Barremian to aptian radiolarian from southwestern Iran (Dariyan Formation), Zagros basin: paleoecological implications

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For the first time, moderate preserved radiolarian fauna were recovered from early Cretaceous (Dariyan Formation) cherty beds and black shales successions outcropping at Kuh-e Banesh located in high Zagros belt, southwestern Iran. Radiolarian assemblages were recovered from the lower part of Daryian Formation are described and assigned Late Barremian to Early late Aptian time interval. This study provides palaeoenvironmental interpretations of radiolarian and relationship between distribution abundance of radiolarian and calcareous planktonic foraminifera. The high abundance of radiolarian, chert beds and presence of scarce planktonic foraminifera suggest carbonate deposition under shoaling of the CCD or unfavourable conditions. Radiolarian blooms and organic-rich black shales indicate high productivity, eutrophic conditions, and regarding to age diagnostic radiolarian assemblages possibly correlate to Oceanic Anoxic Event 1a (OAE 1a). The formation of black shales with radiolarian within carbonate platform was resulted by Aptian tectonic activities in Zagros basin. The depositional trend of the Dariyan Formation represents three stages. The stage 1 and 3are defined by similar conditions that characterised by Orbitolina limestone. The stage 2 consists of radiolarian beds and marls with planktonic foraminifera that indicate abruptly deepening on the shallow water carbonates.

***Keywords**: Zagros, Aptian, Dariyan Formation, Radiolarian, Planktonic Foraminifera*

Introduction

The Dariyan Formation is mostly known to have a potential carbonate reservoir in Zagros basin (van Buchem et al., 2010). Its lower part conformably overlies the Gadvan Formation and its upper part overlain by Kazdumi Formation contains marl with intercalations of limestone levels.The top of Dariyan Formationis associated with a few iron oxide nodules indicative of shallow water conditions and subaerial exposure, (Mojab 1974, van Buchem et al., 2010). In many sections, radiolarian assemblages in chert beds are so abundant that is proposed as a radiolarite horizon, so-called Radiolarian Flood Zone, (James and Wynd 1965, Moosavizadeh et al., 2014, 2015). The Dariyan Formation deposited in a homoclinal ramp to theintrashelf basin environment in the northeastern of Arabian plate (van Buchem et al., 2010, Khoshfam et al., 2016). The integration of the 13C stable isotope from the Dariyan Formation at the Kuh-e Banesh provides characteristic features of the oceanic anoxic event (OAE) 1a interval (Moosavizadeh et al., 2014). Some Aptian sections have been studied in Fars area of the Zagros fold-thrust belt and are dated Gargasian based on Globigerinelloides ferrolensis Zone (Hosseini and Conrad 2010). The investigations of isolated planktonic foraminifera of the lower part of Dariyan Formation assigned early Aptian to early late Aptian to be regarded as anequivalent level of oceanic anoxic event 1a (Yavari et al., 2015).

We conducted field work at Kuh-e Banesh area, north of Shiraz, southern Iran (Fig.1) to investigate lithostratigraphy and biostratigraphy of the Dariyan Formation and their relationship with palaeoecological factors. This study area is tectonically situated in the northern Tethyan, southeastern Arabian plate (Fig. 2).

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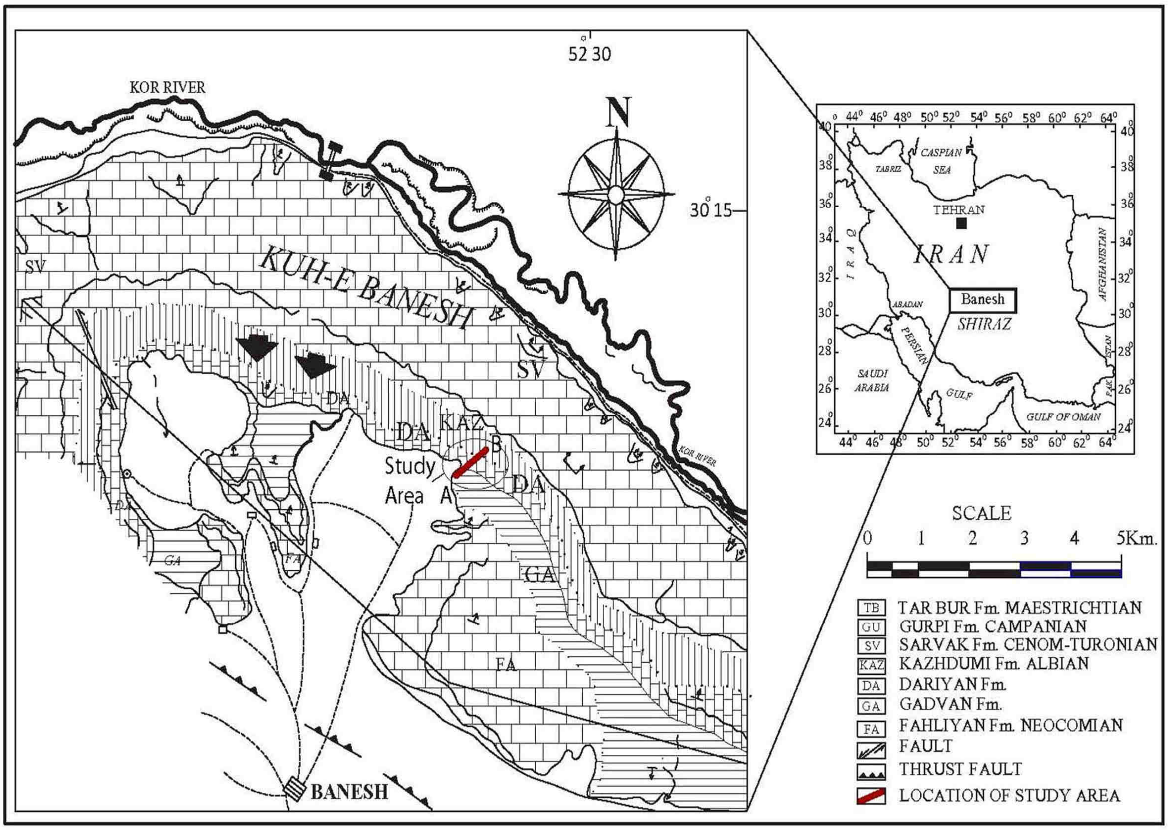

Fig. 1. Location of study area, red symbol shows studied section.(after Mojab, 1974).

For the first time, lower Cretaceous radiolarians from the Dariyan Formation in southern Iran have been examined by scanning electronic microscopic method (SEM). Radiolarians are the most common microfossils out of cherty beds and black shales from the Dariyan Formation. The aim of this study is to 1) make new documentations of radiolarian assemblages from the Dariyan Formation of high Zagros basin and its relationship with organic matter distribution 2) define a direct age of black cherts and shales of the Dariyan Formation using radiolarian assemblages 3) explanation of the distribution pattern of Radiolarian and planktonic foraminifera in black shales and marls in the lower part of Dariyan Formation and implications to OAE 1a.

Geological Setting

The Zagros orogenetic belt of Iran extends from north-west to south-east about 2000 km (Berberian and King, 1981). In both Iran and Arabia, lithologic investigations indicate that the Precambrian basement is the same and overlain by laterally continuous Cambrian to Triassic sequences (Stöcklin, 1968). In thePermo-Triassic period, Iranian plate was separated from the Arabian plate with NW-SE trending and started to open the Neo-Tethys Ocean in southern Iran. Neo-Tethys Ocean was closed in the late Cretaceous. Zagros orogenic belt results from the opening and closure of the Neo- Tethys oceanic realm during Cenozoic times (Alavi, 2007). This belt from north-east to south-west consists of four parallel tectonic subdivisions including Urumieh-Dikhtar Magmatic Assemblage, Sanandaj-Sirjan Zone, High Zagros Belt and Zagros Simply Folded Belt (Alavi, 2004; 2007; Stöcklin, 1968) (Fig. 2). The boundary between Urumieh-Dikhtar Magmatic Assemblage and Sanandaj-Sirjan Zone is marked by ophiolite rocks in a linear belt extends several kilometres from north-west to south-east. The boundary between Sanandaj-Sirjan Zone and High Zagros Belt is defined by the main Zagros thrust and finally, the boundary between High Zagros Belt and Zagros Simply Folded Belt is determined by high Zagros fault (Alavi, 2004; 2007).

The Zagros fold thrust-belt is the central part of the Alpine-Himalayan system. Fars province belonging to Zagros Fold-Thrust Belt lies in southwestern Iran and northeastern of Arabian plate. In thenorth of Fars province occur high Zagros belt,so-called Zagros imbricate zone (ZIZ) (Alavi, 2004; 2007). The high Zagros fault divides Zagros basin into two major belts parallel structural zones known as the high Zagros belt (Stöcklin, 1968) (Fig. 2) or the imbricate belt (on intensely deformation zone) to the north-east and the folded or simply folded Sepehr and Cosgrove (2004).

The Banesh outcrop (studied section), is located in the north of Shiraz, and tectonically in thehigh Zagros belt at 52° 25´ 57" E and 30° 8´ 59" N (Fig. 1).

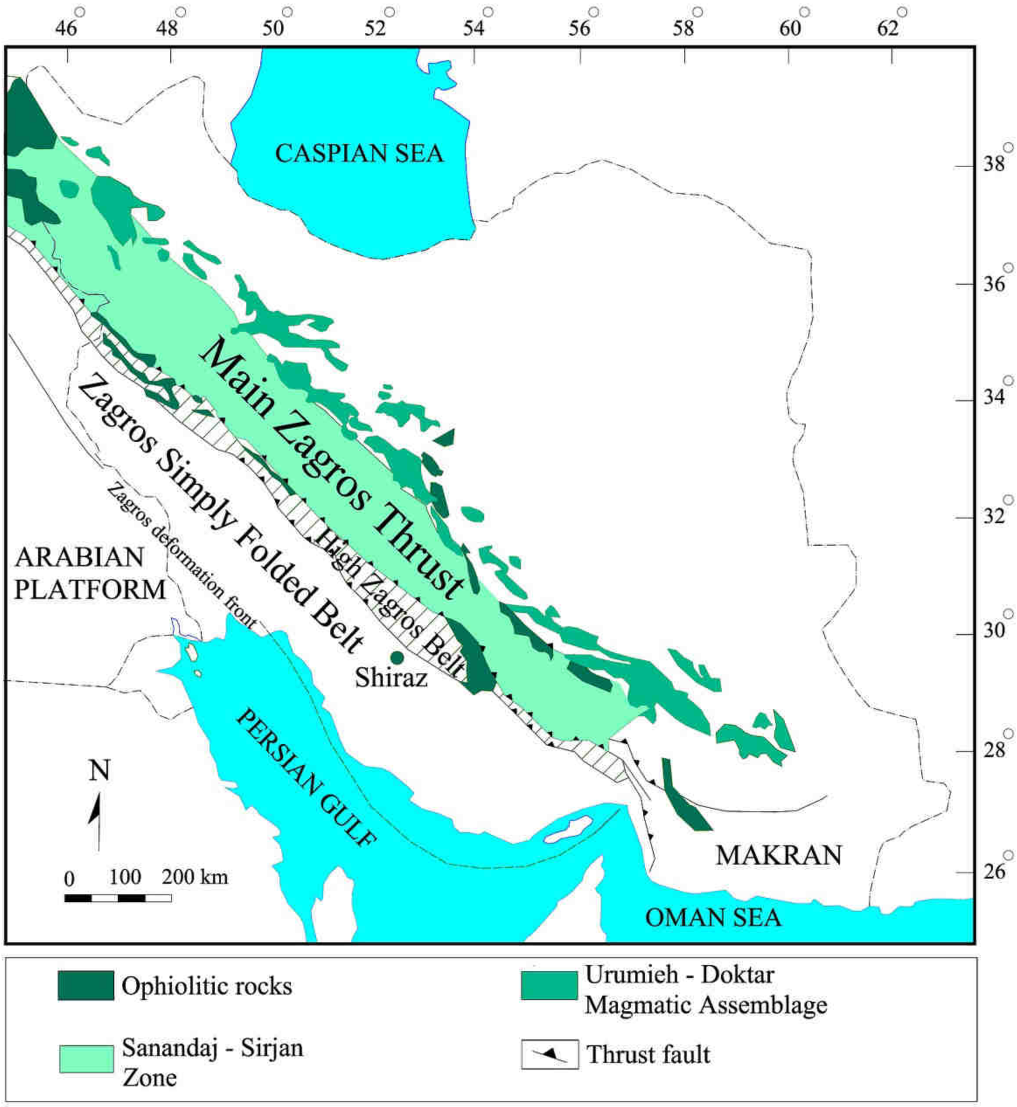

Fig. 2. Structural subdivisions of Zagros orogenic belt modified from Stöcklin, (1968).

Methods

The study is based on a section (278 m in thickness) located at Kuh-e Banesh, southern Iran. The section was chosen for good exposure and low tectonic overprint. Ten washed samples of black shales and chert beds, and hundred and fifty samples of limestone were collectedin order to prepare thin sections from the lower Cretaceous strata at the Kuh-e Banesh Section. The extraction and identification of radiolarians from washed samples were done in the laboratory of Isfahan University and National Iranian Oil Company. The radiolarian specimens are recovered from chert and black shale levels. These samples werefirstly mechanically broken into small pieces, thenthe acetic acid was used in the leaching process (after 24 hours), then washed and sieved through 200 >100 >60 meshes. Representatives of each gold-coated sample are photographed using a Scanning Electronic Microscope (SEM). The scanning electronic microscopic methods create a much greater magnification and it was used for studying the wall and inner structure of the cephalis as well as external morphology of specimens. Taxonomic classificationswere based mainly on shell texture and morphology by O'Dogherty (1994). Biostratigraphy is based on Radiolarians, which were picked from residues of washed material. The relative abundances of radiolarian and planktonic foraminifera were determined in thin sections. Components with abundances of below 5 % are classified as rare as and higher than 20 % as abundant. For Rock-Eval Analysis, each sample of 0.1g bulk powderwas prepared and heated during helium atmosphere condition during three minutes. The Rock-Eval pyrolysis parameters (total organic carbon and quantity of free hydrocarbons) content were calculated by the apparatus of the Amirkabir Technical University of Tehran. All samples were redeposited in the collection of the Exploration Directorate, National Iranian Oil Company (Tehran).

Results

The throughout Dariyan Formation with a total thickness of 275 m is divided into three parts which are the Lower Dariyan, Middle Dariyan and Upper Dariyan (Fig. 3).

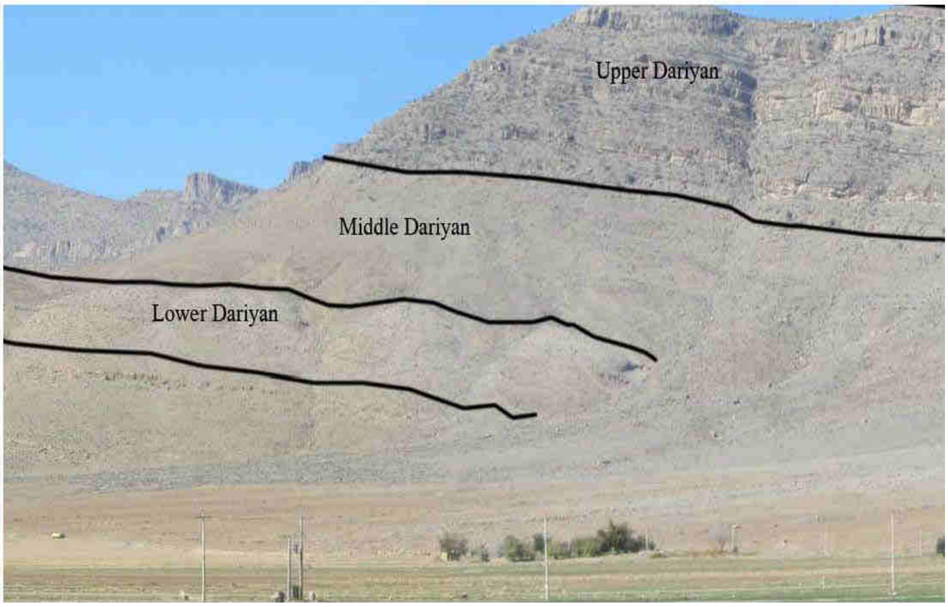

Fig. 3. Subdivisions of the Dariyan Formation at Kuh-e Banesh.

The lower Dariyan is about 25 m thick and consists of thick to medium-bedded limestone and comprises the benthic fossils, dominantly bivalves. The uppermost of lower Dariyan contains thin-bedded limestone, black shale and black chert beds (Fig. 4a) bearing abundant radiolarian, ammonites imprints and planktonic foraminifera (Fig. 4b, 4c and 4d). Chert beds (Fig. 4a) and black shales are considered as marker bed in the uppermost of the lower Dariyan member. The thickness of chert beds are about 10 cm and limestone beds are30-50 cm thick. There are radiolarian blooms in chert beds and black shales but planktonic foraminifera are rare. There is a considerable thing in thedistribution of radiolarian and planktonic foraminifera. Planktonic foraminifers are scarce or absent in radiolarian-rich beds. In the upper parts of the black shales abundance of radiolarian are low but planktonic foraminifera are abundant (Fig.4c and 4d).

According to the Rock-Eval analysis of specimens of the uppermost of the lower Dariyan member, the amount of organic matter is relatively high (Fig. 5). Based on the analysis, total organic carbon (TOC) in investigated interval varies from 0.35 to 1.92 percent (Tarhande and Rashidi, 2006) (Fig. 5).

The lithology and biostratigraphy of the Dariyan Formation at Kuh-e Banesh area are summarized in Figures 4 and 6. Radiolarian species are listed in Figure 6 and radiolarian assemblages are illustrated in Figures 7, 8 and 9. The ages and biostratigraphical attributions are based on zonal schemes proposed by O'Dogherty (1994). The samples were collected from the topmost of the lower Dariyan Formation of black shales, and specimens are moderately preserved. These radiolarian assemblages include *Cryptamphorella clivosa* (Barremian to late Aptian), *Godia decora* (Barremian to late Aptian), *Hemicryptocapsa* sp., (Barremian to Late Albian), *Dictyomitra communis* (Late Barremian to Early Aptian), *Pseudodictyomitra* aff. Carpatica (Late Barremian to early Albian),*Thanarlabrouweri* sp.,(Late Barremian to middle Albian), *Pseudoeucyrtis* sp., (Early Barremian to Late Aptian), *Crolanium* sp., (Barremian to Cenomanian) (Figures. 7, 8 and 9).

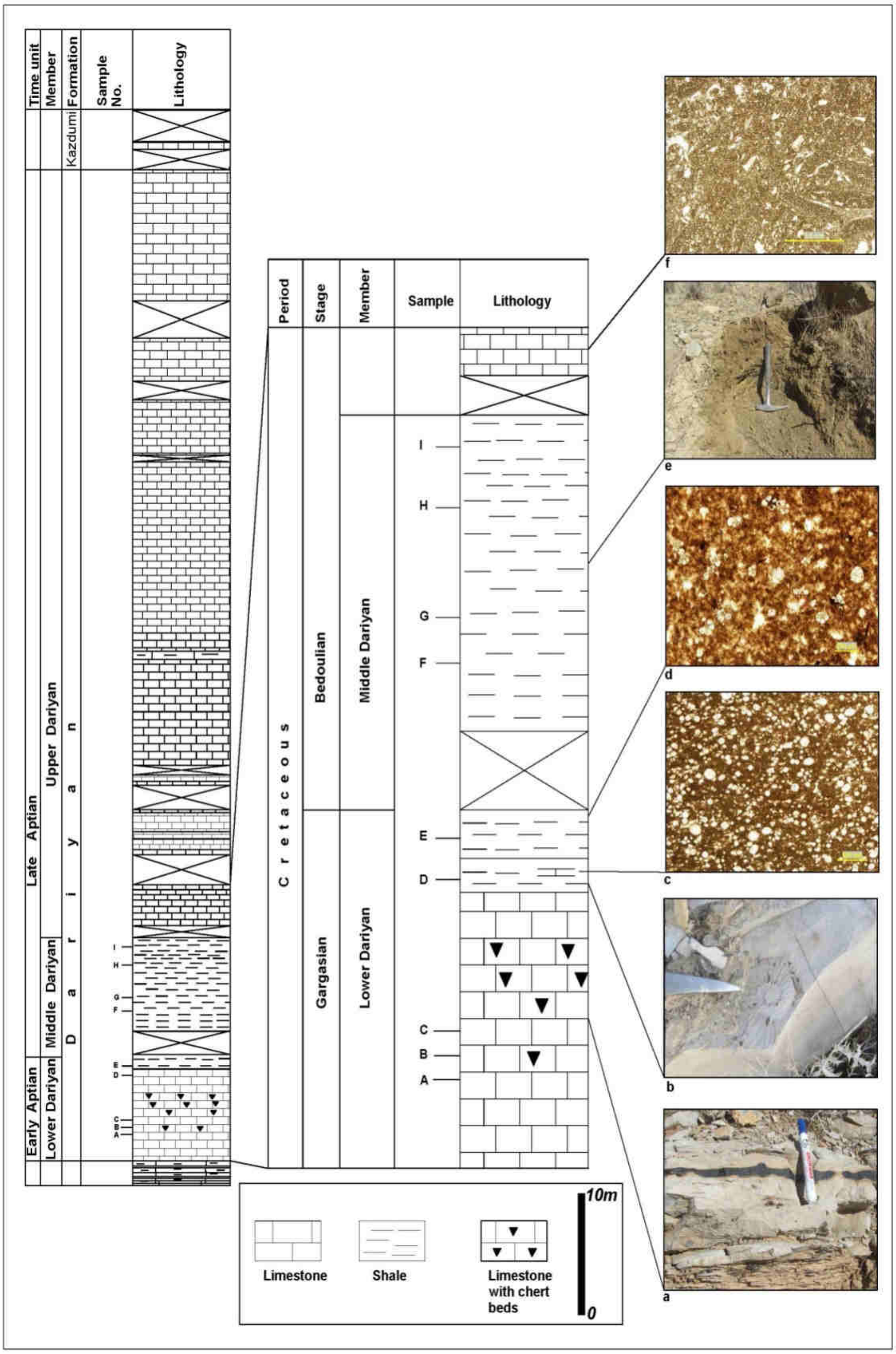

Fig. 4. The lithostratigraphy of the Dariyan Formation. a) chert beds with pelagic limestone b) Ammonite prints in radiolarian beds.c) Radiolarian Packstone in the lime mud matrix in the transmitted light microscope, Scale bar = 500µm. d) Planktonic foraminifers Wackestone in thetransmitted light microscope, Scale bar = 200µm. e) Marls in the middle part of Dariyan Formation with abundant planktonic foraminifers. f) Orbitolina grainstone in the transmitted light microscope, Scale bar = 2mm.

Discussion

The early Cretaceous period is indicated by high burial rate of organic carbon associated with the widespread organic-rich deposits or black shales, known as oceanic anoxic events (Larson and Erba, 1999; Leckie et al., 2002). This is coeval with marine productivity and significant changes in marine biota including theappearance of radiolarian blooms (Erbacher et al., 1996; Hochuli et al., 1999). In western Tethyan domains, the early Aptian black shale deposition, considered as the record of OAE 1a, is associated with abundant radiolarian fauna and organic matter known as ranging between 0.2 and 6.5 % wt. (Menegatti et al., 1998; Danelian et al., 2002).

Radiolarians are the major microfossils in the black shales of the Daryian Formation (Fig. 4c). The facies associations are characterised by radiolarian wackestone and packstones and rare planktonic foraminifera, which are interpreted as distal deep marine facies deposited under progressive conditions (Heldt et al., 2008).

The dating of theintervalis based on radiolarian recovered from the studied succession. The radiolarian tests are silicified and moderately preserved. Zonal markers are missing in this interval, but the comparison of radiolarian-rich deposits with δ13C isotope stratigraphy (Moosavizadeh et al., 2014) (Fig. 5) is in agreement with OAE 1a interval. Moreover, the litho and microfacies association is thought to represent the OAE event. The high abundance of radiolarians corresponds to previous studies on OAE related to deposits in pelagic successions (Erba et al., 1999; Danelian et al., 2002; 2004; Xiang et al., 2013). In the successions related to OAE radiolarians, blooms are associated with high organic matter (Erbacher et al., 1996; Erba, 2004, Xiang et al., 2013; Ben Fadhel et al., 2014), so probably represent high productivity and nutrient concentrations (Heldt et al., 2008; Baxter et al., 2010; Ben Fadhel, 2011; 2014). There is a considerable pattern of distribution of radiolarian and moderately preserved calcareous planktonic foraminifera in the Dariyan Formation at Kuh-e Banesh which is acomparison with OAE 1a interval in other worldwide successions. In OAE 1a, deposits planktonic foraminifera are often scarce or absent during pelagic succession (Coccioni et al., 1992; Premoli Silva et al., 1999). Scarcity or absence of calcareous planktonic foraminifers in radiolarian deposits possibly OAE interval can be attributed to shoaling of CCD (Bralower et al., 1994; 2002) or unfavourable conditions for calcareous planktonic foraminifera in surface waters (Ebra et al., 1999). In studied succession, planktonic foraminifer’s assemblages in radiolarian beds are scarce and moderately preserved. Moreover, Hedbergellids and specially Globigerinelloidids in black shale’s are rare, correlating with results from some other localities (Luciani et al., 2006; Premoli Silva et al., 1999). Gelobigerinolloidids indicate oligo to mesotrophic conditions and Hedbergellids signify meso to eutrophic conditions in the upper water column (Coccioni et al., 1992; Premoli Silva and Sliter, 1999). Leopuldinids are one of theorders of planktonic foraminifera in pelagic succession during early Cretaceous (Aguado et al., 1999; Ezampanah et al., 2013; Premoli Silva, 1999). This group represents eutrophic and low or lack of oxygen in the upper water column (Coccioni et al., 2006; Ezampanah et al., 2013; Premoli Silva et al., 1999). Regarding ecological conditions with high abundance, radiolarian and rare planktonic foraminifers including Hedbergellids indicate meso to eutrophic conditions in the upper water column of the studied area and higher oxygen levels in comparison with other pelagic deposits. In the studied interval,bentic foraminifers are scarce or absent and possibly indicate anoxic or dyoxic conditions at the basin floor (Heldt et al., 2008). Besides the presence of siltstone and cherty beds, carbonate sedimentation under shoalings of carbonate compensation depth (CCD) may be affected (Guobiano et al., 2011; Heldt et al., 2008). The deposition of siliceous beds with ammonites and radiolarian (Figs. 4b and 4c) indicates an episode of a sediment-starved deep oceanic basin with deposition of biogenic siliceous sediment (Xiang et al., 2013) below the CCD (Guobiano et al., 2011). In the study area, ammonites are present in black shale and limy siltstone levels. Bernaus et al. (2003) believed that ammonites have lived in hemipelagic facies, but in black shale, marlstone and claystone levels are uncommon. In some Tethys basins including Tunisia (Heldt et al.,2008), early Aptian deposits with ammonites correspond to OAE 1a interval. Regardingthe age of radiolarian assemblages in study succession, ammonite deposits are correlated to early Aptian deposits in southern Tethys margin possibly related to OAE 1a interval. We postulate that shoaling of the CCD occurred during the deposition of cherty limestone beds and siltstone may be the result of subduction event characterising the Zagros orogeny. The abundance of radiolarians and high organic matter shows that radiolarian assemblages can be considered as a proxy of productivity (Ben Fadhel et al., 2014; Xiang et al., 2013) during the OAE 1a interval. During the late Aptian, the presence of Orbitolina-rich carbonate platform (Fig. 4f) was resulted from changes in ocean chemistry, climate and low terrigenous input (Najarro et al., 2011). Therefore, restricted basins resulting from Aptian extensive tectonic phase (Navabpour et al., 2010), and subsequent volcanism (Tejada et al., 2009) have enhanced eutrophic conditions, high marine productivity and the widespread of radiolarian and organic-rich black shales deposits at Kuh-e Banesh.

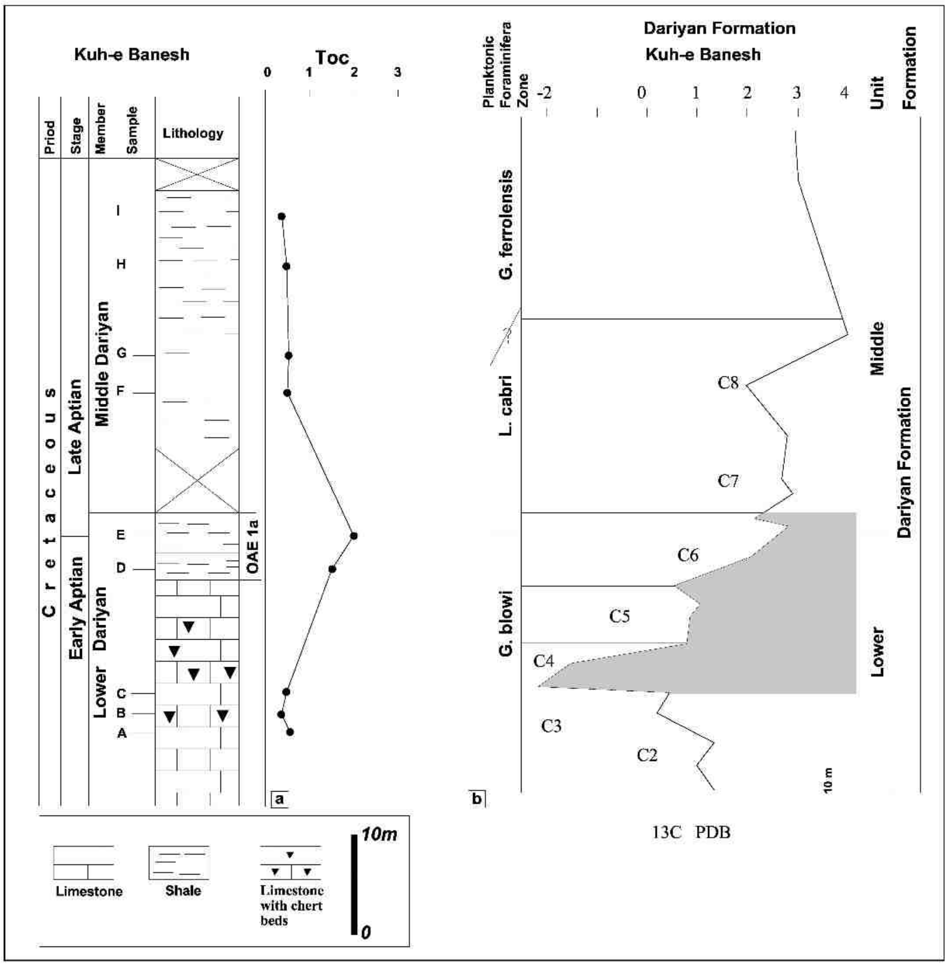

Fig. 5. a) Rock-Eval analysis data. b) Isotope stratigraphy of Kuh-e Banesh section from modified after Moosavizadeh et al. (2014).

The Dariyan Formation is distinctively composed of three parts, the lower parts bearing Orbitolina-Chofatella limestone beds underlies shales and marls with abundant radiolarian, planktonic foraminifers, and ammonites, overlaid by the upper part, which is composedof Orbitolina-rich limestone beds and the last part overlies with Orbitolina limestone. This depositional trend indicates three stages of deposition palaeoenvironment. Stage 1 is defined by marine transgression with the shallow water environment and benthic foraminifers' biota including Orbitolina and Chofatella taxa. Stage 2 indicates abruptly shale and marl intervals overlie the shallow carbonates. These intervals represent deposition of deep-marine. Stage 3 is characterised by thick bedded-Orbitolina limestones which indicate return to shallow marine (Fig. 4f)

Age diagnostic radiolarian assemblages from chert and black shales beds of the Daryian Formation have been studied and based on O'Dogherty (1994), the radiolarian assemblage constrains the stratigraphic range from Late Barremian to Aptian Age.However, the assemblage composed of *Dictyomitra communis* (SQUINABOL), *Thanarla brouweri* (TAN) and *Pseudodictyomitra carpatica* (Lozyniak) have been mentioned and described in Massif Ladakh, northwestern India, corresponding to mid Valanginian-mid Aptian range (Baxter et al., 2010), also *Hemicryptocapsa* sp., *Pseudodictyomitra* aff. *carpatica*, *Thanarlabrouweri* sp., were reported to occur in early to middle Cretaceous radiolarian assemblages from equatorial Atlantic, Poland, Hokaido, Malaysia domains (Erbacher and Thurow, 1998; Gorka and Geroch, 1989; Taketani and Kanie, 1992). In addition, all genus and species were reported from Nidarophiolites indicate Barremian - Late Aptian range (Zyabrev et al., 2008). It was suggested that these radiolarian assemblages correspond to *Sticocapsa euganea* Zone (Guobiano et al., 2011), indicates at least an early to early late Aptian.

To conclude, the studied assemblages recovered from the lower part of the Daryian Formation have a stratigraphic range from Late Barremian to Early late Aptian. Therefore, based on biostrarigraphic study and published results of 13C stable isotope (Moosavizadeh et al., 2014) (Fig. 5) probably indicate the record of OAE 1a in Zagros belt area, southern Iran, can be constrained to the early to late Aptian. This is coeval with global transgression, marine productivity, global warming and significant changes in marine biota including the appearance of radiolarian blooms (Erbacher et al., 1996; Hochuli et al., 1999).

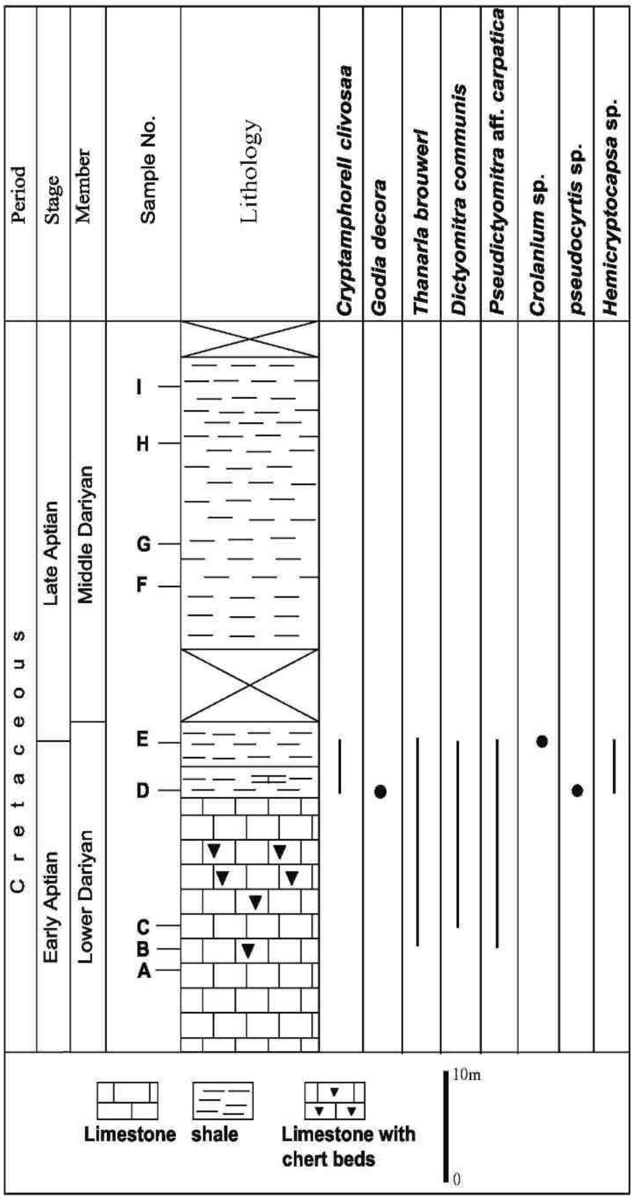

Fig. 6. Succession of radiolarian assemblage from the Dariyan Formation at Kuh-e Banesh.

Conclusion

For the first time, radiolarian specimens from Dariyan Formation have been studied and illustrated by scanning electronic microscopic method (SEM). The radiolarian assemblages correspond to early to late Aptian. Extensive tectonic phase and basin configuration has led to an abrupt change in basin configuration, therefore a transition from mesotrophic carbonate platform to eutrophic environment characterised by the deposition of radiolarian-rich black shale.

Distribution abundance of radiolarian and calcareous planktonic foraminifera in the lower Dariyan Formation is unusual, so the studied interval, planktonic foraminifera are often scarce during cherty limestone and black shale succession. We conclude that shoaling of the CCD or unfavourable chemical conditions in surface waters occurred during the deposition of radiolarian interval possibly OAE deposits. The high abundance of radiolarian and rare planktonic foraminifera indicates high productivity and eutrophic and anoxic conditions during deposition of black shales. Age diagnostic radiolarian fauna allows to constraint these black shale to the Barremian to mid Aptian which can be correlated to the OAE 1a (Selli event) recorded in western Tethys realms. This study provides a palaeoceanographic drawing of early Cretaceous black shales, but further studies in the Zagros basin could be useful to establish paleoceanographic schemes and interpretations in southern Tethyan realms during early Cretaceous.

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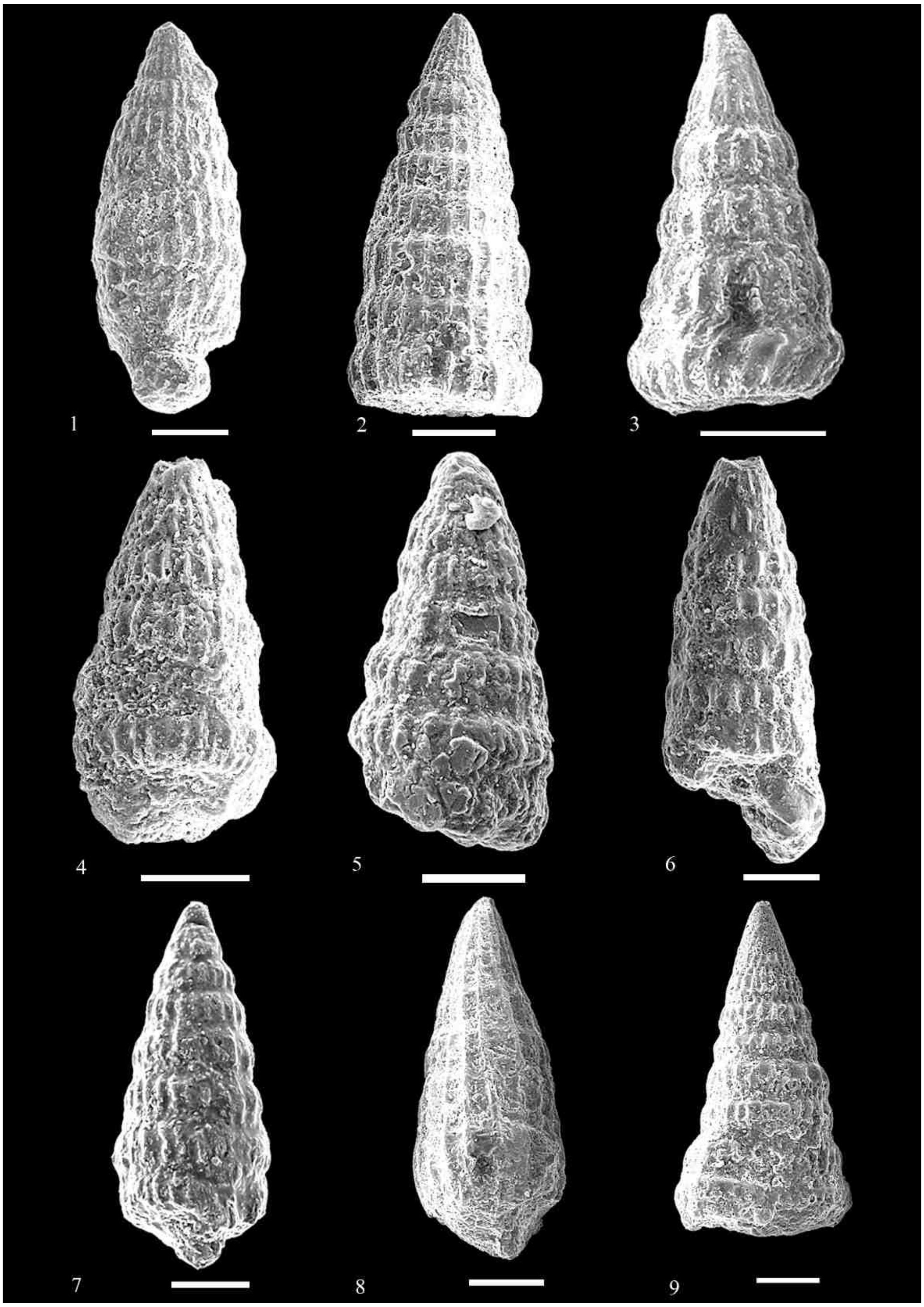

Fig. 7. 1. Dictyomitra sp. (SQUINABOL), 2, 3, 4, 5, 6, 7, 8. Dictyomitra communis (SQUINABOL), 9. Pseudodictyomitra aff. carpatica(LOZYNIAK). White scale bar=50µ.

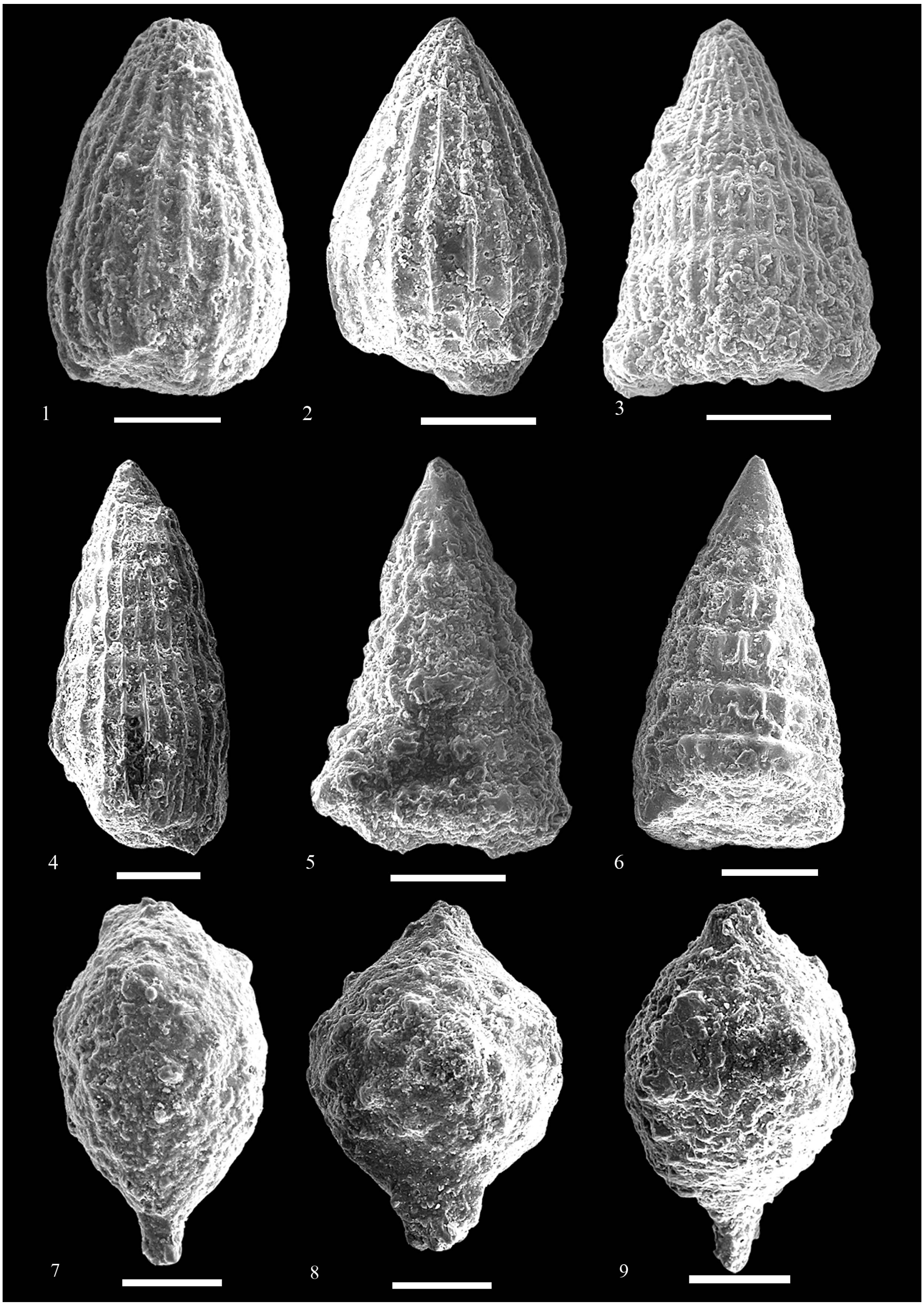

Fig. 8. 1, 2. Thanarlabrouweri (TAN), 3, 4. Dictyomitra communis (SQUINABOL), 5. Dictyomitra sp.?. 6. Pseudodictyomitraaff.carpatica(LOZYNIAK), 7, 8, 9. Pseudoeucyrtis sp.?. White scale bar=50µ.

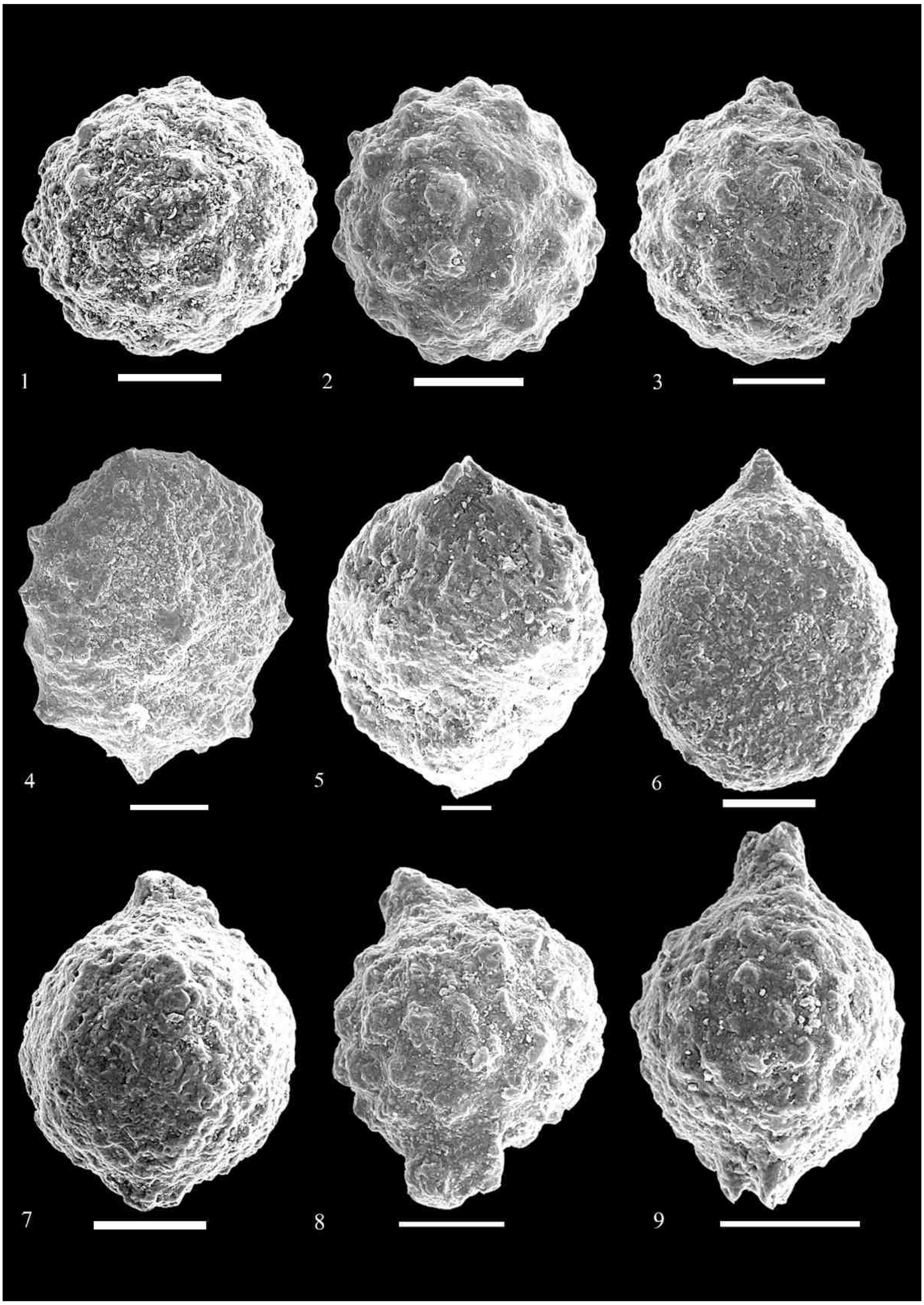

Fig. 9. 1, 2, 3, 8. Cryptamphorella clivosa (ALIEV)?,4. Godia decora (Li & Wu), 5, 6. Sethocapsa? sp., 7, 9. Acaeniotyle sp.8. Cryptamphorella clivosa (ALIEV)?. White scale bar=50µ.

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