

Planktonic Foraminifera of the Dariyan formation and implications of Oceanic Anoxic Event 1a

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Abstract

The investigated section cropping out in Kuh-e-Banesh, Zagros basin (southern Iran) is represented by limestone, Cherty beds and marl levels bearing abundant Planktonic foraminifers, radiolarian microfaunas, and ammonite imprints. For the first time, well to moderately preserved forms of Planktonic foraminifera have been extracted from black shale and marls levels. Extracted biota was studied with regard to relationship with abundances of radiolarian and total organic carbon. Rock Eval analysis shows high total organic carbon content within Dariyan Formation (lower part). The presence of high abundances of planktonic foraminifers and radiolarian associated with high total organic carbon content in the lower part of the Dariyan Formation suggest a high productivity event, eutrophication, and warming phenomena of the ocean during early Cretaceous. Biostratigraphical ranges of planktonic foraminifera in the studied section indicate Early Aptian to early Late Aptian age. It is, therefore, implicated that the oceanic anoxic event 1a (OAE 1a) interval be regarded as equivalent levels in Tethys domains. The black shale of oceanic anoxic event is characterized by the widespread existence of regionally organic-rich beds in the Tethys basins. Micro-paleontological and geochemical results provide new insights into the paleogeography of the Tethys realm and better correlation with well-studied worldwide successions.

Keywords: Aptian, Dariyan Formation, Iran, Planktonic Foraminifera, Total Organic Carbon.

Introduction

The lower and middle parts of the Dariyan Formation are represented by pelagic sequences and constituted by limestone, cherty beds, black shale and marls that yielded radiolarian records and planktonic foraminifers. Planktonic foraminifers are marine protista that have excellent geological record characterized by diversity of morphology (Premoli Silva *et al.*, 1999; Moullade *et al.*, 2002). Due to the abundances of Planktonic foraminifers in Cretaceous and their rapid evolution, they are significant in biostratigraphical and paleoceanographical studies in marine deposits (Premoli Silva *et al.*, 1999; Leckie *et al.*, 2002; Moullade *et al.*, 2002). In general, the Aptian appears as the significant period of radiation among planktonic foraminifers (Moullade *et al.*, 2002). Moreover, radiolarian blooming is interpreted as the signature of two global oceanic anoxic events (OAE1 and OAE2) (Talbi, 1991; Danelian *et al.*, 2007; Heldt *et al.*, 2008; Robaszynski *et al.*, 2010; Ben Fadhel *et al.*, 2011, 2014).

The good exposure of the deposits (60m) provides an excellent opportunity to study well-preserved specimens of microfossils, required for the age calibration of Kuh-e Banesh outcrop. The

age of the Dariyan Formation in the type section was established as lower Aptian to middle Albian based on benthic foraminifera within thin sections (James & Wynd, 1965). The lower part of middle Dariyan Formation had been studied in other sections in Fars area, Zagros basin. It corresponds to Gargasian based on the presence of *Globigerinelloides ferrolensis* Zone (Hosseini & Conrad, 2010). Dariyan Formation was deposited in a homoclinal ramp to intra shelf basin environment in the northeastern part of Arabian plate (Van Buchem, 2010). The top of Dariyan Formation, associated with a few iron oxide nodules, is indicative of shallow water conditions (Mojab, 1974; Van Buchem, 2010), the presence of discontinuity and erosional surface (James and Wynd, 1965), and Type I sequence boundary (Van Buchem, 2010).

This study focuses on the litho-biostratigraphy and bioevents of Aptian successions outcropping in Kuh-e Banesh, southern Iran (Fig. 1). The main goal of this study is to give new illustrations of planktonic foraminifers recovered from pelagic deposits of Dariyan Formation. The conclusion of this research led to the establishment of a direct age of these sequences using planktonic foraminifers'

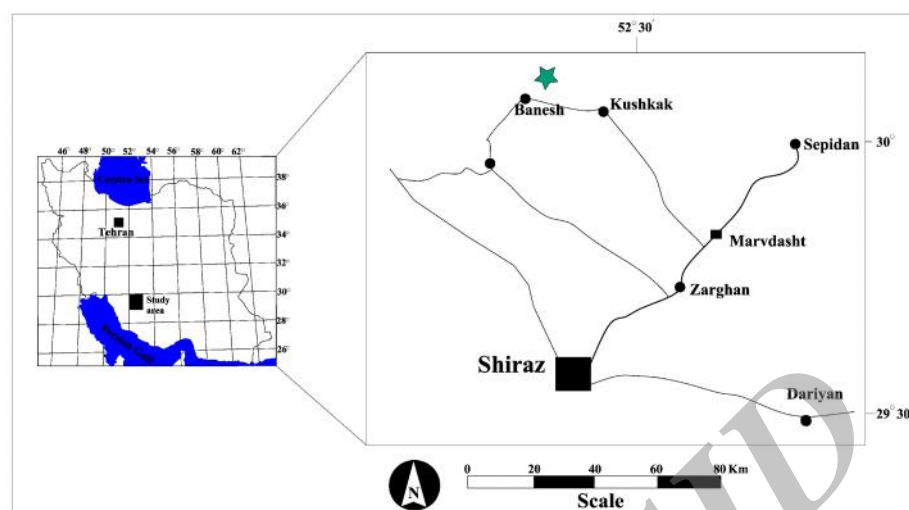


Figure 1. Location of the study area

assemblages. We also attempt to constrain the timing of black shale deposition and correlation with equivalent black shale levels recorded in the Tethys basins.

Geological Setting

The opening of the NW-SE trending Neo-Tethys Ocean in the Permo-Triassic separated the Arabian plate to southwest from the Iranian plate to the northeast. During this period, a considerable volume of sediments, dominantly marine carbonates and evaporations were deposited in the Zagros, and volcanic sedimentary units were deposited to the northeast of the present Zagros Main Thrust Fault (Berberian & King, 1981). Following the Permo-Triassic rifting episode, passive margin sediments in the Zagros basin continued to develop above or in the shoulder of the rifted continental margin. (Setudehnia, 1978).

The general tectonic framework of the Zagros Folded Belt Zone was defined by major thrust folds (fronts) which are parallel to the Belt (the High Zagros and the Mountain Front Faults) (Sepehr & Cosgrove, 2004). The high Zagros fault divides the Zagros basin into two major belt parallel structural zones known as the imbricated belt or Zagros Thrust Belt (on the intensely deformed zone) to the northeast, and the folded or simply folded belt (Fig. 2; Sepehr & Cosgrove, 2004).

The studied section cropping out in the Kuh-e-Banesh is located in the south of Iran, at: $52^{\circ} 25' 57''$ longitude and $30^{\circ} 8' 59''$ latitude (Fig. 1).

The Dariyan Formation is characterized by a Carbonate reservoir in the Zagros basin (Van

Buchem *et al.*, 2010). It overlies the Gadvan Formation conformably and is overlain unconformably by Kazhdumi Formation whose upper part is outlined by a few iron oxide nodules. This phenomenon indicates shallow water conditions (Mojab, 1974; Van Buchem, 2010) corresponding to type I sequence boundary (Van Buchem, 2010). In the studied area, the Dariyan Formation has a thickness of 275 m and can be divided into three members that are as follows: Lower Dariyan, Middle Dariyan and Upper Dariyan (Fig. 3). The Lower Dariyan is about 25 m thick and consists of thick to medium-bedded limestone bearing benthic fossils which are dominantly bivalves; most of the upper part of Lower Dariyan contains thin bedded limestone, black shale, and black cherty beds bearing abundant radiolarian, ammonite imprints, and relatively abundant planktonic foraminifera (Fig. 3). Black shale and cherty beds are good level markers in the uppermost sections of the lower part of Dariyan Formation. The thicknesses of cherty beds are about 10 cm and limestone beds are 30-50 cm thick. The middle part of Dariyan Formation is the so-called Kazhdumi Tongue (James & Wynd, 1965). This part consists of 40 m thick yellow to greenish grey shale and marl levels associated with high abundance of planktonic foraminifers (Fig. 3), especially Hedbergellids.

The upper Dariyan Formation is composed of 208 m of buff to grey medium, Orbitolina-rich thick bedded limestone (Fig. 3), and echinoderms grading upward into iron oxide in the surface of beds

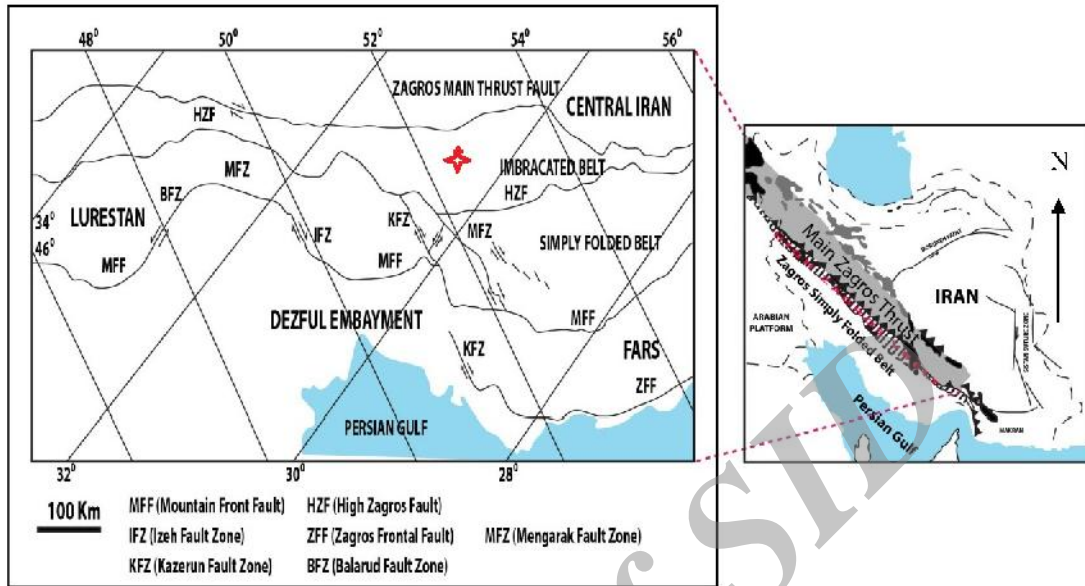


Figure 2. Structural subdivisions of the Zagros basin (Sepehr & Cosgrove 2004) and location of the study area

Figure 3. Lithostratigraphic of the Dariyan Formation. a) Radiolarian beds bearing ammonite imprint. b) Thin bedded black shale containing abundant radiolarian and planktonic foraminifera. c) Thick bedded Orbitolina limestone of the upper Dariyan Formation d) Thin section showing radiolarian and organic-rich packstone. Scale bar: 500µm e) Thin section showing Planktonic foraminifera in transmitted light microscope. Scale bar: 200µm f) Thin section showing micritized Orbitolina grainstone. Scale bar: 2mm

Methods

In this study, 60 samples were collected and 51 thin sections were prepared. 9 samples from the softer layers including shale, marls and calcareous marl levels were washed according to standard techniques (soaked in diluted acetic acid for 24 hours) sieved through $>100\mu\text{m}$ $>60\mu\text{m}$ meshes and observed under a binocular microscope; the harder calcareous lithotypes were investigated in thin sections using a transmitted light microscope. Specimens which were washed after preparation and coated by gold have been photographed using a Scanning Electronic Microscope (SEM). The scanning electronic microscopic methods create much greater magnification, and it was used for studying the wall structure as well as the external morphology of the collected specimens.

For Rock-Eval Analysis, each sample (0.1 gr bulk) powder was prepared and heated during Helium atmosphere conditions during three minutes. The Rock-Eval pyrolysis parameters (total organic carbon and quantity of free hydrocarbons) content were calculated by the apparatus of National Iranian Oil Company.

In this study, the numbers of specimens extracted from different layers are variable. Many planktonic foraminifera sampled from the radiolarian levels are moderately preserved and the calcite constituting the test wall is replaced by silica. The stratigraphic ranges of small chambered trochospiral and planispiral morphotypes were determined. All samples are deposited again in the collection of the exploration directorate, National Iranian Oil Company.

Biostratigraphy

Several samples from the lower and middle part of the Dariyan Formation were investigated to determine age-dignostic planktonic foraminifer's assemblage. The specimens were covered from black shale and marl levels interval containing moderate to well-preserved planktonic foraminifera. The assigned genus of planktonic foraminifera is as: *Hedbergella* and a few specimens of the genus *Globigerinelloides*. The recovered foraminifers are: *Hedbergella infracretacea*, *Hedbergella aptiana*, *Hedbergella primare*, *Hedbergella gorbachika*, *Hedbergella* cf. *globulifer*, *Hedbergella* cf. *sigali*, *Hedbergella luterbacheri*, *Hedbergella duboisi*,

Globigerinelloides duboisi sigali?, *Globigerinelloides aptiensis* (Figs. 4, 5).

The size of the recovered species is very small (less than $100\mu\text{m}$) and they have no more than six chambers. Relating to the stratigraphical range, *Hedbergella luterbacheri* is considered to be as a marker species of first appearance within the Bedoulian/Gargasian Boundary (Moullade et al., 2002). Moreover, concerning the bioevent record, this interval is characterized by the simultaneous appearance of two morphotypes, first *Hedbergella luterbacheri* and then *Globigerinelloides ferrolensis* (Moullade et al., 2002). Besides, in the *Globigerinelloides blowi* Zone, some species were visible in the lower part including *Globigerinelloides duboisi* and some others, e.g., *Hedbergella primare* and *Globigerinelloides aptiensis* which occurred with long range within this zone (Premoli Silva and Verga, 2004). The Aptian planktic foraminifers' zonal scheme and subdivisions show that the planktonic foraminifers are represented by 7 species or more chambers including *Globigerinelloides ferrolensis* which appears in the middle part of *Leopoldina cabri* Zone (Premoli Silva & verga, 2004). Therefore, taking into consideration the appearance of *Hedbergella luterbacheri* within the E sample and the absence of six or more chambers of planktonic foraminifers in the upper part, deposits of the lower part of the E sample and level can be no younger than lowermost Gargasian. To conclude, the studied assemblage can be assigned to the late early Aptian (Bedoulian)- early late Aptian (Lowermost Gargasian) time interval. Based on the high abundance of specific species and bioevents of planktic foraminifera (Fig. 6), however, further research should be done to fix a reliable zonation because of the sporadic occurrence of the specimens known throughout this interval.

Discussion

The Early to Middle Cretaceous time interval is characterized by greenhouse conditions (climate system) and major global changes in the oceans. Oceanic crustal production and submarine volcanism acted at that time (Sclanger & Jenkeys, 1976; Larson & Erba, 1999; Leckie et al., 2002).

The first globally distributed Oceanic Anoxic Event in the Cretaceous is OAE 1a, regarded as a major turning point in palaeoceanographic changes

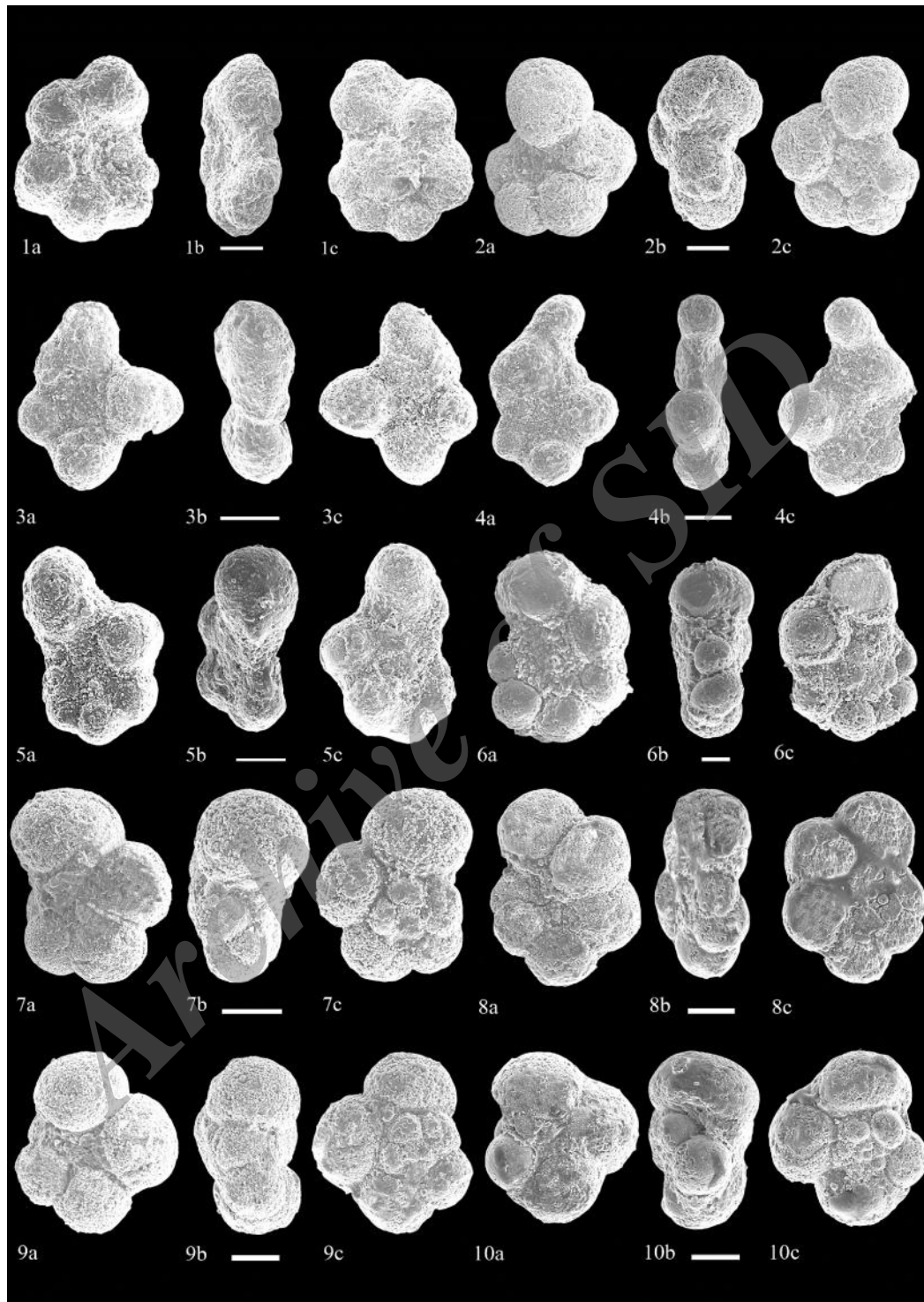


Figure 4. 1, 2, 3, *Hedbergella infracretacea*; 4, 5, 6, *Hedbergella primare*; 7, 8, *Hedbergella lagorbachika*; 9, 10, *Hedbergella aptiana*

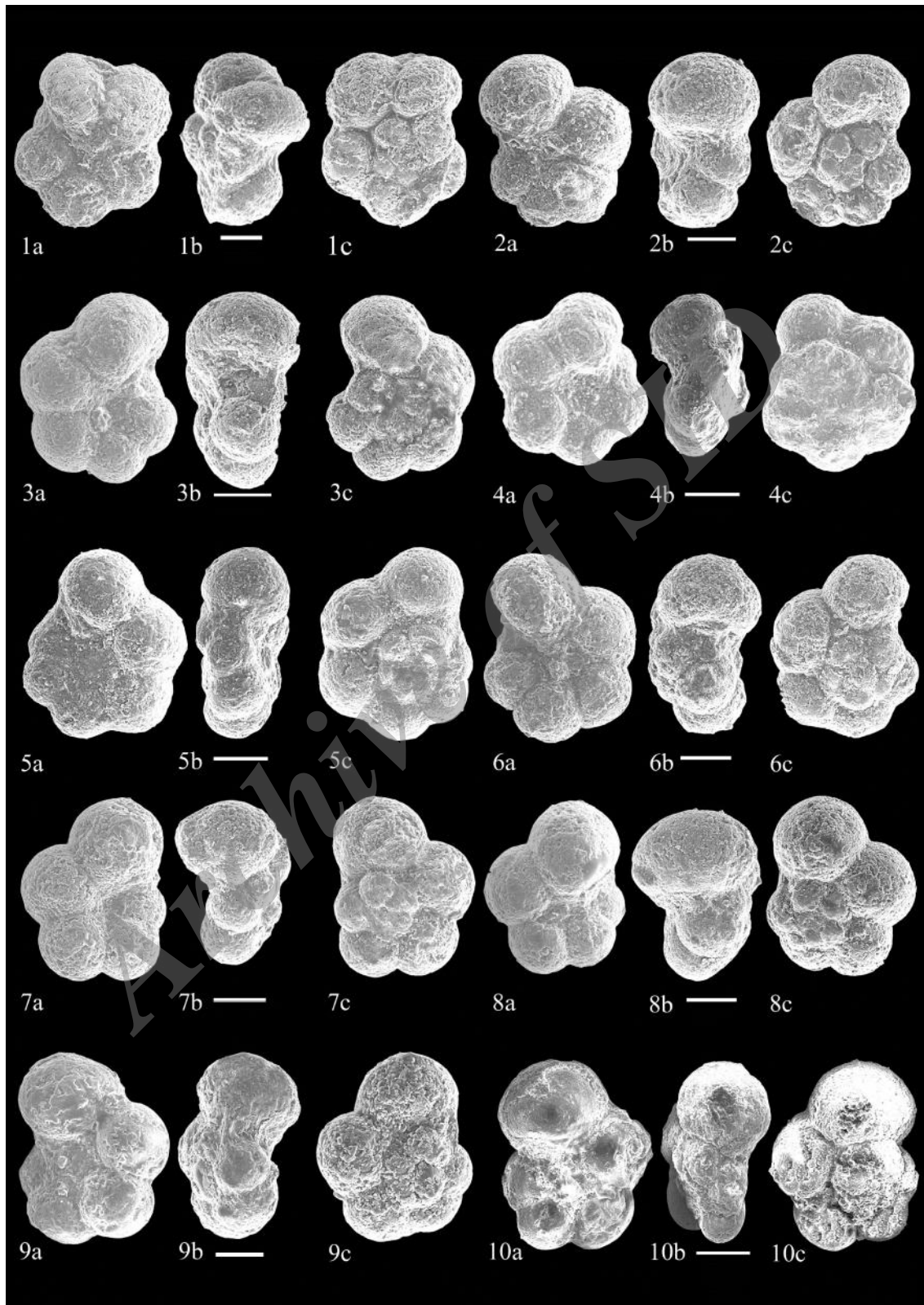


Figure 5. 1, *Hedbergella luterbacheri*; 2, *Hedbergella* cf. *globulifera*; 3, *Hedbergella duboisi*; 4, 5, *Globigerinelloides duboisi sigali*? 6, *Globigerinollides aptiensis*; 7, 8, *Hedbergella aptiana*; 9, 10, *Hedbergella* cf. *sigali*

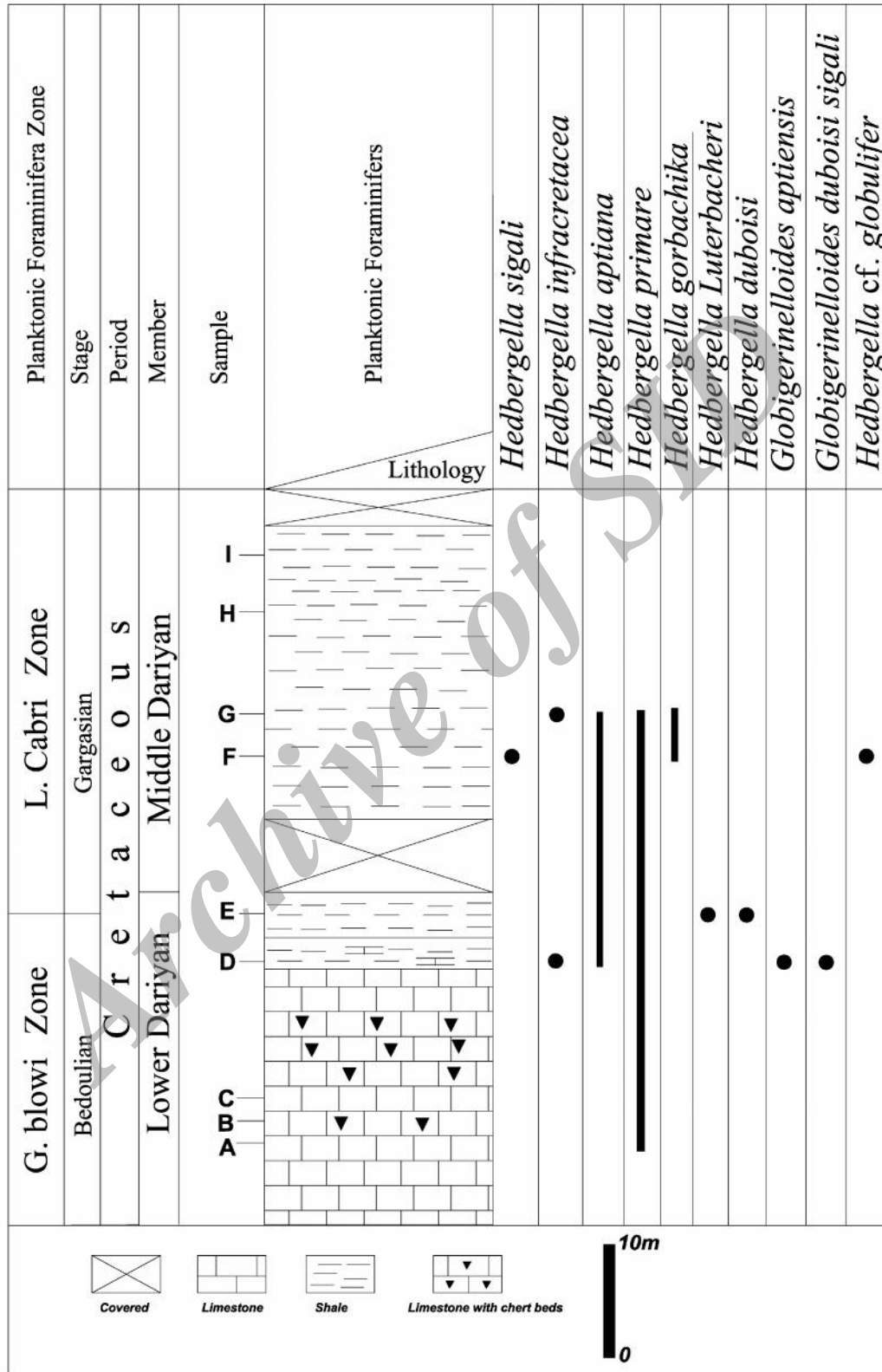


Figure 6. Succession of planktonic foraminifera assemblage of the Dariyan Formation in Kuh-e Banesh

(Leckie *et al.*, 2002). It is characterized by high marine productivity, a sea level rise, significant changes in marine biota, increased burial of organic matter, and dysoxic or anoxic conditions in deep marine bottom waters (Erbacher *et al.*, 1996; Jenkeys, 1999; Erba, 2004; Danelian *et al.*, 2007; Ben Fadhel, 2010; Moosavizadeh *et al.*, 2014). The concentration of CO₂ due to submarine volcanism during early to middle Cretaceous resulted in the depletion of oxygen and, as a consequence, considerable changes occurred in marine fauna especially planktonic foraminifers (Coccioni *et al.*, 2006). It has been suggested that low oxygen conditions indicate various morphology changes in marine fauna especially planktonic foraminifers, e.g., the elongation of final chambers (Premoli Silva & Slitter, 1999; Leckie *et al.*, 2002; Ezampanah, 2013). Under climate conditions of decreasing Oxygen and concentration of CO₂ which was mentioned previously. In other words, the ecosystem has also been involved in high marine productivity and the abundance of planktonic foraminifera, and radiolarians lead to important run off, high nutrient input, and ocean eutrophication (Arthur *et al.*, 1990; Menegatti *et al.*, 1998; Moosavizadeh *et al.*, 2014).

Normal marine deposition in the early Aptian was interrupted by an episode of ocean-wide dyoxic/anoxic event (Bralower *et al.*, 1994). OAE 1a has been recognized worldwide in many different environments (Mengatti *et al.*, 1998; Danelian *et al.*, 2007; Gorin *et al.*, 2009; Najarro *et al.*, 2011; Quijano *et al.*, 2012). This event is recorded by the occurrence of organic carbon-rich beds recognized from sections in Tethyan realm (Bralower *et al.*, 1994). Geochemical analysis in Dariyan Formation shows that total organic carbon (TOC) varies from 0.4 to 1.92 percent which is evidence of oceanic anoxic event in Kuh-e Banesh (OAE 1a or Selli level). The integration of the ¹³C isotope records of Dariyan Formation provides the characteristic features of the oceanic anoxic events (OAE) 1a interval (Moosavizadeh *et al.*, 2014). The abundance of planktonic foraminifers with low and elongated chambers and high abundant radiolarian indicate that Dariyan Formation (lower part) was deposited in the basin environment and low oxygen conditions. Different factors including planktonic foraminifera, radiolarian, high total organic carbon and previously published ¹³C record (Moosavizadeh *et al.*, 2014) provide

paleoenvironmental interpretations of oceanic anoxic event 1a (OAE 1a) in High Zagros basin, southern Iran.

Verga and Premoli Silva (2003) and Hu *et al.* (2013) noted that OAE 1a is confined to the *Globigerinelloides blowi* zone. Erba (2004) and Huck *et al.* (2010, 2011) believed that OAE 1a occurs in the *leupoldina cabri* Zone. For maintaining the original definition of oceanic anoxic event, the zone was extended down and comprised of OAE1a (Erba *et al.*, 1999; Premoli Silva *et al.*, 1999). This event corresponds to the transition zone between *Globigerinelloides blowi* Zone and *leupoldina cabri* Zone (Moullade *et al.*, 2002; Garziano, 2013). Quijano *et al.* (2012) proposed that in the Selli event, the biozonation of planktonic foraminifera varies from *Gelobigerinelloides blowi* Zone to *Globigerinelloides algerianus* Zone.

According to the stratigraphical range of planktic foraminifera assemblages of Dariyan Formation, the OAE 1a lies between *Globigerinelloides blowi* and *leupoldina cabri* Zones which coincides with the topmost Bedoulian–lowermost Gargasian (Figs. 6, 7). The stratigraphic column consists of siliceous limestone, cherty beds bearing abundant radiolarian, ammonite, and a few planktonic foraminifera. Facies and fauna with the base of E sample and level represent changes in bathymetry, deposition environment, decreasing abundance of radiolarian, and changes in the morphology of planktonic foraminifera. Based on geochemical analysis, the amount of total organic carbon is enhanced to 1.92 (Fig. 7). Studying high organic matter, low oxygen in black shale, and cherty limestone levels in the area resulted in a decrease of atmospheric carbon dioxide (Gorin *et al.*, 2009). Many authors have postulated the proximity between organic matter and radiolarian in the Atlantic and Tethyan realm (Erbacher & Thurow, 1998; Danelian *et al.*, 2004, 2007; Ben Fadhel, 2011). All planktonic foraminifers in the lower part of Dariyan Formation have less than 6 chambers and some fauna have elongated chambers (Figs. 4 and 5). There is highly abundant radiolarian associated with planktonic foraminifers and ammonites in the lower part of the Dariyan Formation, but in the upper part the abundance of radiolarian and organic matter decreased and ammonites nearly disappeared; however, the planktonic foraminifers ratio increased. Enhanced

organic matter in the Tethyan domain is thought to involve a different process. One of them is based on the predominance of strong thermohaline stratification (deep, warm, saline waters or freshwater surface input) associated with low rates of deepwater turnover and surface productivity (Brass *et al.*, 1982; Bralower and Thierstein, 1984; Erbacher *et al.*, 2001; Hemiofer *et al.*, 2006).

The other refers to high surface ocean fertility and primary production with an intensified deep and intermediate water circulation (Hochuli *et al.*, 1999). The third proposition is that concentration of

organic matter is essentially benthic microbial mats, regardless of whether anoxia originates from surface productivity or restricted circulation in the basin (Gorin *et al.*, 2009). With regard to the increase of radiolarian abundance, planktonic foraminifers and high total organic carbon indicate high productivity and deep water circulation; however, changes of ratio of radiolarian abundance and planktonic foraminifera in each of the layers represent changes of environment temperature and fluctuations of sea level.

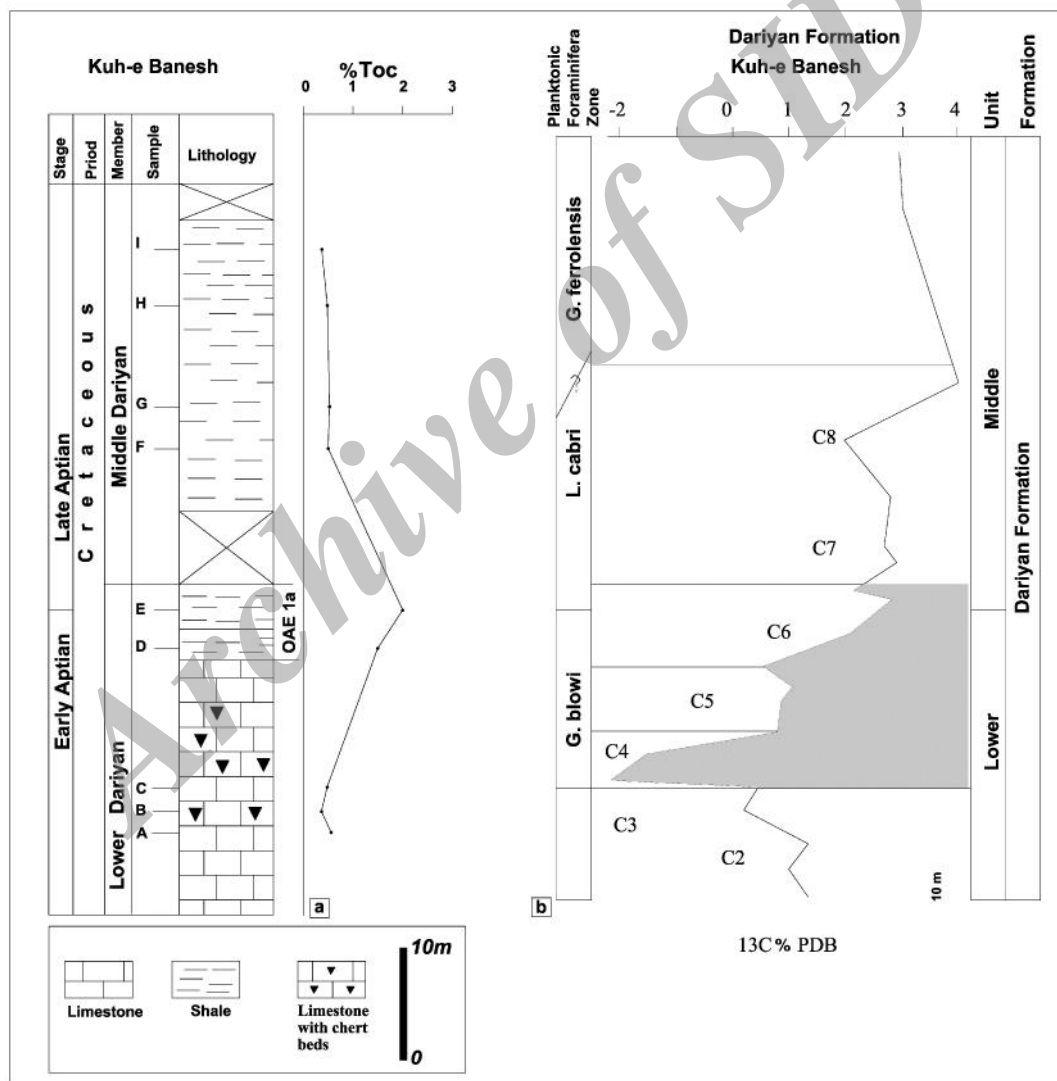


Figure 7. Lithologies, total organic carbon, isotope stratigraphy of the early Aptian in Kuh-e Banesh section a) Rock-Eval analysis data. b) Isotope stratigraphy in Kuh-e Banesh section (modified after Moosavizadeh *et al.*, 2014)

In the Dariyan Formation (middle part), the morphology of planktonic foraminifera has been changed. In addition, the appearance of morphotypes with 6 chambers, i.e., *Hedbergella luterbacheri* and the absence of elongated chambers may indicate changes of ecological settings and bioevents. In fact, the lower part of Dariyan Formation shows the high abundance of radiolarian associated with Planktic foraminifer specimens bearing less than six chambers and high contents of organic carbon can implicate the zone of oceanic anoxic event 1a. With regard to oceanic anoxic event 1a zone, it has occurred mainly in early to late Aptian time interval (Bralower et al., 1993; Erba, 1999, 2004). OAE 1a within Dariyan Formation represents the topmost Bedoulian-lowermost Gargasian age (Fig. 7). Based on $\delta^{13}\text{C}$ stable isotope analysis, the Dariyan Formation records have been correlated with others from worldwide sections (Fig. 8) and indicated the timing of the deposition of black shale levels (Moosavizadeh et al., 2014). The correlation of sections from different geodynamic and tectonics contexts indicates different biozonations of planktonic foraminifers from *Globigerinelloides blowi* Zone to *Globigerinelloides algerianus* Zone (Quijano et al., 2012). Although C-isotope stratigraphy can be correlated to other parts of the

world, as can be seen from figure 6 the timing of deposition of organic-rich sediments is not coeval (e.g. Jenkeys et al., 2010; Fig. 8).

Changes in ocean circulation of water column stratification and nutrient partitioning led to the recognition of plankton community structure and the widespread existence of carbonate deposition during the late Cretaceous (Leckie et al., 2002). Fluctuations in primary productivity affected composition and abundance of pelagic fauna (Premoli Silva et al., 1999; Leckie et al., 2002; Moullade et al., 2002). In the investigated section, reductions of radiolarians were associated with increasing planktonic foraminifers and vice versa. It seems that these bioevents correspond to fluctuations, changes of fertility and their habits, and ecological conditions. These factors lead to the appearance of opportunistic taxa.

In the studied samples, planktic foraminifer specimens are mostly composed of Hedbergellids and a few Globigerinelloides. Among planktonic foraminifers the Hedbergellids seem to indicate a more eutrophic habitat than the Globigerinelloides (Coccioni et al., 1992). Anoxic events may have caused mass extinctions both in the Paleozoic and Mesozoic (Wignall et al., 1996; Meyer, 2008) and it probably led to the survival of some taxa, e.g., Hedbergellids.

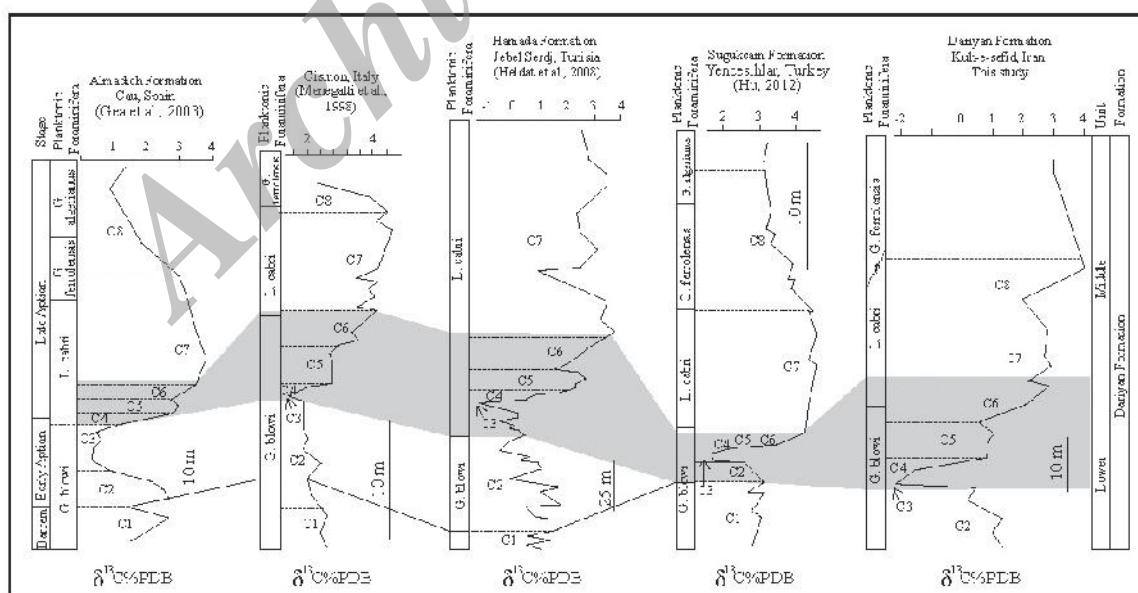


Figure 8. Chemostratigraphy correlation of stable carbon isotopes from Dariyan Formation outcropping in Kuh-e Banesh area (modified after Moosavizadeh, et al., 2014), with the Yencesihlar section, Turkey (Hu et al., 2012), Jebel serdj section (Heldt et al., 2008), Cison section, Italy (Menegatti et al., 1998), and Cau section, Spain (De Gea et al., 2003)

Conclusion

For the first time, we carried out an integrated biostratigraphical, lithostratigraphical, and geochemical investigation to elucidate the relationships between the amount of organic matter and planktonic foraminifera diversity in the studied area. Besides, planktonic foraminifera recovered from Kuh-e Banesh section have been studied and illustrated by Scanning Electronic Microscopy (SEM) method.

The specimens associated with black shale and marls contained moderate to well-preserved age-diagnostic planktonic foraminifera. The planktonic foraminifer's assemblages can be dated to late early Aptian (Bedoulian) to early late Aptian (Lowermost Gargasian) time interval. Ecological data out of planktonic foraminifera as well as its relationship with radiolarians and geochemical data revealed an epipelagic setting of open-shelf water paleoenvironment for the studied section.

Based on age diagnostics, it was revealed that the recovered planktonic foraminifera and TOC content allow to constrain the uppermost part of the Dariyan Formation lower part to the Early Aptian which can be correlated to the OAE 1a (Selli event) recorded in Tethyan domains. The strong relationship between abundances of planktonic foraminifera, radiolarian, and TOC indicates high

productivity during deposition of black shale levels. Radiolarian and planktonic foraminifera abundance variations are simultaneously in relationship with nutrient input and the spreading of oxygen minimum zone that represent the changes of environment temperature and the fluctuations of sea level at that time interval. Although further studies on planktonic foraminifera assemblages and their relationship with organic matter and abundances of radiolarian in the Zagros Basin are required, this study provides new insights into the paleogeography of Southern Tethyan realms during the Early Cretaceous.

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