Quantitative analysis, basin evolution and paleoecology of Early Miocene ostracods in the southwest of Kerman, Iran

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(*received : 08/01/2017 ; accepted: 08/04/2018*)

Abstract

This paper focuses on the quantitative analyses of Early Miocene ostracods in south and north of the Sirjan area, southwest of Kerman. Detailed studies resulted in identification of 23 species of ostracoda. The coexisting benthic foraminifera and comparing the identified microfauna assemblages with previous studies confirms the Early Miocene age for the strata. The quantitative analysis show a low diversity in the ostracoda assemblages, in compare with other areas. The ostracoda community is classified into seven morphogroups. Several communities are recorded in the ostracoda morphogroups, which reflects basic changes in the basin condition. The morphogroups analysis also reveals that the basal parts of the sections are deposited in shallow and poorly ventilated waters, while a normal condition prevailed through upward. A period of instability is predominant after the normal condition and final stages of deposition took place in the near shore environment, which reflects the end of sea life. The stratigraphical position and structural history of the basement suggest that syndepositional tectonic activities were responsible for the fluctuations in the environmental conditions. This suggestion is confirmed by comparing the studied area with adjacent areas, where similar deposits are deposited on different basements.

Keywords: *Ostracods; Lower Miocene; Basin Evolution; Sirjan; Kerman.*

Introduction

During the Cenozoic, various important marine basins have been developed by tectonic activities in the Iranian plateau In Central Iran structural zone(Dabaghi Sadr & Schmiedl 2017). The Oligo-Miocene deposits are the most famous and studied Cenozoic marine strata. In general, these deposits comprise of marl, argillaceous limestone, limestone, reefal limestone and minor clastic and evaporitic deposits and is named as Qom Formation (Stöcklin & Setudehnia 1971). Duo to presence of reefal and evaporitic unites in the Qom Formation deposits, valuable hydrocarbon reservoirs are formed in this formation. The formation has been studied by many researchers from different aspects, because of its hydrocarbon capability (Mohammadi & Ameri 2015; Amirshahkarami & Naimi 2016; Karami-Movahed *et al.*, 2016; Roozpeykar & Moghaddam 2016; Sardarabadi *et al.,* 2016; Dabaghi Sadr & Schmiedl 2017; Daneshian & Ghanbari 2017; Daneshian *et al.,* 2017; Zágoršek *et al.,* 2017). The Qom Formation is the most fossiliferous outcroup of Iran, especially from the view point of foraminifera and ostracods. The ostracods are employed as a powerful tool for paleoceanographical analysis and are used by many researchers (Danielopol *et al.,* 2007; Irizuki *et al.,* 2007; Reeves *et al.,* 2007; Gopalakrishna *et al.,* 2008; Hosseinipour *et al.,* 2010; Pieri *et al.,* 2009; Torkzadeh *et al.,* 2011; Wilson *et al.,* 2014). However a few studies have been carried out on Qom Formation ostracods, specially in the Kerman province (Hosseinipour *et al.,* 2010; Torkzadeh *et al.,* 2011; Hassani, 2012). One of the most conspicuous feature of Oligo-Miocene deposits in study sections, compare with adjacent area, is its relatively low diversity of fauna and also more lithological and facies changes through the sections. This research, tries to describes the ostracod content of the Lower Miocene strata in south and north parts of the Sirjan area (SW of Kerman province, SE Iran) for the first time form the microbiostratigraphical and paleoecological aspects.

Geological settings and stratigraphy

The present geology and morphology of the Iranian Plateau have been formed by complex structural, sedimentological, igneous and metamorphic activities (Aghanabati, 2004). Based on these essential differences, several authors divided the Iranian Plateau into different structural zones (Stocklin, 1968; Nabavi, 1976; Stampfli, 1978; Alavi, 1991). According to these classifications, the Iranian Plateau is divided into eight main structural zones (Fig. 1A).

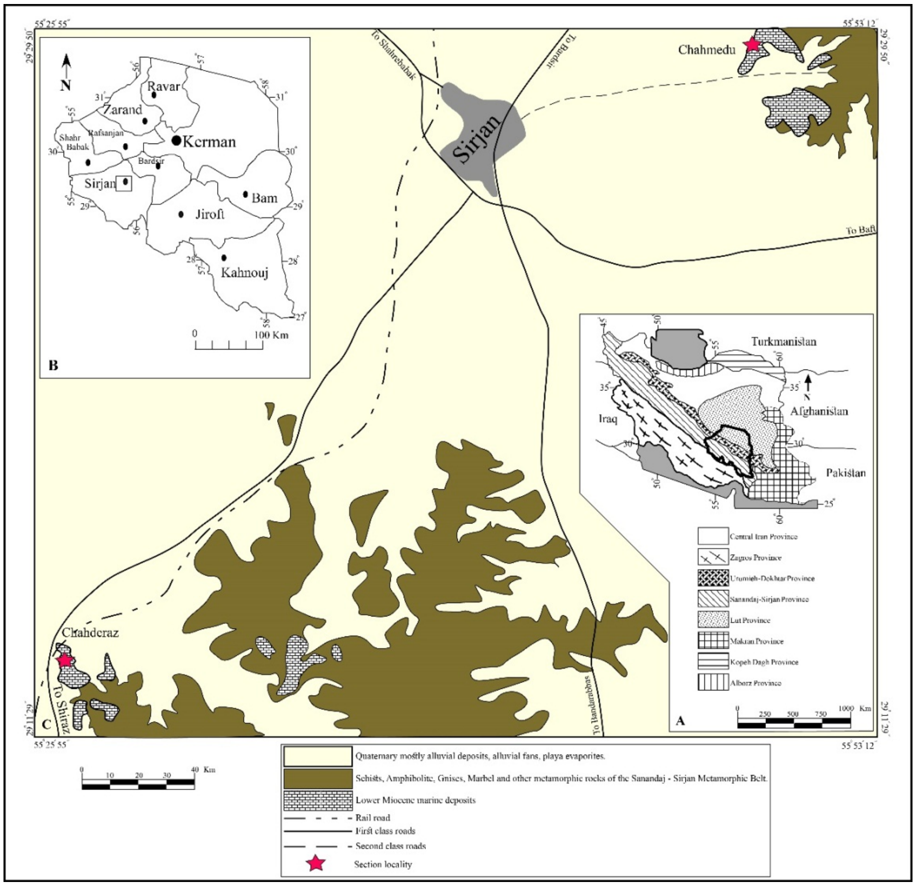

Figure 1. A, the major structural zones of the Iranian Plateau and the location of Kerman Province (Sadeghi *et al*., 2010); B, the location of studied area in Kerman Province; C, The simplified geological map of the study area.

The studied area locates in the Sanandaj-Sirjan Metamorphic Belt in the Kerman Province (Fig. 1B). In this region, metamorphic rocks constitute the most common unites, while the Lower Miocene deposits outcrop as small patches. Around the Sirjan city, these deposits are cropped out in the northeastern and southwestern parts (Fig. 1C) and mostly consist of marl, argillaceous limestone and reefal limestone. The studied sections are located in two different localities. The first, near Chahderaz village, at the south (55° 26' 36" E, 29° 11' 54" N), and the second, near the Chahmedu village, at the north (55° 49' 55" E, 29° 32' 27" N) of Sirjan, (Fig. 1C). Both sections are composed essentially of greenish marl and light cream limestone strata. These sections are underlain nonconformably by a low to medium graded metamorphic rocks (Fig. 2), while their upper surface is covered by weathered and eroded deposits. The Oligo-Miocene Qom Formation sedimentary basin has been assumed as a critical part of the Tethyan Seaway, which has been located at the connection area between the Mediterranean and Indo-Pacific domains of the Tethys Ocean (Reuter *et al.,* 2007).

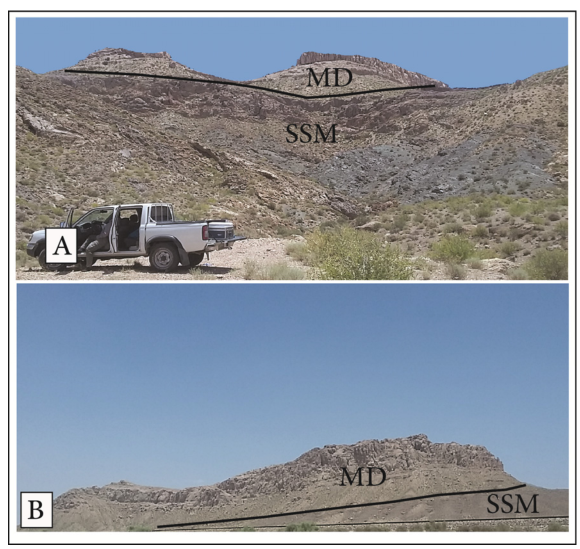

Figure 2. The lithological units in the stratigraphic sections. A, Chahmedu section; B, Chahderaz section. SSM, metamorphic rocks of the Sanandaj-Sirjan Zone; MD, Miocene deposits

Therefore, paleoceanographic interpretations in such terminal part of the main basin could be helpful to clarify the common ambiguities about the evolution of the whole basin.

Material and methods

The total thickness of the Chahderaz section is about 150 m, comprises of 97.5 m. marl at the base, 15 m. reefal limestone in the middle part, 15 m. marl in the upper part and 22.5 m. limestone at the top. The Chahmedu section consists of about 63 m. marl with fossiliferous argillaceous limestone intercalations at the base, 28 m. reefal limestone in the middle part, 23 m. marl in the upper part and 6 m. limestone at the top. Totally, 74 samples from the marls and 15 samples from the hard rocks were collected from the studied strata. To prevent contamination from eroded layers, loose samples were taken from the bottom of a half meter deep holes. About 250 gr. dried sediments of each sample were soaked in the diluted 10% hydrogen peroxide solution for 24 hours, and once disaggregated washed through a 63µm sieve (Gebhardt, 2004). The total ostracod content of samples were handpicked and counted, using a stereomicroscope. The best preserved forms of identified ostracods photographed by a Phenom Pro-X Desktop Scanning Electron Microscope in the Payame Noor University of the Yazd. For paleoecological and basin analyses, the Fisher diversity index measured for each sample. Based on morphological characteristics and ornament similarities, the identified ostracods classified in to seven clusters (morphogroups), by R-mode clustering method using SPSSV. 19 Software. All the samples are housed in the museum of the Graduate University of Advanced Technology, Kerman.

Systematic Paleontology

In general, 23 species related to 19 genera of ostracoda have been identified, among which 17 genera belong to podocopids and 2 genera to platycopids (Tab. 1). Although the species are reported for the first time from the studied sections, most of them are reported from the Cenozoic deposits of various locations in the world. This paper deals with brief systematic state and conspicuous remarks are outlined.

Table 1: The identified ostracoda, the letter of them in the plate and their abundance in the studied sections.

Letter in the Plate	Taxa	No. of specimens in Chahmedu section	No. of specimens in Chahderaz section	Taxon Code in Tab.2
x	*Acanthocythereis dunelmensis*	252	-	1
w	*Actinocythereis rosefieldensis*	268	-	2
l	*Argilloecia* sp.	140	-	3
k	*Argilloecia triangularis*	104	-	4
t	*Aurila* sp.	376	-	5
i-j	*Australoecia posterocurua*	148	208	6
g-h	*Bairdoppilata* sp.	124	108	7
v	*Buntonia* sp.	184	176	8
q	*Costa* sp.	332	-	9
p	*Costa tricostata*	284	-	10
o	*Euxinocythere quadricostata*	138	-	11
z	*Hermanites rectangularis*	288	376	12
m	*Krithe* sp.	496	580	13
n	*Krithe trinidadensis*	344	-	14
y	*Legitimocythere* sp.	332	156	15
u	*Mutilus fortireticulata*	276	140	16
d-e	*Neonesidea gerda*	188	-	17
s	*Pokornyella italica*	228	244	18
r	*Procythereis deformis*	292	228	19
f	*Xestoleberis vicksburgensis*	152	184	20
a	*Cytherella dissimilis*	304	140	21
b	*Cytherella* sp.	508	552	22
c	*Cytherelloidea* sp.	156	204	23

Class Crustacea (Brünnich, 1772)
Subclass Ostracoda (Latreille, 1803)
Order Podocopida (Sars, 1866)
Suborder Podocopina Sars, (Sars, 1866)
Family Trachyleberididae (Sylvester-Bradley, 1948)
Subfamily Trachyleberidinae (Sylvester-Bradley, 1948)
Genus *Acanthocythereis* (Howe, 1963)
Acanthocythereis dunelmensis (Norman, 1865)
Plate 1, Fig. x

Materials: 252 carapaces.

Remarks: Carapace is sub-rectangular and the left valve is slightly larger than the right one in lateral view, posterior and anterior ends are rounded but the anterior area is wilder than the posterior area. The anterior dorsal cardinal angle is slightly more pronounced in the left valve. Valves are highly ornamented by reticulate ridges and conical spines in junctions. Spines are fewer, coarser and node like in males and finer and more in females. The dorsal margin is straight, the ventral margin is concave in males and straight in females. The medium length of the carapace is 0.63-1.0 mm and the medium height is 0.3- 0.6 mm.

Genus *Actinocythereis* (Puri, 1953)
Actinocythereis rosefieldensis (Howe and Law, 1936)
Plate 1, Fig. w

Materials: 268 carapaces.

Remarks: Carapace is trapezoidal to sub-rectangular in lateral view, thick, pockmarked with coarse and huge nodes especially in anterior and ventral margin. Nodes in posterior and dorsal margin are finer. The anterior is rounded and slightly extended upward; the posterior is rounded but lower than anterior area. The dorsal margin is straight; the ventral margin is straight or slightly sinusoidal. The medium length of carapace = 0.45-0.9 mm and the medium height = 0.22-0.5 mm.

Genus *Legitimocythere* (Coles and Whatley, 1989)
Legitimocythere sp.
Plate: 1, Fig. y

Materials: 488 carapaces.

Remarks: Carapace is trapezoidal and elongated, voluminous in the central zone and ornamented with irregular and sporadic nodes, which are coarser in the center and finer in the marginal area. Anterior is rounded and posterior is pointed. The ventral margin is slightly convex and has inclined to the posterior. The dorsal margin is straight. The medium length = 0.6-0.8 mm and the medium height = 0.4-0.5mm

Genus *Hermanites* (Puri, 1953)
Hermanites rectangularis (Ruggieri, 1962)
Plate: 1, Fig. z

Materials: 664 carapaces.

Remarks: The carapace is sub-rectangular to trapezoidal in lateral view and equivalve, voluminous in the central area. Valves ornamented with honeycomb like reticulation. A distinctive node is located at the center of valves. Two smaller and semi-conical nodes are present at antro-dorsal and postero-dorsal angles. A tiny ala is located at the ventral margin in posterior half. The anterior end is broadly rounded and extended upwards with moderate high anterior margin rim. The posterior end is rectangular. Greatest height passing through the anterior cardinal angle. The ventral margin is straight; the dorsal margin is straight and inclined to the posterior end. The medium length of the carapace = 0.6-0.9 mm and the medium height = 0.4-0.55mm.

Genus *Costa* (Neviani, 1928)
Costa tricostata (Reuss, 1850; Ruggieri, 1992)
Plate 1, Fig. p

Materials: 284 carapaces.

Remarks: This species has a sub-rectangular carapace with rough tegminate reticule ornamentation. The dorsal margin has a conspicuous ala. A central nude and tow ridges are present on each valve. The posterior end is characterized by a pointed tail like appendage. The anterior margin has a crescent like keel on bout valves. Dorsal and ventral margins nearly straight and converging towards the obtuse posterior end. The left valve is slightly larger than the right one. The medium lent of carapace 0.65-0.95 mm and the medium height= 0.36-0.4 mm.

Subfamily Buntoninae (Apostolescu, 1961)
Genus *Buntonia*, (Howe and Chambers, 1935)
Buntonia sp.
Plate 1, Fig. v

Materials: 360 carapaces.

Remarks: The carapace is pear-shaped, greatest height anteriorly, maximum width posterior. Ornamented by a framework of ridges. The central area of valves is almost smooth and just small sporadic pits are present. The left valve is larger than the right one. The anterior end is regularly rounded but the posterior end is pointed. The dorsal margin is convex in both of male and female forms. The ventral margin is straight in males, but in females it is slightly convex and a lobe-like turgidity is present in both of left and right valves. The length of carapace is 0.75-1.0 mm, the height ~ ½ length.

Family Pontocyprididae(Müller, 1894)
Genus *Argilloecia* (Sars, 1866)
Argilloecia triangularis (Dall'Antonia, 2003b)
Plate: 1, Fig. k

Materials: 104 carapaces.
Remarks: This species has a moderately thick, smooth and elongate carapace, dorsal and ventral margins are parallel in right valve and concave-convex in the left valve. The posterior end is pointed and slightly truncated, but the anterior end is rounded. The right valve is larger than the left valve and overlies it in ventral margin. This species is medium to large sized (0.75 – 2.0 mm)

Argilloecia sp.
Plate: 1, Fig. l

Materials: 140 carapaces.
Remarks: the carapace is elongated and fusiform, not ornamented and equivalve. The anterior margin is highly rounded and the posterior end is strongly pointed. The dorsal margin is broadly convex; the ventral margin is straight in the middle, but it has inclined upward in anterior and posterior end. The medium length =0.8-1.1mm and the height ~ 1/3 lent.

Genus *Australoecia* (McKenzie, 1967)
Australoecia posterocurua (Barra & Bonaduce, 2001)
Plate: 1, Fig. i-j

Materials: 356 carapaces.
Remarks: The carapace is large, ovate to droplet like. Compacted in posterior half, voluminous in anterior area, the anterior end is broadly rounded, the posterior end is pointed. The dorsal margin is domelike and concave, the ventral margin is sinusoidal, convex in the anterior half and convex in the posterior half. The lent of male carapaces is larger than the females. The female carapaces are 1/3 length of males.

Genus *Xestoleberis* (Sars, 1866)
Xestoleberis vicksburgensis (Howe and Law, 1936)
Plate: 1, Fig. f

Materials: 336 carapaces.
Remarks: The carapace is sub-ovate in lateral view. The dorsal margin is highly convex, the ventral margin is sinuous. It is slightly convex in posterior half and concaves in the anterior half; the anterior margin is narrowly rounded and extends downward; the posterior margin is broadly rounded. The left valve is larger than the right one, surface of the carapace is smooth and normal pores in part with cribrate sieve plates are present. This species is medium to large sized, the length of carapace = 0.8-1.8 mm and the height ~1/2 length.

Family Cytheridae, (Baird, 1850)
Subfamily Leptocytherinae, (Hanai, 1957)
Genus *Euxinocythere* (Stancheva, 1968)
Euxinocythere quadricostata (Pipík & Bodergat, 2004)
Plate: 2, Fig. o

Materials: 138 carapaces.
Remarks: The carapace is sub-rectangular and equivalve, ornamented by reticulate ridges which are finer and honeycomb like in marginal area and coarser and irregular in the central area. The anterior end is regularly rounded and has extended downwards. The posterior end is irregularly rounded and slightly sinusoidal. The dorsal margin is straight and gently has inclined to the posterior end. The ventral margin is slightly convex with maximum hollowness in the mid length. The medium length= 0.7-09mm and the height ~ 1/3 length.

Family Krithidae, (Mandelstam, 1958)
Subfamily Krithinae, (Mandelstam, 1958)
Genus *Krithe* (Brady et al., 1874)
Krithe sp.
Plate 1, Fig. 13

Materials: 1076 carapaces.
Remarks: The carapace is parabolic and elongated in lateral view, cylindrical in general and has ornamented with irregular elongated sporadic pits. The anterior end is parabolic, rounded and has slightly extended upwards. The posterior is pointed and has inclined downwards. The ventral margin is straight to slightly concave. The dorsal margin is straight in mid length of the carapace, highly inclined downward to posterior end and slightly inclined upward to the anterior end. The length of carapace= 0.7-1.2mm and the height ~1/3 length.

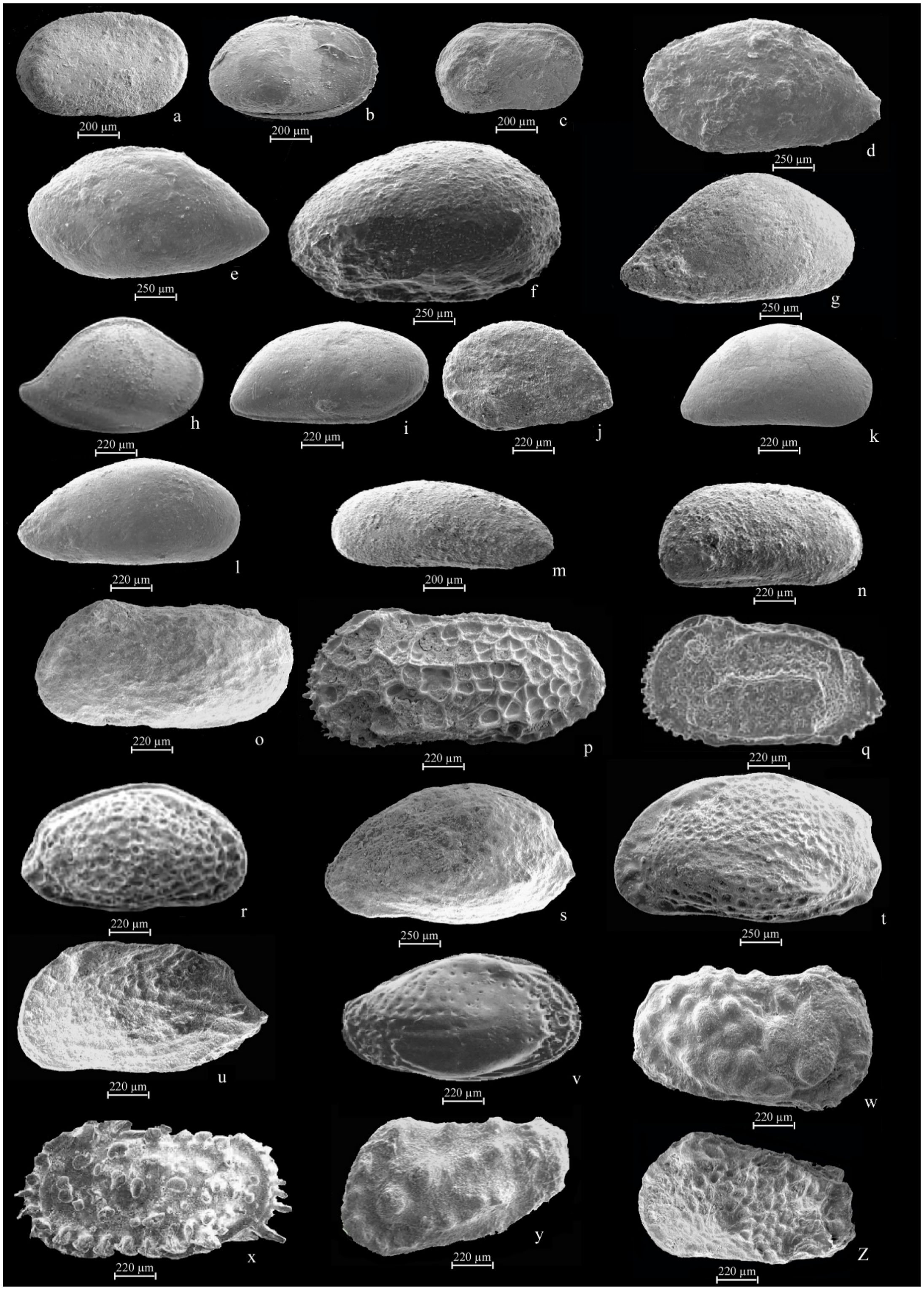

Plate 1. a: *Cytherella dissimilis*, carapace, right lateral view; b: *Cytherella* sp., carapace, right lateral view; c: *Cytherelloidea* sp., carapace, right lateral view; d,e: *Neonesidea gerda*, carapace, left lateral view; f: *Xestoleberis vicksburgensis*, carapace, right lateral view; g,h: *Bairdoppilata* sp., carapace, right lateral view, g, female; h, male; i,j: *Australoecia posterocurua*, i, right lateral view of male, j, left lateral view of female; k: *Argilloecia triangularis*, carapace, right lateral view; l: *Argilloecia* sp., carapace, right lateral view; m: *Krithe* sp., carapace, left lateral view; n: *Krithe trinidadensis*, carapace, right lateral view; o: *Euxinocythere quadricostata*, carapace, left lateral view; p: *Costa tricostata*, carapace, left lateral view; q: *Costa* sp., carapace, left lateral view; r: *Procythereis*

deformis, carapace, right lateral view; s: *Pokornyella italica*, carapace, left lateral view; t: *Aurila* sp., carapace, left lateral view; u: *Mutilus fortireticulata*, carapace, left lateral view; v: *Buntonia* sp., carapace, right lateral view; w: *Actinocythereis rosefieldensis,* carapace, right lateral view; x: *Acanthocythereis dunelmensis,* carapace, left lateral view; y: *Legitimocythere* sp., carapace, left lateral view; z: *Hermanites rectangularis,* carapace, left lateral view.

Krithe trinidadensis (Van den Bold, 1958)
Plate: 1, Fig. n

Materials: 334 carapaces.

Remarks: The carapace is elliptical to parabolic and non-ornamented, valves are equal, but in the ventral margin, the left valve is more projected then the right valve. The anterior end is regularly rounded but the posterior end is pointed and inclines downward. In both male and females, the dorsal margin is slightly convex. The ventral margin is straight in males and slightly convex in females. The length of carapace= 0.7-1.2mm and the height = 0.2-0.35mm.

Family Hemicytheridae, (Puri, 1954)
Genus *Pokornyella*, (Oertli, 1956)
Pokornyella italic, (Ruggieri et al., 1977)
Plate: 1, Fig. s

Materials: 472 carapaces.

Remarks: This species has a dome-like and sub-ovate carapace, ornamented with irregular pits and ala like spines near the ventral margin. The carapace is too voluminous in dorso-central area. In females, the voluminous body is larger and carapace becomes chubby or belly. The anterior is rounded parabolically and extended to the ventral margin. The posterior end is pointed and sinusoidal. The ventral margin is sinusoidal, convex in mid length and concave in posterior and anterior areas. The dorsal margin is convex and dome-like. The length of carapace= 0.7-1.1 mm and the height = 0.6-0.9mm.

Subfamily Hemicytherinae, (Puri, 1954)
Genus *Procythereis*, (Skogsberg, 1928)
Procythereis deformis,(Reuss, 1850; Van den Bold, 1965)
Plate: 1, Fig. r

Materials: 520 carapaces.

Remarks: The carapace is ovate to ovate-subrectangular, plump and ornamented with pits and small and irregular nodes. There are two projected nodes located at the antro-dorsal and postero-dorsal angles and another distinct node located at the postero-ventral angle. The anterior is rounded, extended and inclines downward. The posterior end is pointed and sinusoidal. The ventral margin is sinusoidal; the dorsal margin is straight to slightly concave. The left valve is larger than the right one and overlaps the right valve in dorsal margin. The length of carapace= 0.6-0.9 mm and the height = 0.2-0.35mm.

Genus *Mutilus* (Neviani, 1928)
Mutilus fortireticulata (Khalaf, 1988)
Plate: 1, Fig. u

Materials: 416 carapaces.

Remarks: The carapace is elliptical to subquadrate in lateral view, inflated ventrally with ventro-lateral prolongation. The anterior area is rounded; the posterior margin is narrower, concave in the upper part and ending postero-ventrally in a short truncate caudal process. The dorsal margin is slightly convex in the left valve and straight in the right valve. The ventral outer margin is slightly concave. Posteriodorsal cardinal angle conspicuous and nearly 90°. Four concentric ridges in the anterior area characterize this species. The length of carapace= 0.7-1.1mm and the height ~ ½ length.

Genus *Aurila*, (Pokorný, 1955)
Aurila sp.
Plate: 1, Fig. t

Materials: 376 carapaces.

Remarks: This species has an ovate carapace that is chubby in ventral margin. The carapace ornamented with reticulated ridges. The anterior end is rounded and extended downwards; the posterior end is pointed, rectangular and scattered. The dorsal margin is dome-like and the ventral margin is sinusoidal. The length of carapace= 0.8-1.2mm and the height ~ ½ length.

Superfamily Bairdiacea (Sars, 1866)
Family Bairdiidae (Sars, 1866)
Genus *Bairdoppilata* (Coryell et al., 1935)
Bairdoppilata sp.
Plate: 1, Fig. g-h

Materials: 232 carapaces.

Remarks: The carapace is huge, bairdoid and sub triangular, smooth or finely punctuate in lateral view. The left valve is larger than the right valve, often resulting a pronouncedly different outline of the dorsal margin in the right and left valves. Posterior end is boat-shaped and anterior end is rounded. The medium length of the carapace is 0.8-

1.5mm and the height ~ ½ length.

Genus *Neonesidea* (Maddocks, 1969)
Neonesidea gerda (Benson & Coleman, 1963; Maddocks, 1969)
Plate: 1, Fig. d-e

Materials: 188 carapaces.

Remarks: The carapace is semi bairdoid, equivalve and smooth, valves are voluminous in central area and slightly compacted in anterior and posterior ends. Anterior regularly rounded, posterior severely pointed. The dorsal margin is convex and dome-like, inclines to the posterior end. The ventral margin is straight, pushed upward at posterior and anterior terminals. The medium lenght of the carapace is 0.7- 1.3 and the height ~ ½ lenght.

Order Platycopida, (Sars, 1866)
Suborder Platycopa (Sars, 1866)
Family Cytherellidae (Sars, 1866)
Genus *Cytherella* (Jones, 1849)
Cytherella dissimilis (Donze, 1965)
Plate: 1, Fig. a

Materials: 444 carapaces.

Remarks: The carapace is sub-rectangular in males and elliptical in females. The dorsal and ventral margins are concave. The surface of the carapace is smooth. The posterior area is thicker than the anterior area. The medium length of the carapace is 0.5- 0.9 and the height = 0.35-0.6mm.

Cytherella sp.
Plate: 1, Fig. b

Materials: 1060 carapaces.

Remarks: The carapace is elliptical. The left valve is larger than the right one and overlays the right one especially in anterior and ventral margins. The dorsal margin in both valves is convex, but slightly higher in the left one. The ventral margin of the right valve is sinusoidal, but in the left valve is convex. In the right valve of the females, the posterior half is voluminous than the anterior half. The anterior end is regularly rounded; the posterior end is rounded and inclines downward. The medium length of the carapace is 0.6- 0.9 and the height = 0.35-0.6mm.

Genus *Cytherelloidea* (Alexander, 1929)
Cytherelloidea sp.
Plate: 1, Fig. c

Materials: 360 carapaces.

Diagnosis: The carapace is elliptical, elongated and non-ornamented. The left valve is larger than the right one and overlays the right one especially in antero-dorsal and postero-dorsal margins. The Posterior and anterior ends are regularly rounded. The dorsal margin is straight in both of male and females. The ventral margin is straight in males and convex in females. The posterior half is voluminous in females. The medium length of the carapace is 0.4- 0.8 and the height = 0.36-0.45mm.

The identified ostracoda and their abundance in Chahmedu section represented in figure 3.The figure 4 also shows the recovered ostracoda and their abundance in Chahderaz section.

Palaeoecology

Ostracoda have long been known to be useful tools as indicators of fluctuation in the environment, such as salinity, depth, substrate, nutrient level, ventilation and temperature changes (Matzke-Karasz *et al.,* 2005). They found in fresh, brackish and marine watersand have adapted to live in very narrow ecological niches throughout the geologic time, therefore, they are highly sensitive to fluctuations in environmental factors (Matzke-Karasz *et al.,* 2005; Matzke-Karasz *et al.,* 2007). Ostracoda have been used for paleoecological interpretations in different environments by many researchers (Gross, 2004, 2008; Mazzini, 2005; Matzke-Karasz *et al.,* 2005; Matzke-Karasz *et al.,* 2007; Reeves *et al.,* 2007; Irizuki *et al.,* 2009). In this study, the identified ostracods are classified into seven morphogroups, based on their carapace characteristics (Tab. 2), (Fig. 5). In this classification 90% of similarity between the taxa is emphasized (Elewa, 2004). The morphogroups, their taxa, and also their favorable ecologic environment is summarized in table 3.

The identified platycopid ostracods, *Cytherella* and *Cytherelloidea*, are included in the morphogroup no.1. These forms are common in marine environments as auxiliary members. The most conspicuous character of them is theirability to live in low oxygenated waters. This ability is due to their feeding and reproduction strategies, which makes them as the most resistant ostracods in non-ventilated waters (Whatley & Maybury 1990; Whatley, 1991).The morphogroup no. 2 comprises Xestoleberis, Neonesidea and Bairdoppilata. These genera are able to survive in wide ecological niches, but they are flourished in oligotrophic to mesotrophic zones in moderately shallow waters at coarse-grained substrate (Kondo *et al.,* 2005; Sato & Kamiya 2006).

Table 2. The data matrix of similarities in the studied ostracodes, which used for R-mode clustering analyses.

Taxon Code	**Order**		**Valves**		**Carapace general shape**										**Surface**		**Ornaments**								
	Platycopida	**Podocopida**	**Equivalve**	**Unequivalve**	**Elongate**	**Trapezoidal**	**Spherical**	**Elliptical**	**Ovate**	**Sub rectangular**	**Rectangular**	**Quadrangle**	**Tri angular**	**Pointed**	**Ornamented**	**Non ornamented**	**Ridges**	**Ala**	**Nodes**	**Spines**	**Reticulate**	**Honeycomb**	**Belly**	**Tubercles**	**Pits**
1	0	1	1	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	1	0
2	0	1	1	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	1	0	0
3	0	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	1	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	1	0	0	1	0
6	0	1	0	1	1	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
7	0	1	0	1	0	0	1	1	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
8	0	1	1	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	1	1	0	0	1
9	0	1	1	0	0	1	0	0	0	0	1	1	0	0	1	0	1	1	0	0	1	1	0	0	1
10	0	1	1	0	0	1	0	0	0	0	1	1	0	0	1	0	1	1	0	0	1	1	0	0	1
11	0	1	1	0	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
12	0	1	1	0	0	1	0	0	0	1	0	0	0	0	1	0	1	1	1	0	1	0	0	0	0
13	0	1	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
14	0	1	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
15	0	1	1	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0
16	0	1	1	0	0	0	0	0	1	0	0	0	0	1	1	0	0	1	0	1	0	0	1	0	0
17	0	1	0	1	0	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
18	0	1	1	0	0	0	0	0	1	0	0	0	0	1	1	0	0	1	0	1	0	0	1	0	0
19	0	1	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	1	1	0	0	0	1
20	0	1	0	1	0	0	1	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
21	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	1	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 3. Ostracoda morphogroups and their morphological and ecological characteristics.

Morphogroup	Genus	Morphological characteristics	Ecology
1	*Cytherella* *Cytherelloidea*	Elliptical to sub-rectangular and unornamented	Predominant in relatively harsh and poorly ventilated basins.
2	*Xestoleberis* *Neoneside* *Bairdoppilata*	Spherical to elliptical unornamented with large carapace	Living in oligotrophic to mesotrophic zones at coarse-grained substrate in moderately shallow waters
3	*Krith* *Australoecia* *Argilloecia*	Elongated and pointed, triangular to droplet like in lateral view, unornamented,	Flourishing at fine grained and relatively hard substrates in relatively deep waters
4	*Euxinocythere quadricostata*	Sub-rectangular in lateral view, voluminous in posterior half, ornamented by pits and fine marginal ridges.	Living in fresh to brackish and shallow waters in intermountain basins
5	*Costa*	Sub-rectangular, ornamented with irregular pits and ala like ridges	Dominant at soft and fine grained substrate; in nutrient rich and saline environments of moderately deep waters
6	*Mutilus* *Pokornyell* *Procythereis* *Buntonia* *Aurila*	Ovate to elliptical, ornamented by various sized pits, and an ala like ridge parallel to the ventral margin which ends to a short spine	Flourishing at soft, medium to coarse-grained substrates in the normal saline and nutrient rich environments near and in the back of reefal environments
7	*Actinocythereis* *Acanthocythereis* *Legitimocythere* *Hermanites*	Trapezoidal in lateral view, ornamented by various sized spines, nodes and tubercles	Predominant at fine-grained, relatively hard and nutrient rich substrate of relatively deep waters

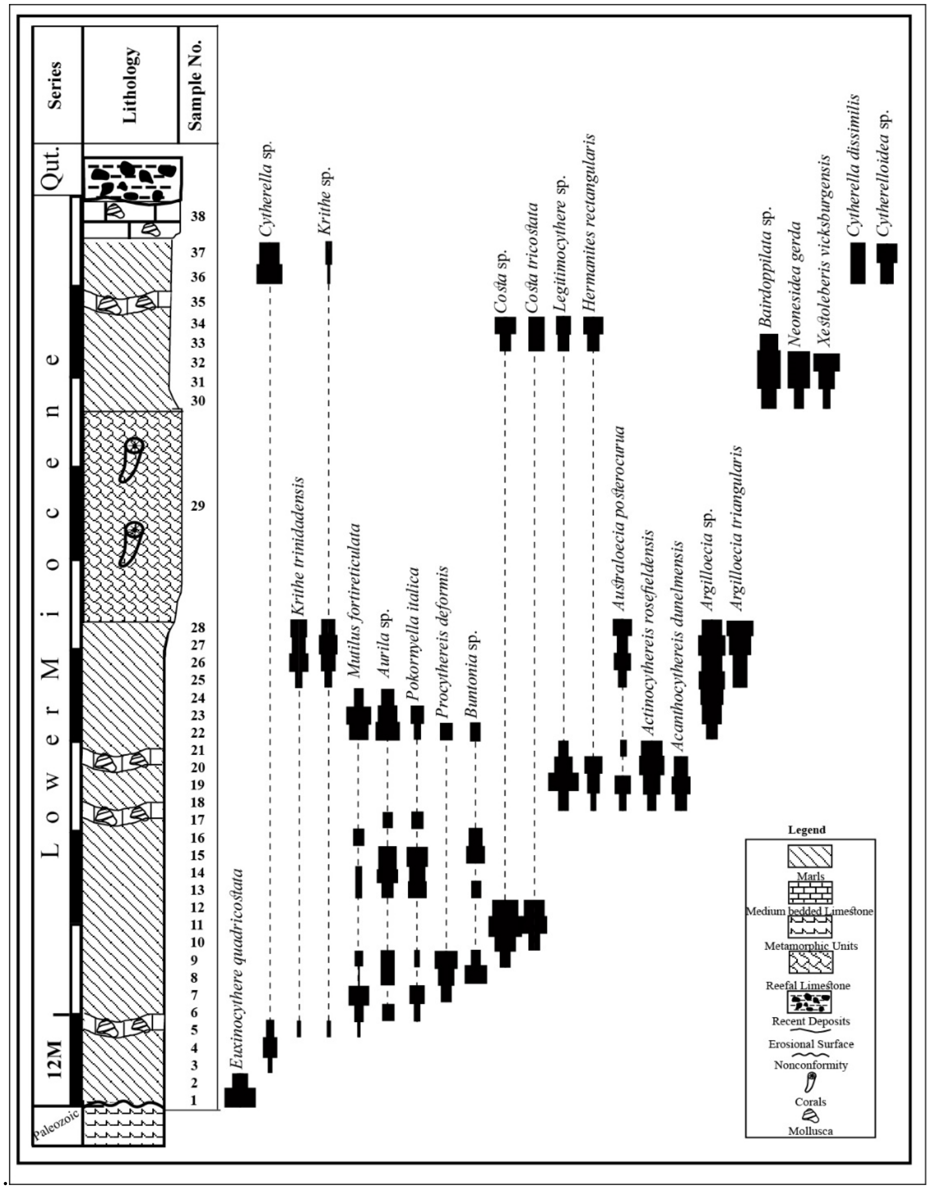

Figure 3. Stratigraphic column and the range chart of the ostracoda in the Chahmedu section.

These genera are able to survive in wide ecological niches, but they are flourished in oligotrophic to mesotrophic zones in moderately shallow waters at coarse-grained substrate (Kondo *et al.,* 2005; Sato & Kamiya 2006).

The morphogroup no.3 includes genera *Krithe*, *Australoecia* and *Argilloecia*. These genera adapted to living at fine grained and moderately hard substrates in relatively deeper parts of the environment (Zhao & Whatley 1997; Sartori & Coimbra 2010).

The morphogroup no.4 includes only taxon *Euxinocythere quadricostata,* this species is reported from fresh to brackish and shallow waters from intermountain basins (Pipik & Bodergat 2004).

The morphogroup no. 5 consists only of genus *Costa*. This morphogroup is dominant at soft and fine grained substrate in nutrient rich and saline waters in moderately deeper parts of marine environments (Van den Bold, 1970; Dall'Antonia, 2003a, b).

The morphogroup no. 6 includes genera *Mutilus*, *Pokornyella*, *Procythereis*, *Buntonia* and *Aurila*.

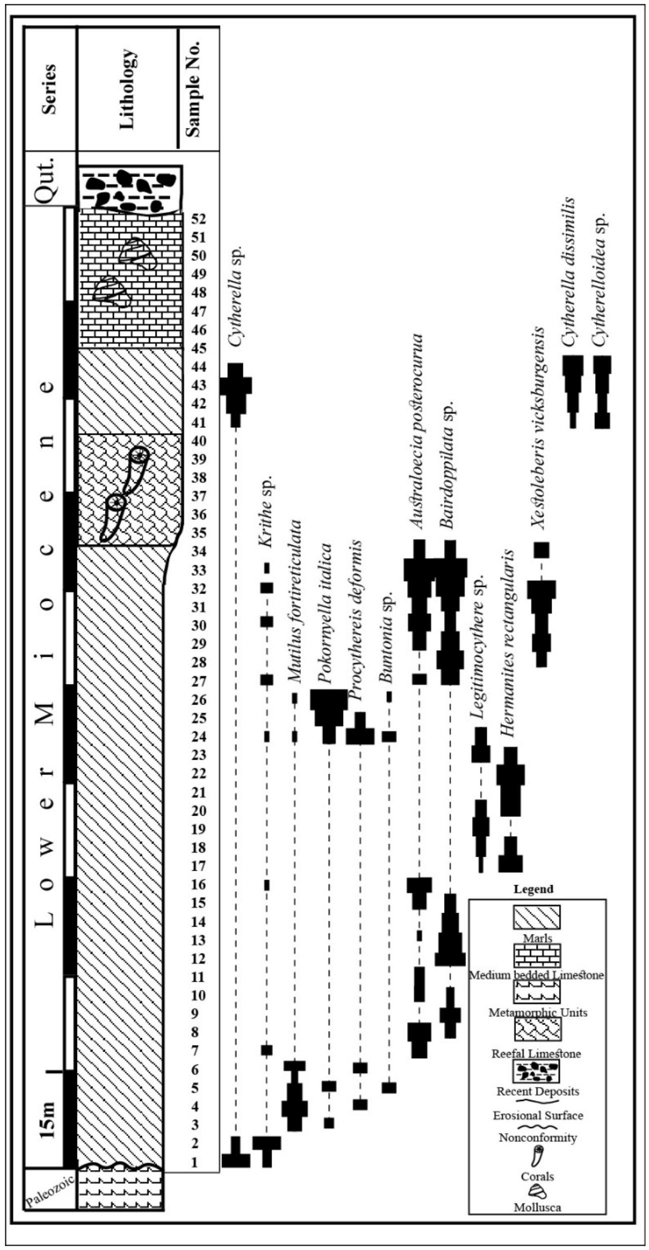

Figure 4. Stratigraphic column and range chart of the ostracoda in the Chahderaz section.

This morphogroup is common in the studied area and present in most of the samples. The individuals of this morphogroup flourish at soft, medium to coarse-grained substrates in the normal saline and nutrient rich environments, especially near and in the back of reefal environments (Van den Bold, 1967, 1972; Wouters, 1973; Bonaduce *et al.,* 1987). The morphogroup no. 7 consists essentially of genera *Actinocythereis*, *Acanthocythereis*, *Legitimocythere* and *Hermanites.* These taxa are common in various depths, but the substrate is the main ecological factor which affects their proliferation (Moore, 1961). These genera prefer to live at fine-grained, relatively hard and nutrient rich substrate in relatively deeper parts of marine environments (Khalaf, 1989; Ozawa and Kamiya, 2001; Mostafawi *et al.,* 2005; Yamada *et al.,* 2005).

Disscusion

In general, ostracodal biostratigraphy is not as much detailed as those based on foraminifera, due to their great sensitivity to ecological factors that control their distribution. However, based on some previous studies (Van Morkhoven, 1963; Bhatia, 1984; Khalaf, 1984; Pipík & Bodergat, 2004; Guernet, 2005; Ayress, 2006; Babinot *et al.,* 2007), the stratigraphic range of the identified ostracoda in the studied sections is summarized in Fig. 6.

The Lower Miocene strata in Kerman province have received many attentions in recent years and their benthonic foraminifera content has been studied in detail (Hosseinipour, 2004; Hassani, 2012; Mohammadi, 2014). The, studied sections show a low diversity fauna both in foraminifera and ostracod assemblages.

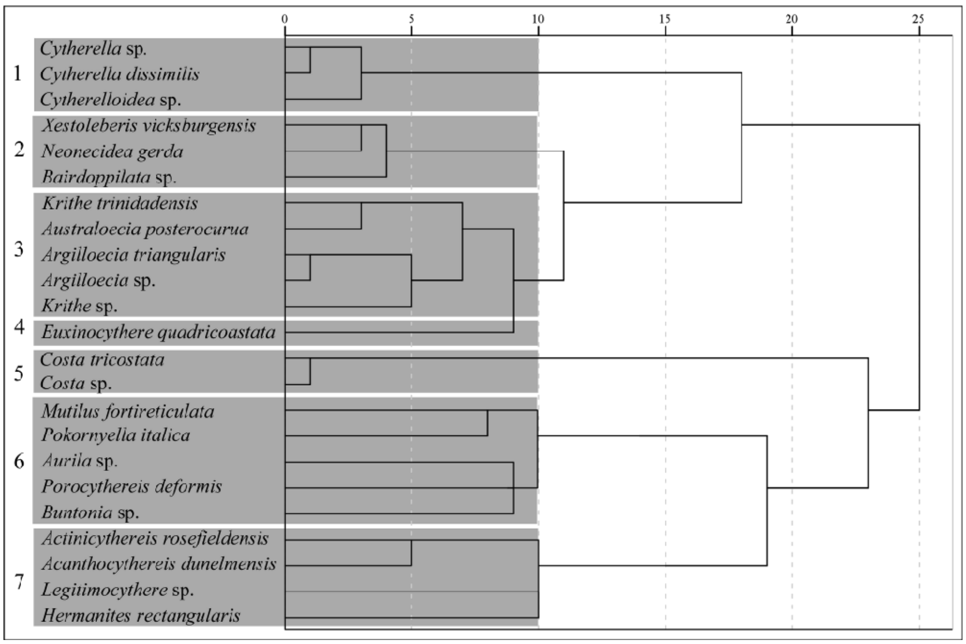

Figure 5. The cluster diagram resulted from R-mode analysis and identified morphogroups of recovered ostracoda.

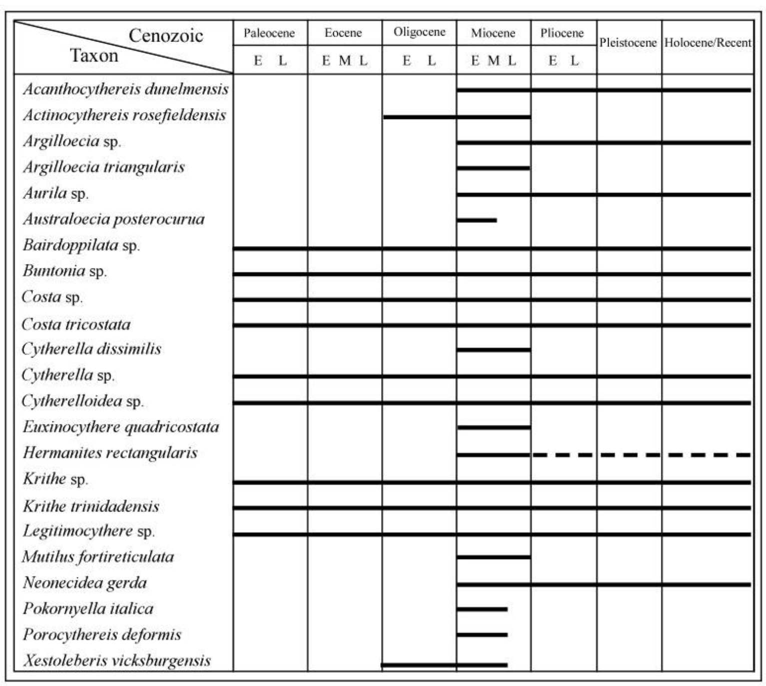

Figure 6. The stratigraphic distribution of the identified ostracoda.

Based on rare individuals of Early Miocene benthic foraminifera such as *Borelis pygmaea, Borelis melo curdica, Austrotrillina howchini, Rotalia viennoti, Miogypsina* spp.*, Miogypsinoides* spp. and *Elphidium* spp. a Lower Miocene age has been assigned to the studied sections.

The distribution of morphogroups, their fluctuations, and also simple diversity of ostracods through the Chahmedu section is shown in Fig. 7.

As it is shown, the basal part of this section only contains morphogroup no. 4. Therefore, it seems that in the initiating stage of basin evolution, fresh to brackish intermountain water bodies are formed by the intrusion of fresh and marine waters to the valleys in the northern parts of the Sirjan Basin. In the next step, the occurrence of the morphogroup 1 in the lower part of the section indicates the low ventilated waters. This condition is common, happens in almost all young shallow restricted basins, and indicates weak connection with oceanic waters (Kumar & Kumar-Saraswati, 1977). In the next step, the appearance of morphogroups no. 3, 5, 6 and7 indicates the deepening of the sedimentary basin and relatively normal marine condition, which is accompanied by the increase in faunal enrichment. In this part of the section, the coarse substrate is changed into relatively fine-grained sandy/muddy floor, several micro and macro-fauna occurred in the ecosystem and the trophic level is shifted to oligotrophic conditions. Several fossiliferous, benthic foraminifera bearing, argillaceous limestone intercalations are recorded in this part of the section. The high abundance of some larger benthic foraminifera (15-20 individuals per each thine section) such as large lepidocyclinidae, *Heterostegina* and *Operculina* confirms the depth increment and also oligotrophic conditions (BouDagher-Fadel, 2008). The next phase of the basin evolution characterized by the occurrence of a massive reefal limestone, this reefal limestone interval mainly consists of hermatypic scleractinian corals such as *Favites*, *Dichocoenia*, *Leptoria* and *Leptoseris*. This facies indicates a shallow basin with moderately warm and saline waters in subtropical altitude (Bosellini & Perrin, 2008). The reefal limestone interval topped with a thick marly interval, which is divided into two parts by a fossiliferous limestone horizon.

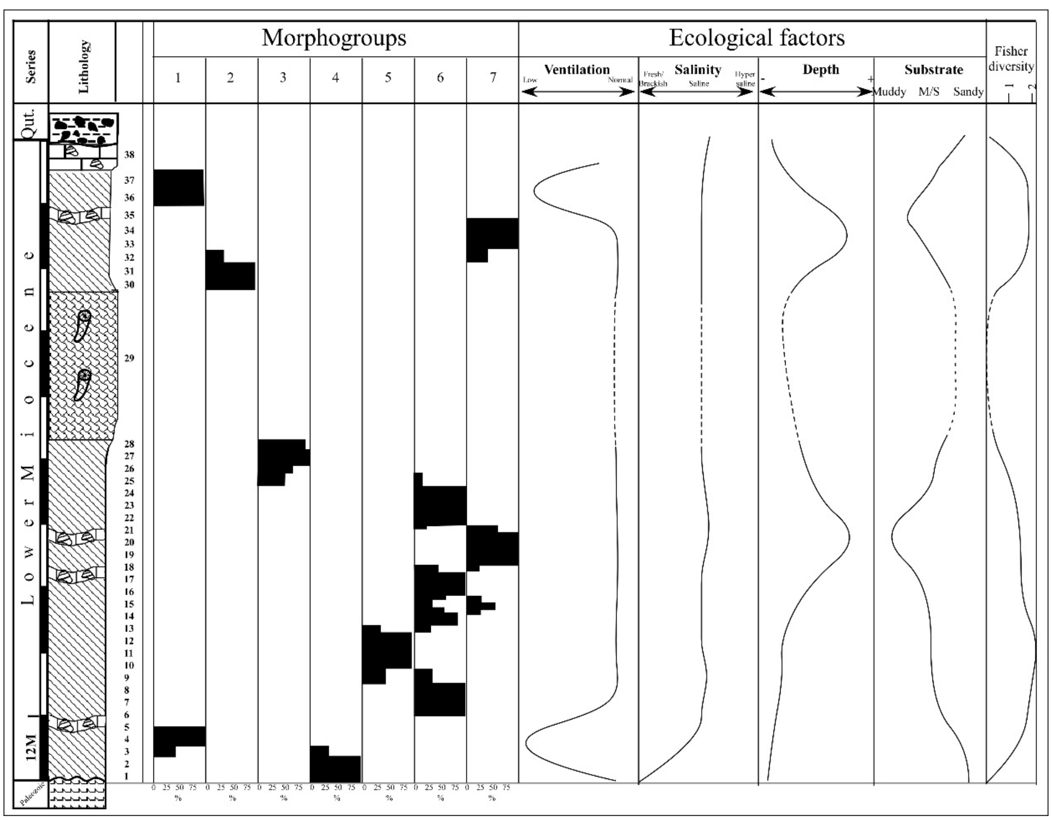

Figure 7. Distribution of morphogroups, ecological factors and diversity changes through the Chahmedu section.

The presence of morphogroups 2 and 7 in the lower part indicates the depth increment and increase in mud content in the substrate. The morphogroup 1, which is recorded in the upper part indicates weak ventilation. This condition may be caused by the sea level fall and probable disruption in basin connection to the oceanic waters. The Chahmedu section is topped with a thick limestone layer containing molluscan fauna, especially gastropods, and small intraclast particles. Introduced morphogroups, their distributional patterns and diversity fluctuations in Chahderaz section are shown in figure 8. In general, the lithology of the Chahderaz section is similar to Chahmedu section. The only differences between these two sections is that the Chahderaz section is topped with a relatively thick (≈22 m) fossiliferous limestone interval, while the final part in the Chahmedu section is thinner (≈ 4 m). Besides, the fossiliferous marly limestone intercalations which exist in Chahmedu section are absent in Chahderaz section.

Like the Chahmedu section, basal marly strata are deposited in poorly ventilated waters. , In the next step, the depth increased, the substrate changed into fine grain sandy to muddy floor, various morphogroups appeared and trophic level shifted to oligotrophic condition. The presence of morphogroup no. 1 in the upper marly strata indicates a poor ventilated basin. In the Chahderaz section, uppermost limestone strata contain large intraclasts and relatively large bivalve shells which indicates a relatively long lived, shallow near tidal zone environment with abnormal salinity and relatively muddy substrate prevailed at the end of the basin's life.

Conclusion

The Lower Miocene deposits in Sirjan area, in compare with southern realm of the Oligo-Miocene basin in the Kerman Province, are younger and deposited during the Early Miocene while in the southern realm, the basin was born in the Oligocene (Hassani, 2012; Mohammadi, 2014). On the other hand, in the Sirjan and adjacent areas, such as Balvard, Chahargonbad, Golegohar and Zardu, the Miocene marine strata are deposited on the Sanandaj – Sirjan Metamorphic Belt.

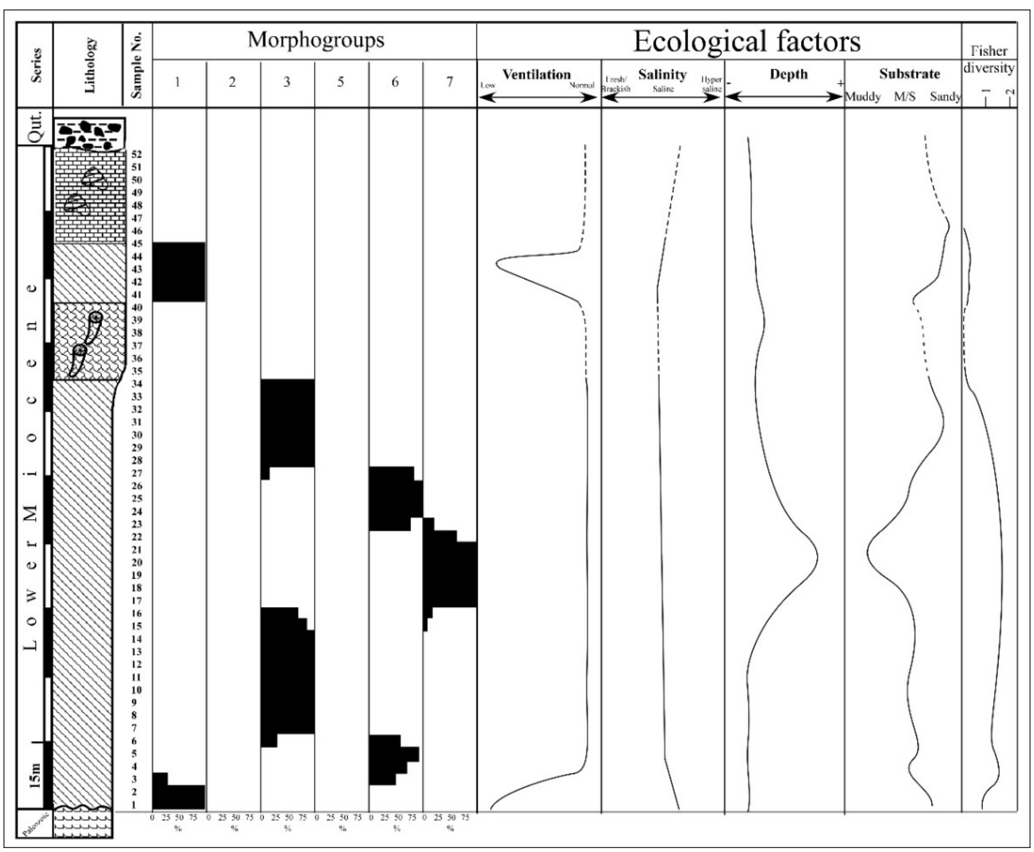

Figure 8. Distribution of morphogroups, ecological factors and diversity changes through the Chahderaz section.

This structural zone has been known as the most tectonically active zone of the Iranian plateau since the Late Paleozoic and affected by almost all of happened post Paleozoic structural events (Mohajjel *et al.,* 2003). During the Early Miocene, the vertical movements of active faults formed the main graben in the Sirjan region and the basin evolution is controlled by subsequent syndepositional activities of these faults. (Mohajjel *et al.,* 2003; Sarkarinejad *et al.,* 2008). As well as structural activities of the basement, the nature of the sedimentary environment affected by transporting sediments from the loose metamorphic rocks to the sea. This condition resulted in a harsh ecosystem that affected the aquatic communities (Westphal & Munnecke, 2003; Westphal, 2006). These instabilities were more common in the marginal parts than the central part of the Sirjan Basin (Hosseinipour, 2004; Hassani, 2012), therefore, the abundance and diversity of ostracoda in the studied sections (Figs. 7 & 8) are lower than central parts of the Sirjan and other southern adjacent areas (Torkzadeh *et al.,* 2011; Hassani, 2012). In comparison with other Tethyan and Indo-pacific realms, the ostracode community is less enriched (Guha, 1968; Dall'Antonia, 2003b; Irizuki *et al.,* 2004; Guernet, 2005; Irizuki *et al.,* 2009). It seems that the deposition of marly deposits in the basal parts of both sections resulted by the relatively rapid transfer of large amount of fine-grained terrigenous materials to the newborn shallow sedimentary environment. This situation resulted in a moderately stressful environment and the basin vacated from ecological sensitive creatures such as ostracods. On the other hand, vertical movements of faults may be responsible for the periodical restrictions by cutting the basin’s connections with the open marine parts. The presence of massive reefal limestone interval in the mid-life of the basin points to the stable marine condition, which followed by the next period of instabilities. The morphogroup no.1, presented in the second marl interval of both sections, which are the most resistant taxa indicates that an unfavorable ecological condition, especially low ventilation level was prevailed during the deposition of these strata. In this part, similar to basal parts, the lack of planktonic fauna and relatively coarse-grained substrate rejects deepening of the basin (Figs. 7 and 8). Furthermore, the presence of morphogroup no. 1 maybe points to the dominance of a harsh environment such as poor nutrient content and low transparency. This is a common feature on marginal mixed siliciclastic-carbonate platforms (Bassant *et al.,* 2005; Brandano *et al.,* 2009).

This condition is very sharp in the southern parts of the basin, the Chahderaz section, while in the northern realm, regarding the presence of morphogroups no. 2 and 7, it can be concluded that basal and middle parts of upper marl, are deposited in a relatively deeper waters than the southern realm. In these parts, the morphogroup no. 2 is recorded at the base, which is replaced by the morphogroup no. 7 upward. It seems that the increase in depth caused this replacement.

The depth increment is confirmed by the decrease of the substrate grain size in this part. Subsequent vertical movements disrupted the depth increment and a short period of stability, which is accompanied by the deposition of a thin layer of fossiliferous limestone, has been occurred. The upper part of the upper marl interval of Chahmedu section is quite similar to the upper marl interval of Chahderaz section. Both sections are terminated by a relatively dense fossiliferous limestone interval. Large-sized molluscan shells, along with coarse intraclasts and micritic matrix are the main characteristics of these strata (Fig. 9). Based on changes in the composition of ostracode community, it can be assumed that the depositional basin of the Lower Miocene deposits in both northern and southern flanks of the Sirjan Basin could be demonstrated as a relatively shallow marginal sea with prolonged branches in the valleys which is periodically separated from the oceanic waters by tectonically made buildups (Fig. 10).

In addition, it could be concluded that the distribution of ostracode morphogroups reflects several steps in the basin evolution history during the Early Miocene in the southern and northern margins of the Sirjan Basin. Each step is characterized by changes in depth, grain size and depth related ecological factors, which fundamentally effects the ostracode community.

These fluctuations in basin chrachtristics seems to be localal and limited to the studied sections, because during the Early Miocene, no such fluctuations in the oceanic characteristics have been reported from central parts of the Sirjan and other adjacent basins (Hosseinipour *et al.,* 2010; Torkzadeh *et al.,* 2011; Hassani, 2012; Mohammadi, 2014). Finally it could be concluded that the structural activities of the Sanandaj – Sirjan Metamorphic Belt, as the basement of studied sections, could be assumed as the main cause of the changes during the evolution of the basin.

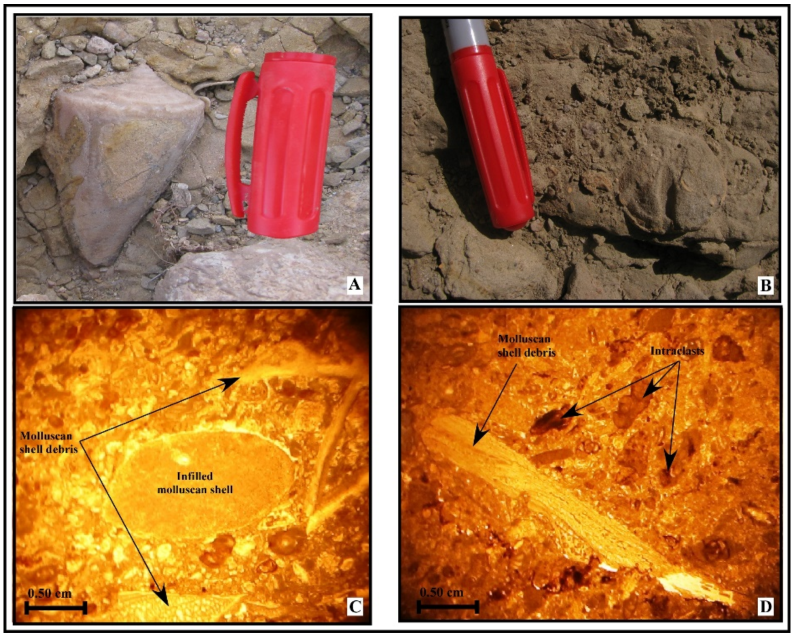

Figure 9. Outcrop exposure of a gastropod (A) and bivalves (B) in the uppermost limestone in the Chahmedu and Chahdreaz sections; C & D, Bioclastic wakestone with Mollusca shell debris, final limestone strata of C, Chahmedu Section, D, Chahderaz Section.

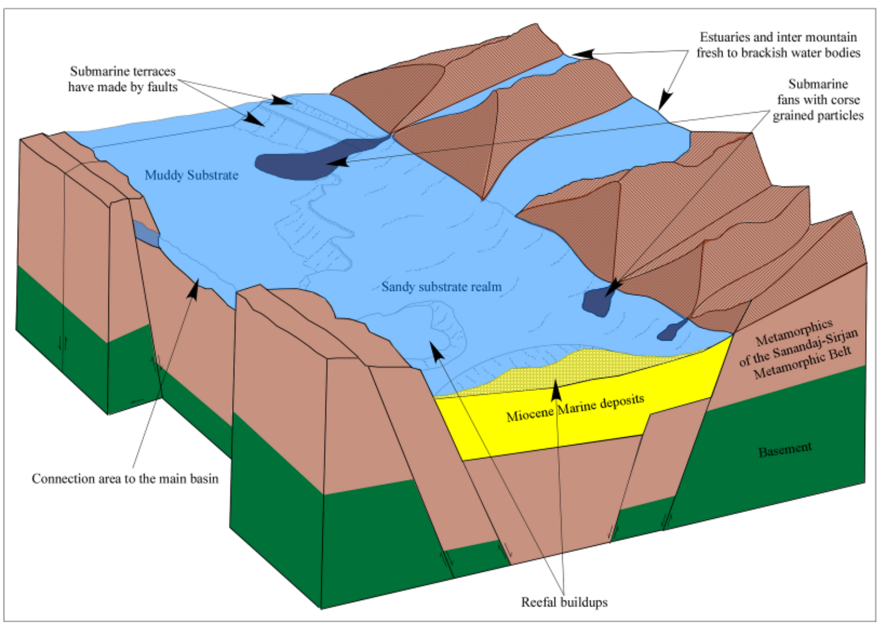

Figure 10. A conceptual block diagram of the marginal sea during the Lower Miocene in the northern and southern flanks of the Sirjan Basin.

Acknowledgments:

The Graduate University of Advanced Technology, project no. 7.394, supports this study. Special thanks to Dr. A. Lotfabad Arab (Shahid Bahonar Univ. of Kerman) for his valuable helps in identification of the fossils. Also, the authors express a deep sense of gratitude to Prof. N. Moeinzadeh (Kerman Institute of Higher Education) for his helps in taking ESM photography and editing the manuscript. Authors also thankful to reviewers for their valuable comments and advises.

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