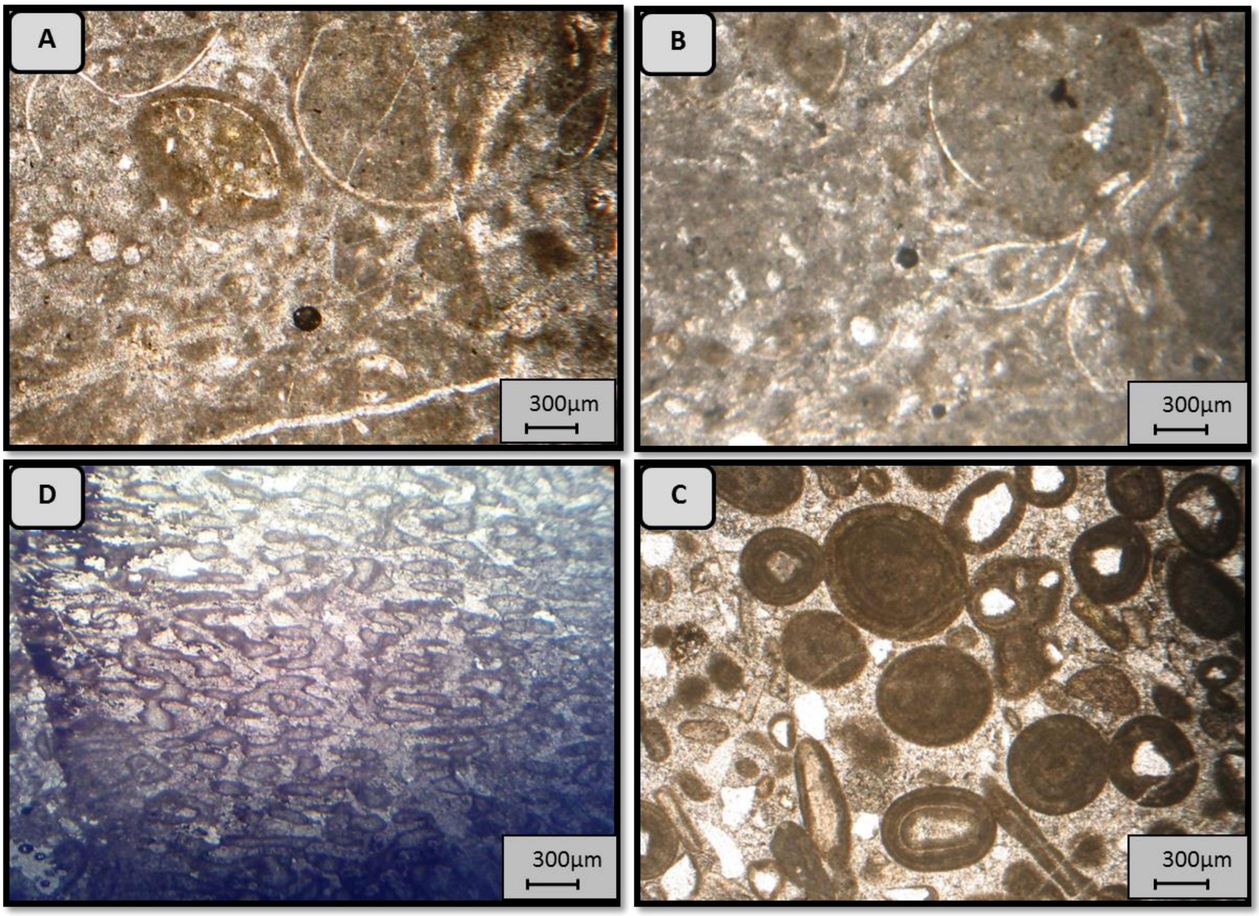

Figure 4) A– The microscopic images of thin sections of the: bioclastic/intraclastic wackestone (PPL), B– bioclastic/intraclastic packstone (PPL), C– oolitic grainstone (PPL), D– coral boundstone (PPL).

3.1.1.b- M_2: Bioclastic/Intraclastic packstone Microfacies

This facies is composed of different allochems and particularly non-skeletal grains such as intraclast and skeletal components including bivalves, ostrcods, gastropods, and echinoderms as well as a little detrital quartz in a micritic matrix. The size of the intraclasts varies in this facies. High amounts of allochems and micrite represent a low-energy shallow marine environment.

The composing elements of this facies include 20-50% of inratraclast, an overall 20-30% of skeletal components (including ostracods, bivalves, gastropods, and echinoderms in their respective order of frequency), 3% of detrital quartz, 10% of cement, and 20-35% of micritic matrix (Fig. 4-B).

3.1.2- Shoal Facies Belt (S)

3.1.2.a- S_1: Oolitic Grainstone Microfacies

The most frequent component of this formation is ooids, which is well-sort and contains slight amounts of micro-fossils. This microscopic facies extends along Badamu Formation. In the given zone, medium oolitic limestone is located in the middle of the formation. Ooids forming this facies mostly composed of simple concentric ooids, which in some cases have radially oriented blades, as well as superficial ooid, which in some cases includes composite ooid. The center of most of the ooids contains detrital quartz and in cases skeletal components. The ooids of this microfacies are covered by a cement of spar calcite. This cement is isopachous, drusy, and blocky. Some parts of the facies do not have cement and reflect dissolution under pressure. Fossil shells are surrounded by a micrite layer. Some ooids have gained micritic features and turned into peloids. Rarely does the facies include skeletal components of gastropod and echinoderms. Geopetal fabrics can also be seen in this facies. In some samples, there are also little amounts of detrital quartz.

This facies contains 35-53% of ooids, an overall of 10-20% of skeletal components (gastropods and echinoderms), up to 3% of detrital quartz, up to 25% of cements, and about 3-5% of micritic matrix (Fig. 4-C).

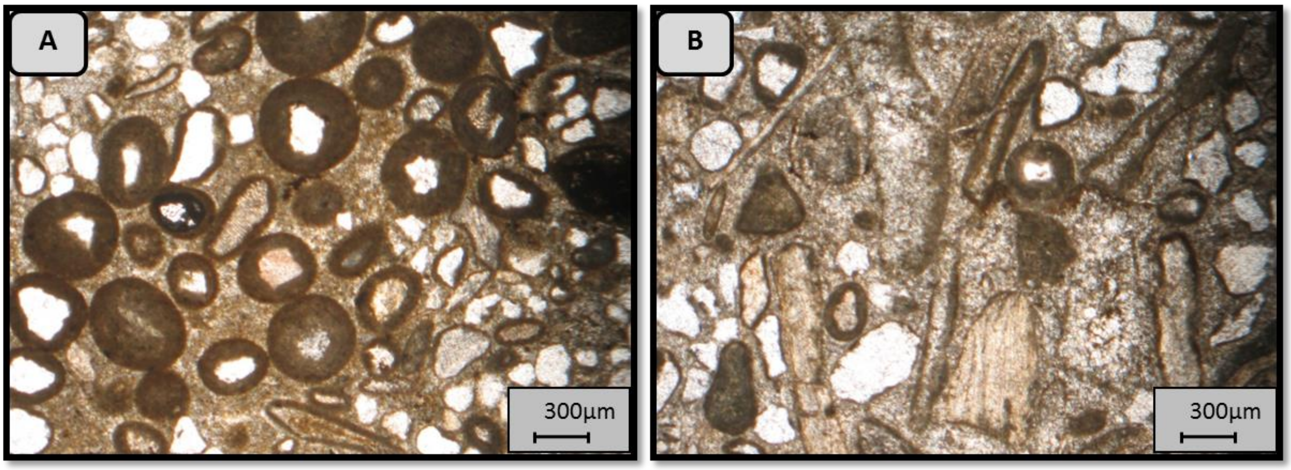

Figure 5) A- The microscopic images of a thin sections of the: oolitic packstone (PPL), B–bioclastic grainstone (PPL).

3.1.2.b- S_2: Coral Boundstone Microfacies

This microscopic faces is mainly composed of corals. The rapid growth of corals has formed this microfacies. The pore space in the skeleton is mostly filled with micrite and in cases with sparite. The alternation of these microfacies with lagoon, field evidence, and untraceability of the reefs in long distances represent the features of patch reefs.

The composing elements of this microfacies include 45% of fossil skeletal grains, 5-7% of intraclast, 10% of peloids, 20% of micritic matrix, and 5% of spar calcite (Fig. 4-D).

3.1.3- Semi-restricted Lagoon Facies Belt (L)

3.1.3.a- Oolitic Packstone Microfacies

The most frequent component of this facies is superficial ooid. In addition, there are concentric simple ooids and, less frequently, composite ooids. The central part of most ooids is composed of detrital quartz and, less frequently, of skeletal components. Other elements include intraclasts, peloids, fossils (brachiopod, echinoid, and gastropod), and detrital quartz in a micrite matrix.

The components of this facies include 20-60% of ooids, 5% of intraclast, 10-40% of peloids, 10-25% of fossil components, up to 5% of detrital quartz, 20-35% of micritic matrix, and up to 5% of spar calcite (Fig. 5-A).

3.1.4- Tidal Channel Facies Belt (T)

3.1.4.a- Bioclastic Grainstone Microfacies

The components of this microfacies are mainly skeletal components including echinoid, bivalve, gastropod, and partially ooids, intraclasts, and peloids. In this microfacies, fossils are surrounded by spar calcite cement. This cement is isopachous, drusy, blocky, and syntaxial overgrowth.

The composing elements of this microfacies include 32-40% of skeletal components, 10-15% of ooids, 5-7% of intraclasts, 5% of peloids, 7% of micritic matrix, and 40% of spar cement (Fig. 5-B).

3.2- Interpretation

The facies have been deposited in an open-marine system with low-moderate energy (Mohammadi Ghiasabadi, 2012). The texture and the size of the skeletal components indicate that this facies was deposited in shallow open-marine. The main components of the facies have been transmitted over a short distance. The fossils in this facies include benthic foraminifera, algal grains, and echinoderms, which represent an environment of shallow open-marine (Flügel, 2010). In some of the samples, thin ostracod was observed within a micritic matrix, which indicates a low-energy environment. The environment of this facies is regarded to be the upper part of the open-marine. With respect to the amount of micrite in the matrix, it can be said that belong to a deeper part in comparison to packstones, wackestones (Mohammadi Ghiasabadi *et al*., 2013; Mohammadi Ghiasabadi, 2012; Mohammadi Ghiasabadi *et al*., 2012b; Saeidi *et al*., 2010). This depends on the energy of the environment, i.e., an increase in energy washes more micrite and substitutes more spar. With regards to ramp classification presented by (Read, 1990), the open-marine is classified as an outer ramp.

In shoal facies (S1), the limestone mud has drastically decreased and spar calcite cement has increased. Presence of the high energy has led to the deposition of bioclast components and ooids in this part. With respect to its properties, this facies is deposited in the area where waves pound against the shore. The presence of spar calcite cement shows that carbonate mud is washed off due to the energy increase leaving space for cement to fill the pore space. Regarding S1 facies and the grains found in this facies, the microfacies can be classified as oolitic grainstone with its non-skeletal components including rounded ooids and skeletal components. By and large, the shoal facies can be presented as a crucial component of a facies belt in the margin of the carbonate ramp platform and the middle ramp (Read, 1990).

The only fauna of S2 facies is intact corals. The lateral discontinuation of the reefs and their untraceability in long distances show the features of patch reefs and deposition of this microfacies in lagoon environments. This facies is part of the patch reef representing the middle ramp.

In the semi-restricted lagoon facies, high-energy allochems such as floating ooids in the mud matrix imply the texture reversal (Wilson, 1975; Flügel, 2010). The low frequency of ooids along with lower energy facies of underwater dams, micritization, an increase in lagoon bioclasts, and presence of peloids show the formation of the this lagoon facies. According to these evidences and based on Read's classification (1990), the semi-restricted lagoon environment is classified within the inner ramp zone.

In comparison to micrite, the T facies most probably show tidal channels for having various intraclasts, more bioclasts belonging to dam environments, and sprite cement.

Since the sequence of carbonate facies is the result of environment changes over time (Tucker and Wright, 1990), identification of the microfacies and their conditions under which they are formed can help interpret the sedimentation environment and present a model for the sedimentation(Mohammadi Ghiasabadi, 2012; Mirab Shabestari and Riasi, 2010; Riasi, 2008; Saeidi, 2010).

3.2.1- The variations in the components along the sequence

Having studied the thin sections and determined the microfacies, we analyzed the vertical variations of equivalent sandstones of Badamu Formation. According to the diagram representing the percentage of the composing elements (Fig. 3), the following can be pointed out.

As one moves toward the shallow open-marine, the sparite decreases and micrite and intraclast increase. There is an increase in sparites and ooids in the shoal facies and an increase in micrite and peloids in the semi-closed lagoon. There is more intraclast and sparite in the tidal channel.

3.2.2- Relative sea level changes

The vertical variation of this facies and the curve showing sea level changes (Fig. 3) indicate that carbonate sediments of this facies begin with a regression and continues with a deepening cycle. It could be seen that there are two deepening cycles in the given zone. The vertical variations in the sea level show that at the time Badamu Formation developed, Baghamshah Formation was in a deeper part. Shemshak Formation, which is formed later, has a lower depth than that of Badamu (Mohammadi Ghiasabadi *et al.*, 2012a).

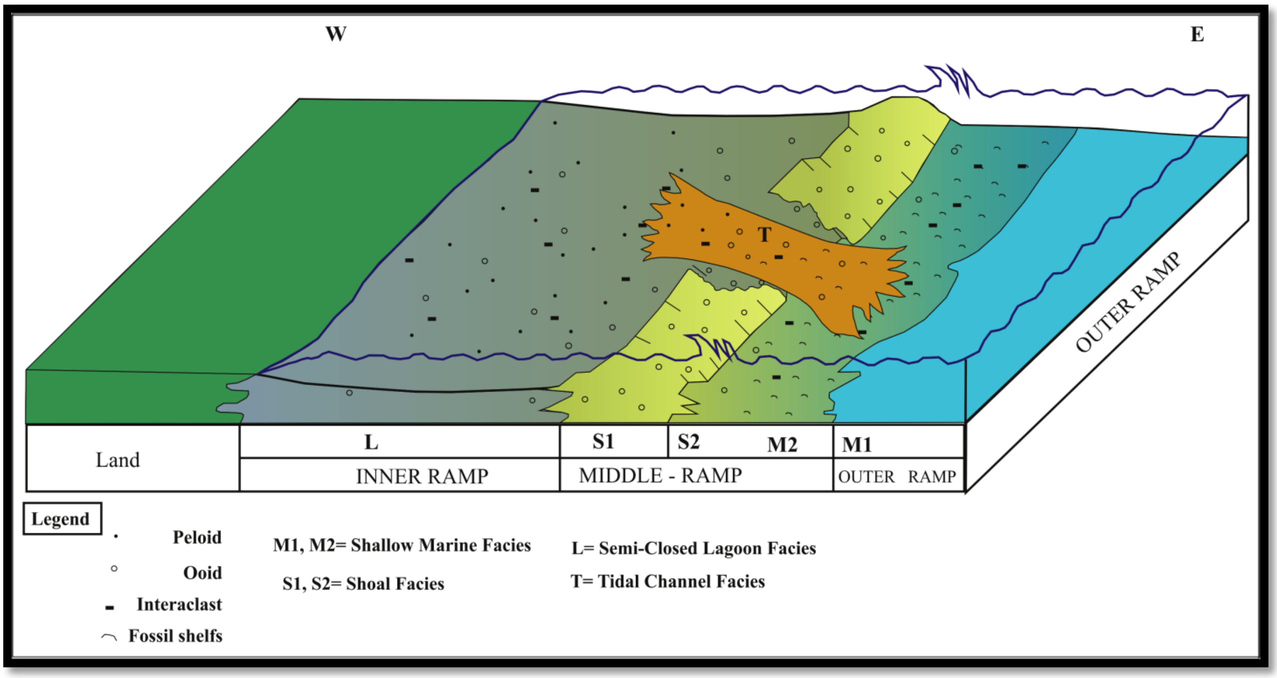

Figure 6) The block diagram of the presented sedimentary model for the carbonate sediments of Badamu Formation (not in scale).

At the beginning of the sequence, where Badamu Formation lies on Shemshak Formation, in the shallow area, one reaches Baghamshah Formation with one large regression of the sea toward the end of the sequence.

3.2.3- The Paleoenvironment and sedimentation model

Any environment has a certain geographical extensions on the earth's crust. This extension is built in a particular period of time (Amini, 2008). With respect to the gradual alternation of the facies; the absence of large reef structures; and the absence of falling and sliding facies, which indicate the steep slope of the environment at the time of sedimentation; the sedimentation model of the equivalent carbonate sequence of Badamu Formation in the stratigraphic section of the carbonate south west Esfak is classified as a homoclinal ramp (Mohammadi Ghiasabadi, 2012). It seems that this carbonate ramp, which entails sparse patch reefs, can be classified into middle ramp, inner ramp, and outer ramp (Fig. 6).

There were no sediments containing pelagic fossils or sponge spicules, etc., which represent the conditions of deep marine.

3.2.4- Geochemistry

Various studies show that carbonate minerals vary with changes in the temperature, concentrations of calcium and magnesium in the solution, salinity, and the pressure of carbonic gas (Morse and Mackenzie, 1990). The composition of minor and major elements of the carbonates can reveal invaluable information on the mineralogy of carbonates, sea water temperatures, oxidation conditions, biochemical differentiation, salinity, the speed with which biotic and non-biotic carbonates are formed, and PCO2 level in the sea (Adabi, 2004).

Distinguishing the primary aragonite and calcite mineralogy in ancient carbonate rocks is a demanding task. Since the majority of the ancient carbonate rocks have undergone changes due to diagenetic, meteoric-pheratic, and burial factors, and then turned into low-Mg calcite. The low-Mg calcite remains essentially unchanged except in diagenetic systems which might lead to further slight chemical changes in the low-Mg calcite. One of the main applications of geochemical studies of carbonate rocks is in determining the primary mineralogy, the sedimentation environment, paleotemperature, and mutation alterations, and in distinguishing different diagenetic environments and diagenetic processes (Adabi and Rao, 1996; Adabi and Asadi Mehmandosti, 2008).

To determine the primary mineralogy of the Badamu Formation carbonates, 16 thin mudstone and wackestone sections were selected for element analysis (Fig. 1). Then, the major and minor elements of the Badamu Formation carbonates were studied. This method helps distinguish limestones including primary aragonite mineralogy from equivalent calcites.

3.2.5- Frequency of carbonates and insoluble residues

The amount carbonates varied from 85 to 90.3 percent (the average being 87.04%) and insoluble residues varied between 9.7 to 15 percent (with the average being 12%) (Table 1). Since the geochemical studies revealed a high percentage of highly pure carbonate mixtures, the samples containing more than 15% of insoluble materials were excluded from the estimations which involved the major and minor elements in the limestone. 16 appropriate samples were selected for minor and major element analysis.

Table 1) Insoluble Residues and carbonate percentages for the Badamu Formation samples.

Sample No.	Carb. (%)	Ins. Res. (%)
M2	87.7	12.3
M3	87.1	12.9
M4a	85.0	15.0
M4b	89.2	10.8
M5	90.3	9.7
M7	88.1	11.9
M11	85.1	14.9
M12	88.1	11.9
M13	85.0	15.0
M14	89.4	10.6
M15	85.2	14.8
M17	88.8	11.2
M23	85.5	14.5
M24	86.0	14.0
M25	86.0	14.0
M27	85.5	14.5

3.2.6- The major elements in the limestone

The main elements composing the limestone samples are calcium and magnesium. After the exclusion of insoluble materials and revising the concentrations, the samples showed that calcium levels vary between 49.5 and 79.5 percent (the average being 55.8%) and magnesium concentrations vary between 0.53 and 1.62 percent (the average being 0.95%) (Table 1).

Showing the percentages of magnesium and calcium on a diagram can help distinguish limestones from dolomitic rocks (Fig. 7). The results show that the given samples are limestone; none of the samples contains dolomite (Mohammadi Ghiasabadi, 2012).

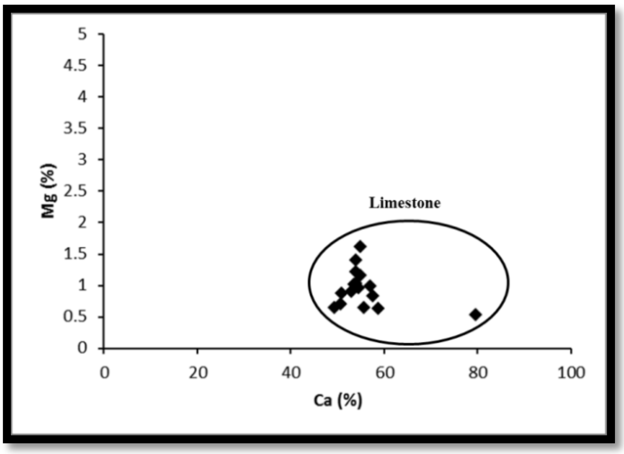

Figure 7) The magnesium variations compared to calcium concentration in limestone samples of Badamu Formation.

3.2.7- Minor elements in the limestone

The minor components in Badamu Formation limestones are strontium, manganese, and Iron as shown in Table 2.

Sr: The amount of strontium varies between 8000 to 10000 ppm in the samples of all carbonates of the present tropical areas (Milliman, 1974). However, strontium varies between 1642 to 5007 ppm in the samples of all the present mild areas (Adabi, 2004).

Strontium concentrations vary according to carbonate mineralogy so that the strontium concentration increases with an increase in the aragonite concentration and decreases with an increase in the calcite concentration (Adabi and Rao, 1991; Rao and Adabi, 1992; Salehi *et al*. 2007; Adabi and Asadi Mehmandosti, 2008; Adabi *et al*. 2010). Furthermore, strontium has a direct relation with water temperature (Morse and Mackenzie, 1990).

This element shows a dramatic decrease in ancient carbonates throughout meteoric and burial diagenesis. The frequency of strontium depends on its distribution factor as well. The distribution factor of strontium is smaller than 1 and the frequency of this element is low in meteoric waters. Most pieces of ancient limestones lose their strontium throughout diagenesis such as undergoing a change from aragonite into calcite, being solved, and falling into an opened diagenesis environment (Veizer and Demovic, 1973; Flügel, 2010).

After the exclusion of insoluble materials in the given limestone samples of Badamu Formation, the strontium concentrations varied between 51.23 to 83.74 ppm (with the average being 68.44 ppm) (Table 2).

The Strontium concentration is much lower than the similar samples of the present time. The decline in the strontium concentration can be attributed to diagenetic processes (particularly meteoric diagenesis) (Brand and Morrison, 1987; Rao and Adabi, 1992). A comparison of the concentrations of strontium and magnesium in the given samples showed an upward trend for strontium, which arises due to primary aragonite composition (Fig. 8). The comparison indicates that most Badamu Formation samples are within the range of Mozduran aragonite formation; hence, the limestone samples of Badamu Formation have primary aragonite mineralogy (Fig. 9).

Table 2) The AAS analysis results of the studied samples.

Sample No.	Ca (%)	Mg (%)	Fe (ppm)	Mn (ppm)	Sr (ppm)	Na (ppm)
M2	55.05	1.16	3450.0	322.80	65.80	214.50
M3	55.00	1.62	3386.8	302.64	77.84	222.84
M4a	54.10	1.03	5556.6	410.70	63.76	235.53
M4b	54.00	1.40	4119.7	327.80	83.74	279.70
M5	50.70	0.70	3065.7	272.31	62.46	211.51
M7	53.66	1.02	4975.0	353.04	64.30	225.45
M11	54.00	1.22	8166.9	525.03	61.70	228.08
M12	54.60	0.96	4272.6	555.84	56.30	230.76
M13	49.50	0.65	3948.8	932.23	51.53	226.35
M14	57.00	0.99	3689.7	673.04	60.06	213.53
M15	79.70	0.53	4750.7	1254.8	53.52	224.06
M17	58.80	0.63	7748.3	1439.5	68.80	204.60
M23	50.90	0.87	7737.5	1365.5	82.76	375.77
M24	53.10	0.90	6564.7	1193.0	83.36	298.20
M25	57.60	0.83	8974.4	1459.7	78.09	335.00
M27	55.70	0.64	11229	1948.6	81.09	353.47

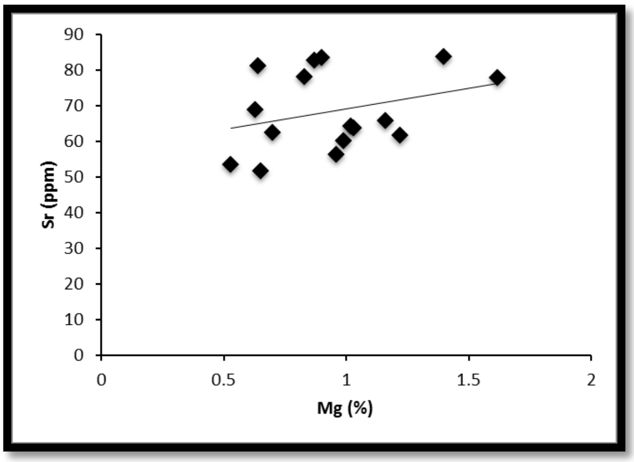

Figure 8) The variations in strontium and magnesium concentrations in limestone samples of Badamu Formation.

Na: Sodium concentration in carbonate sediments depends on salinity, biochemical differentiation, kinetic effects and crystal structure defects, mineralogical composition, and water depth. Na concentration increases as the salinity and depth of the water and aragonite increase. The level of Na in the present tropical carbonates is between 1500 to 2700 ppm (Veizer, 1983).

The concentration of Na in Badamu Formation samples varies from 204.6 to 357.77 ppm (with the average being 242.45 ppm) which shows a marked decline in comparison to the present carbonates due to diagenetic processes (Fig. 10).

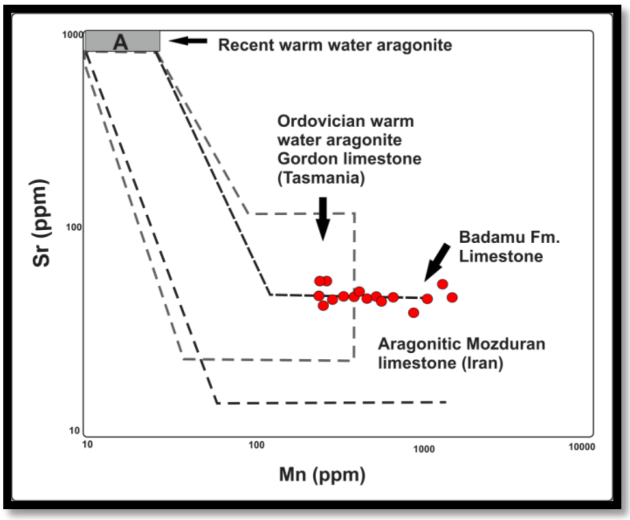

Figure 9) Comparison of the Sr and Mn changes in Badamu Formation in the given range for Mozduran aragonite formation (Adabi and Rao, 1991) and Tasmania's present carbonates (Rao and Adabi, 1992; Rao and Amini, 1995).

Mn: Aragonitic carbonates of warm and shallow seas have low levels of manganese (less than 20 ppm), while manganese concentration in the overall carbonates of the present mild areas is higher than 300 ppm (Rao and Adabi, 1992). Manganese concentrations increase with meteoric diagenesis (Brand and Veizer, 1980).

Mn concentration in Badamu Formation samples is between 272.31 to 1948.62 ppm (with the average being 833.54 ppm). The higher concentration of Mn in Badamu Formation in comparison to Mozduran Formation (243 ppm) indicates that meteoric diagenesic effects have been more dramatic in Badamu Formation in comparison to Mozduran Formation.

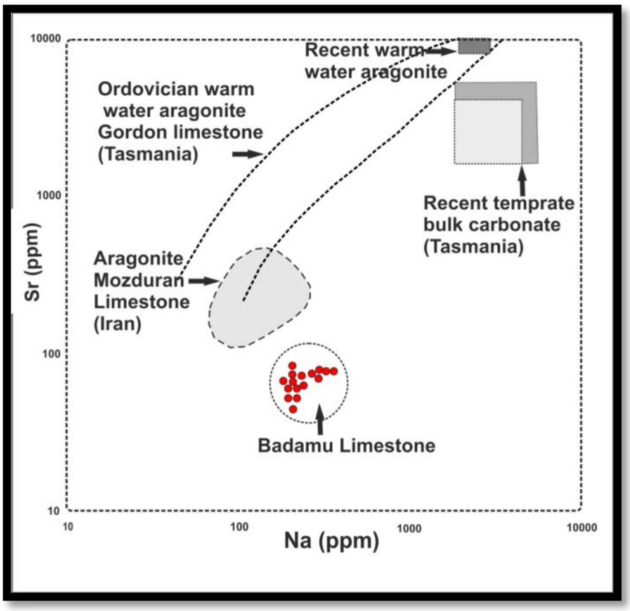

Figure 10) Sr and Na variations in limstones of Badamu Formation

Comparing Sr concentrations and Na and also Na and Mn (Figs. 10 and 11) indicate that Badamu limestone and Mozduran and Gordon (Tasmania) limestone have aragonite mineralogy, so the primary mineralogy of the limestone in Badamu is also aragonitic.

With respect to these diagrams, it could be said the limestone in Badamu Formation is affected by a diagenetic phase, which has led to Na decrease and a very slight increase in Mn due to the rapid change of aragonite to high-Mg calcite (HMC). A second phase of this marked increase in Mg exerts no marked influence on Na and Sr due to the change of the high-Mg calcite (HMC) to low-Mg calcite (LMC) (Adabi, 2004; Brand and Veizer, 1980). Similar trends have been recorded in Ordovician Gordon (Tasmania) Limestone (Rao, 1991), the Upper Jurassic limestone in Mozduran Formation (Adabi and Rao, 1996), and Lar Formation limestone (Abarghani, 2000).

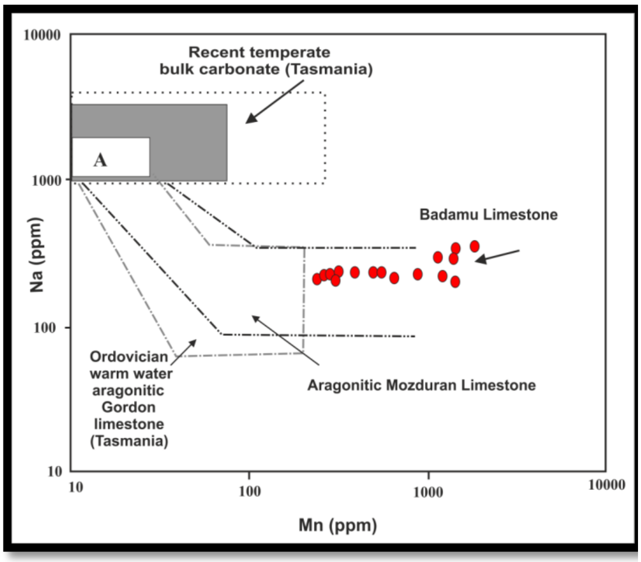

Figure 11) The Na variations compared to Mn concentration in Badamu Formation limestone samples.

Fe: The iron concentration in limestone samples of Badamu Formation varies from 306.67 and 11229.72 ppm (with the average being 5727.33 ppm). The Fe concentration shows a direct relation with manganese, i.e., as the manganese concentration increases, the Fe concentration increases too (Fig. 12). This relation shows that the limestone of Badamu Formation are affected by diagenetic processes, particularly those of meteoric and burial. It also reveals the dominant reduction conditions, a higher alteration, an open diagenetic system, a non-marine diagenesis, and a high rate of sedimentation.

Sr/Mn ratio: Throughout the breakup and change of aragonite and high-Mg calcite (HMC) to stable low-Mg calcite (LMC), the Sr concentration decreases and Mn concentration increases (Adabi, 2004). The process is increasingly facilitated when the sediments leave water and when meteoric fluids are present (Budd, 1992). Since such processes reduce the Sr/Mn ratio, then comparing the Sr/Mn diagram and Mn (Fig. 13) can reflect the level of carbonate solution (Rao, 1991).

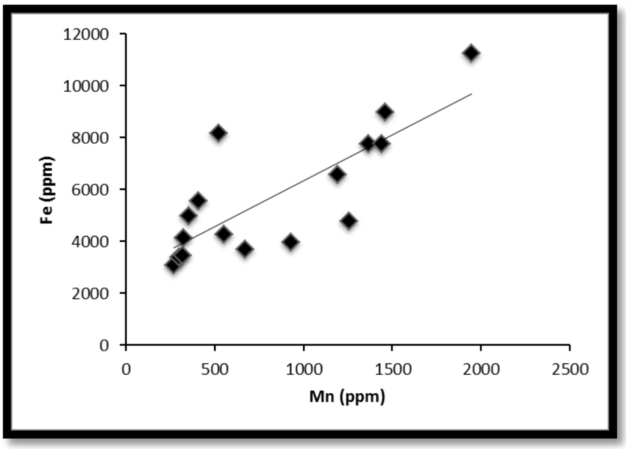

Figure 12) Crossplot of Fe vs. Mn in limestone samples of Badamu Formation.

The marked increase in Mn and the decline in the Sr/Mn concentration in the samples from Badamu Formation could have derived from meteoric diagenesis affect in an opened system and more dissolution (Fig. 14).

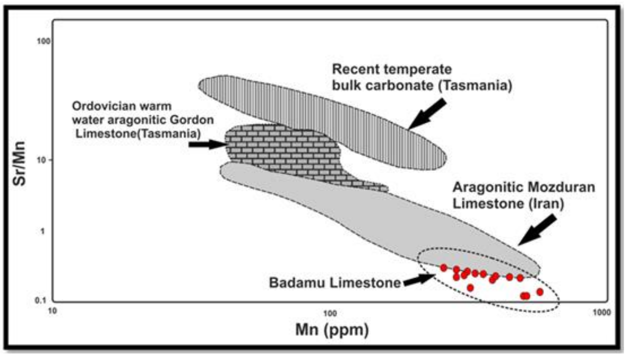

Figure 13) Sr/Mn variations compared to Mn concentration in limestone samples of Badamu Formation.

Sr/Ca ratio compared to Mn concentration: The Sr/Ca ratio in carbonates depends on the Sr/Ca ratio in sea water and strontium distribution factor (Schlanger, 1988; Stoll and Schrag, 1998). The Sr/Ca ratio and Mn quantities can determine the open-marine diagenetic processes in opened and closed systems. As the water-rock exchanges increase in open diagenetic systems, the Sr/Ca ratio decreases and Sr/Ca ratio of diagenetic phase decreases in comparison to the original compositions. An increase in Mn concentration in diagenetic calcite may reflect an open geochemical system and the effect of reducing water.

The Sr/Ca ratio in Badamu Formation varies between 1.02 and 1.62. With regards to the diagram showing the Sr/Ca ratio compared to Mn concentration, it can be said that most limestone samples of Badamu Foramtion have been affected by an open diagenetic system. The diagram presented by Brand and Veizer (1980) entails some boundaries marked for meteoric diagenetic aragonite processes (A), high-Mg calcite (HMC), and low-Mg calcite (LMC) (Fig. 14).

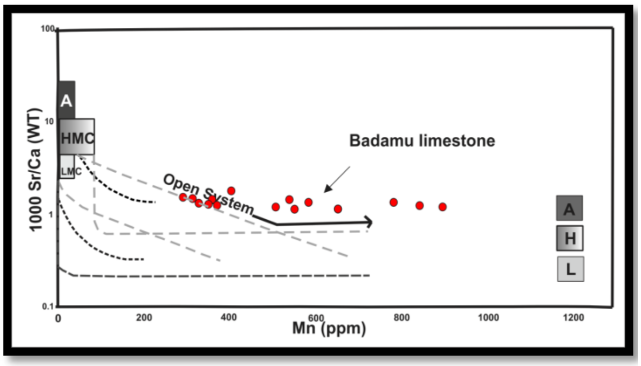

Figure 14) The Sr/Ca ratio compared to Mn concentration and the envisaged boundaries (Brand and Veizer, 1980); data collected from limestone samples of Badamu formation.

The minor and major variations along the given sequence: In order to study the minor and major variations along the given sequence, the concentrations of these elements are checked with respect to the thickness of the sequence (Fig. 15).

In diagenetic systems, geochemical exchanges with adjacent formations can lead to distinct trends in the upper or lower parts of the given sequence (Mirab Shabestari *et al.*, 2009). Sodium, strontium, manganese, Iron, and calcium concentration increase and magnesium concentrations decrease as one move toward the end of the sequence. It seems that these changes have occurred due to the effects of the open diagenetic system, particularly the effect of marl and mudstone rock units of Baghamshah Formation on the upper boundary of Badamu Formation (Mohammadi Ghiasabadi, 2012). Moreover, the decline in magnesium concentration can be attributed to the change of aragonite and the change of high-Mg calcite to low-Mg calcite.

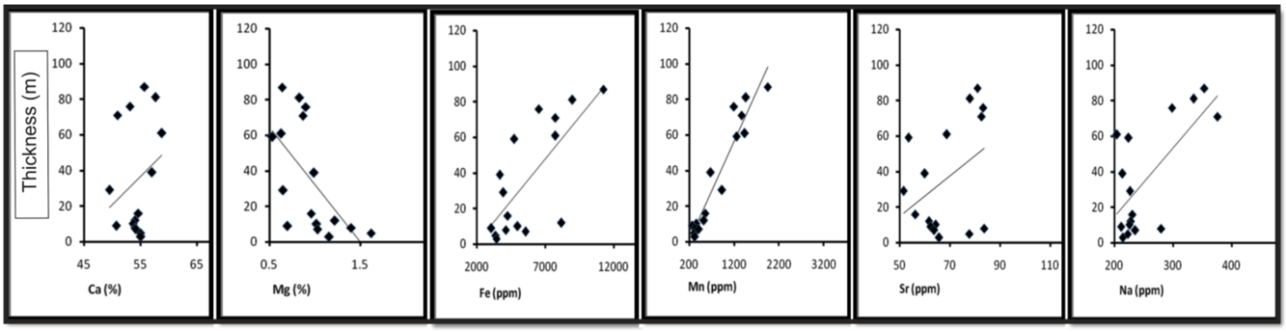

Figure 15) The vertical variations of the minor and major elements of Badamu Formation in relation to the thickness of the given sequence.

4– Conclusion

Badamu Formation (Upper Toarcian-Middle Bajocian) is mainly composed of limestones and shales. The petrographical study of 50 thin sections of the Formation led to the identification of six carbonate microfacies, which were deposited in four microfacies belts of shallow marine, shoal, semi-closed lagoon, and tidal channel. The comparison of the facies with the standard facies indicated that the Badamu formation is deposited in a homoclinal ramp including sub-environments of inner ramp, middle ramp, and outer ramp. The geochemical studies showed high concentrations of calcium and low concentrations of magnesium. Furthermore, an analysis of the minor and major elements indicated that aragonite has been the original carbonate mineral in the limestone of Badamu formation and that these rocks have stabilized in a meteoric-pheratic and burial diagenetic environment. In addition, Sr/Ca ratio variations compared to Mn concentration represent diagenetic alterations in an opened system.

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