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Palynostratigraphy and palaeogeography of the Cambro-Ordovician strata in southwest of Shahrud City (Kuh-e-Kharbash, near Deh-Molla), Central Alborz Range, northern Iran

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Abstract

A total of 66 surface samples from the Mila, Lashkarak and Ghelli formations of Kuh-e-Kharbash (near Deh-Molla) were palynologically investigated, to determine the geological age of the rock units. This study was also undertaken to assess the palaeogeographic relationships of the study area to Southern and Northern Hemispheres during the Palaeozoic interval represented by these formations. 52 palynomorphs (51 acritarchs and one algal body) were recorded, which permit the recognition of six acritarch-based biostratigraphic zones. Acritarch assemblage zone I is Late Cambrian in age and occurs in the upper part of the Mila Formation. Assemblages zones II through IV are present in the Lashkarak Formation and suggest Lower Ordovician (Tremadoc–Arenig). Assemblage zones V and VI are present in the Ghelli Formation and indicate Upper Ordovician (Caradoc–Ashgill) for this formation.

Based on palaeontological data, two hiatuses are present within the studied stratigraphical column. The first hiatus occurs between the Lashkarak and Ghelli formations and encompasses the Middle Ordovician strata. The second hiatus is present between the Ghelli and Geirud formations and includes the whole Silurian and Lower–Middle Devonian deposits. The above-mentioned hiatuses possibly correspond to the Caledonian Orogeny. Diverse acritarch assemblages in the Late Cambrian (Mila Formation), Lower and Upper Ordovician (Lashkarak and Ghelli formations) indicate that a marine environment continued through the entire succession. Comparison of acritarch taxa recorded in Kuh-e-Kharbash (near Deh-Molla) with those reported from other parts of the world, suggests that the Alborz Mountain Ranges have been part of peri-Gondwanan palaeoprovince during the Ordovician.

Keywords: acritarchs; Cambrian; Ordovician; biostratigraphy; palaeoecology; palaeobiogeography; Central Alborz Mountain Range; Northern Iran

1. Introduction

The study area is called Kuh-e-Kharbash, which is located near Deh-Molla, approximately 20 km from southwest of Shahrud city (Fig. 1). The road from Tehran to Shahrud is the principle link to the study area. Cambro-Ordovician strata are well-exposed in Kuh-e-Kharbash (near Deh-Molla) southwest of Shahrud. The study area is part of the Central Alborz Mountain Range, located near to the boundary of eastern Alborz Range, where the Paleozoic rock units display major changes towards the western and eastern Alborz Ranges (Afshar-harb, 1975). Upper Ordovician and Silurian deposits are

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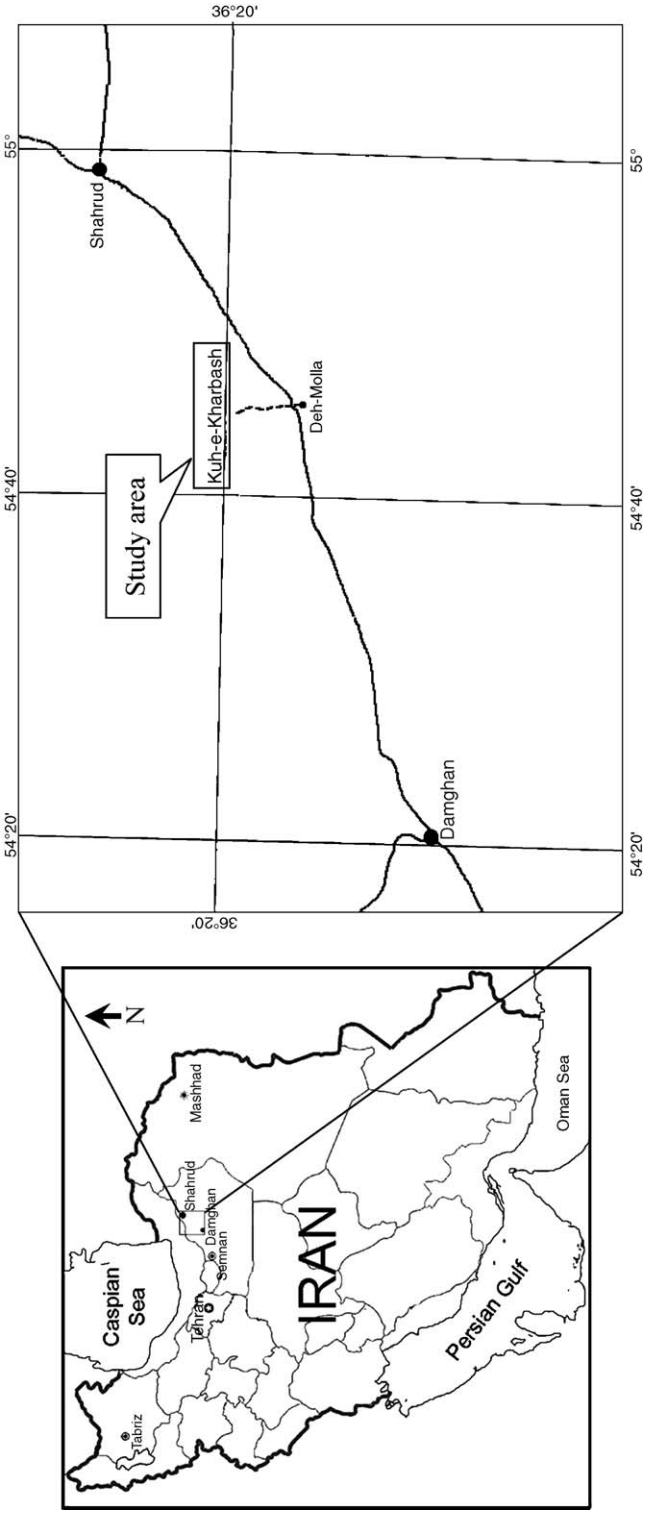


Fig. 1. Location map of study area.

progressively disappeared from the Kuh-e-Kharbash towards the Central Alborz Range and the whole Ordovician and Silurian strata are not completely present in the western Alborz Range, whereas Upper Ordovician and Silurian deposits are present and well-developed toward the eastern Alborz Range (Kopet–Dagh region).

These Lower Palaeozoic strata of Alborz Mountain Ranges have received minimal biostratigraphical attention in the past because of paucity of marine macrofauna. The objectives of this study are to demonstrate the biostratigraphic, palaeogeographic and palaeoecologic significance of acritarch taxa in the Cambro-Ordovician strata of this part of Iran. The palaeogeography and palaeoecology of the study area are important in relation to the western and eastern Alborz Mountain Ranges, as it is not clear that the studied area belongs to the Central or Eastern Alborz Ranges (Kopet–Dagh region).

2. Stratigraphy

The Palaeozoic strata are well-exposed in Kuh-e-Kharbash, consisting of the Mila, Lashkarak, Ghelli and Geirud formations in ascending stratigraphic order (Fig. 2). The Mila Formation consists mainly of limestone with abundant trace fossils (trails, tracks and burrows), especially at its upper contact. Based on trilobite fauna, this formation has been assigned to the Middle and Upper Cambrian at its type locality (Kushan, 1978). The lower contact of Mila Formation is not clear due to the presence of fault, but its upper contact is conformable with the Lashkarak Formation. It should be mentioned that from whole thickness of Mila Formation, only 29.5 m of uppermost part of the formation were measured, sampled and used in this study.

The Lashkarak Formation is 135 m thick and consists mainly of olive-grey fissile shales. The lower and upper contacts of this formation are conformable with underlying and overlying formations. Based on acritarch assemblage zones, the Lashkarak Formation has been assigned to the Lower Ordovician (Ghavidel-syooki, 1995, 2000, 2001) in other parts of Alborz Ranges.

The Ghelli Formation is 299 m thick in the study area and consists mainly of olive-grey, silty shale and dark grey shale. This formation has been intruded by an igneous sill near its top. The lower and upper contacts of this formation are disconformable with the underlying Lashkarak Formation and overlying Geirud Formation. The Ghelli Formation contains trace fossils in some intervals, but it lacks macrofauna. In the type locality, based on palynological data, the Ghelli Formation has been assigned to the Middle–Upper Ordovician (Ghavidel-syooki, 1997, 2000, 2001; Ghavidel-syooki and Winchester-seeto, 2002).

The Geirud Formation is typically represented by red shale and white sandstone, changing to an alternation of shale and fossiliferous limestone toward the top. This formation contains both marine macrofauna and palynomorph entities and based on this combined biostratigraphical data, the Geirud Formation has been assigned to the Upper Devonian (Gaetani, 1965; Kimyai, 1972; Ghavidel-syooki, 1994, 1995).

3. Materials and methods

Palynological study was carried out on 66 surface outcrop samples from the Mila, Lashkarak and Ghelli formations. The field and laboratory description for each sample has been plotted on the stratigraphical column (Fig. 2). Each sample is designated with the National Iranian Oil Company code number with the prefix MG.

The palynomorph assemblages were extracted from shale and siltstone samples by standard palynological procedures, including treatment of the residues of each sample with 30 ml of saturated zinc bromide. Organic residues were sieved through 15 micron nylon mesh sieves to separate the organic residues from the inorganic materials. Extensive scanning electron and transmitted light microscopic examinations were applied on selected specimens during the study.

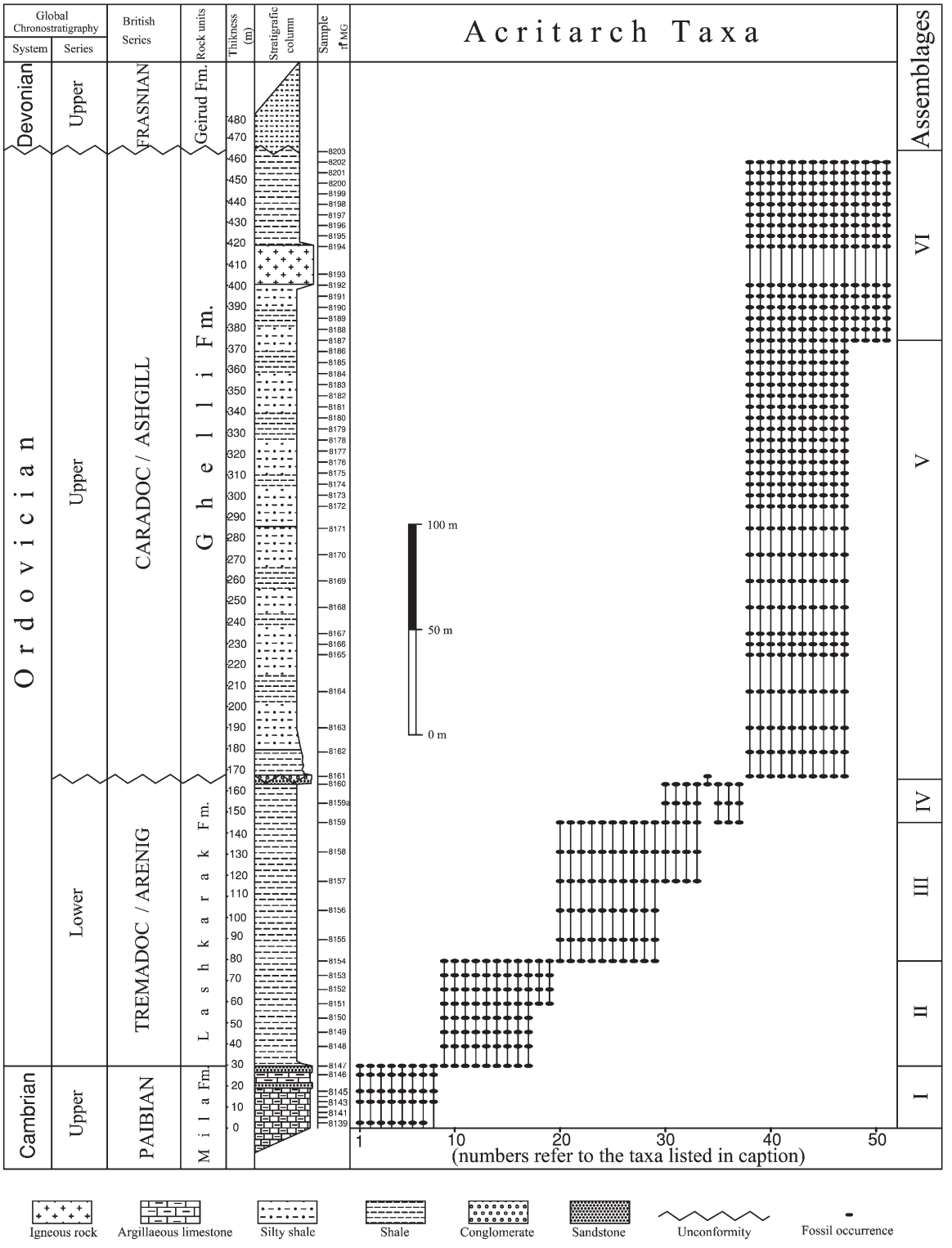
Most samples contain well-preserved and abundant palynomorphs (e.g., acritarchs, chitinozoans, scolecodonts and rare small trilete spores).

In general, the acritarchs are more abundant than other palynomorph entities (e.g., chitinozoans, scolecodonts and small trilete spores). The palynomorphs and organic debris range in color from yellow to orange brown, which indicates a good thermal maturity for the organic materials of Lower Palaeozoic strata in this part of the Alborz Range. However, the intruded basaltic sill in the Ghelli Formation has resulted in color changes of palynomorph entities from dark brown to grey. All slides used in this study are housed in the palaeontological collections of the Exploration Directorate of the National Iranian Oil Company under the sample numbers MG-8139 to MG-8203.

4. Biostratigraphy

A total of 51 acritarch species and one algal cluster were encountered and their distributions are plotted on Fig. 2. Six acritarch assemblage zones have been recognized in the Lower Palaeozoic sequence of Kuh-e-Kharbash and they are discussed below in ascending

stratigraphic order. It should be mentioned that in most cases the taxonomy here follows that of Fensome et al. (1990) and those of Eisenack et al. (1973, 1976, 1979). The scanning electron microscopic photos were prepared for all selected acritarch taxa and illustrated on Plates I–IV.



4.1. Acritarch assemblage zone I

This assemblage zone occurs in 29.5 m of the upper part of Mila Formation. This zone is characterized by appearance of *Acanthodiacrodium achrasii*, *Dasydiacrodium obsonum*, *D. caudatum*, *Goniosphaeridium tener*, *Ooidium rossicum*, *Timofeevia pentagonalis*, *Vulcanisphaera turbata* and abundant algal cluster (coenobium). In this assemblage, the dominated palynomorph group is algal remains, which comprise 80% of the assemblage. From morphological point of view, the algal remains of Mila Formation have broad similarity to those of the United States (Wood and Stephenson, 1989; Miller and Wood, 2001). The above-mentioned acritarch taxa suggest Upper Cambrian for the upper part of the Mila Formation (Fig. 2). The acritarch species of this assemblage have been recorded in the Late Cambrian strata of Canada (Martin and Dean, 1981, 1988; Parsons and Anderson, 2000), United States (Wood and Stephenson, 1989), Sweden (Bagnoli et al., 1988), Norway (Welsch, 1986), Belgium (Vanguestainé, 1973, 1978), Belgium and northern France (Ribecai and Vanguestainé, 1993), Russia (Volkova, 1990), North Africa (Jardiné et al., 1974; Vecoli, 1999) and southern Iran (Ghavidel-syooki, 1997).

4.2. Acritarch assemblage zone II

This acritarch assemblage zone begins at the lowermost part of Lashkarak Formation and extends through a thickness of 50 m in the studied stratigraphic column of Kuh-e-Kharbash (Fig. 2). This assemblage is marked by the introduction of the acritarch species, including *Acanthodiacrodium rotundatum*, *Cymatiogalea cristata*, *C. cuvillieri*, *Dasydiacrodium tremadocum*, *Stelliferidium furcatum*, *S. barbarum*, *S. cortinulum*, *S. gautieri*, *S. stelligerum*, and *Vulcanisphaera cirrita* and *V. africana.* These acritarch taxa of Lashkarak Formation are assigned to the Lower Ordovician (Tremadoc) and have been previously recorded in the Tremadoc strata of England (Rasul, 1974, 1976; Downie, 1984), Ireland (Connery and Higgs, 1999), France (Rauscher, 1974; Martin, 1973), Poland (Görka, 1967), Spain (Cramer, 1964), Italy (Pittau, 1985), Germany (Servais and Molyneux, 1997), Austria (Reitz and Höll, 1991), North Africa (Combaz, 1967; Elaoud-Debbaj, 1988; Deunff, 1961; Jardiné et al., 1974; Vecoli, 1999), Iran (Ghavidel-syooki, 1995, 1997, 2001, 2003), southwest China (Brocke, 1997) and Argentina (Rubinstein et al., 1999).

4.3. Acritarch assemblage zone III

This assemblage occurs in 65 m of the Lashkarak Formation and it is defined by presence of critical Lower Ordovician acritarch species, such as *Arbusculidium filamentosum*, *Arbusculidium iranense*, *Arkonia triangulata*, *Aureotesta clathrata* var. *clathrata*, *A. clathrata* var. *simplex*, *Barakella fortunata*, *Coryphidium bohemicum*, *C. australe*, *C. persianense*, *Polygonium gracile*, *Polygonium* sp., *Striatotheca principalis*, *S. frequens*, *S. transformata* and *S. trapeziformis* (Fig. 2).

From the above-mentioned acritarch species, Martin (in Martin and Dean, 1988) has recorded *Arbusculidium*

Fig. 2. Stratigraphical distribution of selected acritarch taxa in the Late Cambro-Ordovician strata of northern Iran, southwest of Shahrud city (Deh-Molla area) northeastern Iran. The recorded taxa are listed below (numbers refer to the corresponding columns in the figure). 1=*Ooidium rossicum* Timofeev, 1957; 2=*Timofeevia pentagonalis* (Vanguestainé) Vanguestainé, 1978; 3=*Dasydiacrodium obsonum* Martin in Martin and Dean, 1988; 4=Algal cluster (coenobium); 5=*Dasydiacrodim caudatum* Vanguestainé, 1973; 6=*Acanthodiacrodium achrasii* (Martin) Martin and Dean, 1988; 7=*Vulcanisphaera turbata* Martin in Martin and Dean, 1981; 8=*Goniosphaeridium tener* (Timofeev) nov. comb., Elouad-Debbaj, 1988; 9=*Vulcanisphaera cirrita* Rasul, 1976; 10=*Vulcanisphaera africana* Deunff, 1961; 11=*Stelliferidium furcatum* (Deunff) emend. Deunff et al., 1974; 12=*Stelliferidium cortinulum* (Deunff) Deunff et al., 1974; 13=*Stelliferidium stelligerum* (Görka) emend. Deunff et al., 1974; 14=*Cymatiogalea cristata* (Downie) Rauscher, 1973; 15=*Cymatiogalea cuvillieri* (Deunff) Deunff, 1964; 16=*Stelliferidium babarum* (Deunff) Elouad-Debbaj, 1988; 17=*Selliferidium gautieri* (Martin) Pittau, 1985; 18=*Dasydiacrodium tremadocum* (Görka) emend. Tongiorgi *in* Bagnoli et al., 1988; 19=*Acanthodiacrodium rotundatum* Görka, 1967; 20=*Arbusculidium filamentosum* (Vavrdová) Vavrdová, 1972; 21=*Arbusculidium iranense (A. iranica)* Ghavidel-syooki, 1990; 22=*Coryphidium bohemicum* (Vavrdová) Vavrdová, 1972; 23=*Coryphidium persianense* (=*A. persica*) Ghavidel-syooki, 1990; 24=*Barakella fortunata* Cramer and Diez, 1977; 25=*Coryphidium australe* Cramer and Diez, 1977; 26=*Polygonium gracile* Vavrdová, 1966; 27=*Polygonium* sp.; 28=*Aureotesta clathrata var. simplex* (Cramer et al. 1974) emend. Brocke et al., 1998; 29=*Arkonia triangulata* (Cramer et al.) Vavrdová, 1978; 30=*Striatotheca principalis* Burmann, 1970; 31=*Striatotheca transformata* Burmann, 1970; 32=*Striatotheca trapeziformis* Burmann, 1970; 33=*Striatotheca frequens* Burmann, 1970; 34=*Aureotesta clathrata var. clathrata* (Vavrdová) emend. Brocke et al., 1998; 35=*Acanthodiacrodium costatum* Burmann, 1968; 36=*Multiplicisphaeridium multipugiunculatum* Cramer and Diez, 1977; 37=*Peteinosphaeridium armatum* Tongiorgi et al. 1995; 38=*Peteinosphaeridium velatum* Kjellström, 1971; 39=*Baltisphaeridium dasos* Colbath, 1979; 40=*Ordovicidium elegantulum* Loeblich and Tappan, 1971; 41=*Baltisphaeridium longispinosum* subsp. *delicatum* Turner, 1984; 42=*Gorgonisphaeridium antiquum* Loeblich and Tappan, 1978; 43=*Goniosphaeridium splendens* (Paris and Deunff) Turner 1984; 44=*Actinotodissus longitaleosus* Loeblich and Tappan, 1978; 45=*Veryhachium lairdii* (Deflandre) Deunff, 1959 ex Downie, 1959; 46=*Multiplicisphaeridium irregulare* Staplin et al. 1965; 47=*Multiplicisphaeridium bifurcatum* Staplin et al. 1965; 48=*Multiplicisphaeridum* sp; 49=*Veryhachium subglobosum* Jardiné et al. 1974; 50=*Villosacapsulla setosapellicula* (Loeblich) Loeblich and Tappan, 1976; 51=*Orthosphaeridium inflatum* Loeblich, 1970; 52=*Orthosphaeridium insculptum* Loeblich, 1970.

filamentosum, *Coryphidium bohemicum*, and *Striatotheca principalis* from the graptolitic deposits, belonging to the *Didymograptus extensus* graptolite Zone of the Wabana Group, Bell Island, and eastern Newfoundland, Canada (Dean and Martin, 1978), which were assigned to an Arenig age. Furthermore, the co-occurrence of these three species has been recorded in the Arenig sediments of south-west China (Li, 1987; Lu, 1987; Tongiorgi et al., 1995). In Europe, *A. filamentosum* is frequently associated with *C. bohemicum* in Arenig deposits (Vavrdová, 1972, 1974, 1990, 1997; Rauscher, 1974; Burmann, 1968, 1970). The species of *C. bohemicum* has likewise been recorded in the Arenig deposits of England and it has co-occurrence with graptolites biozones of Arenig (Molyneux and Leader, 1997). A detailed study has also been carried out for the stratigraphical distribution of *Arkonia* and *Striatotheca* on the sediments from Belgium and Germany.

This study suggests a Tremadoc/Arenig age for *Striatotheca* and late Arenig for *Arkonia* (Servais, 1997).The easily discernible taxon *Aureotesta clathrata* has great biostratigraphical and biogeographical potential. Its first appearance is in the *Corymbograptus v-similis* Biozone in Bohemia and the *Didymograptus deflexus* Biozone in south China (Brocke et al., 1998). The acritarch species of this assemblage have also been recorded in the Arenig deposits of North Africa (Cramer et al., 1974; Cramer and Diez, 1977; Jardiné et al., 1974; Vecoli, 1999), Argentina (Ottone et al., 1992), south-west China (Li, 1987) and Iran (Ghavidel-syooki, 1990, 1995, 1997, 2000, 2001, 2003). It should be mentioned that some encountered acritarch species of assemblages II and III have reported from the late Tremadoc–Arenig strata in Germany (Servais and Molyneux, 1997) and Argentina (Rubinstein et al., 1999).

Plate I. (see page 87)

1. *Arkonia triangulata* (Cramer et al. 1974) Vavrdová, 1978.
2. *Peteinosphaeridium velatum* Kjellström, 1971.
3. *Peteinosphaeridium armatum* Tongiorgi et al. 1995.
4. *Baltisphaeridium dasos* Colbath, 1979.
5. *Polygonium* sp.
6. *Vulcanisphaera turbata* Martin in Martin and Dean, 1981.
7. *Aureotesta clathrata simplex* (Cramer et al. 1974) *Brocke et al. 1998.*
8. *Striatotheca frequens* Burmann, 1970.
9. *Vulcanisphaera cirrita* Rasul, 1976.
10. *Striatotheca trapeziformis* Burmann, 1970.
11. *Barakella fortunata* Cramer and Diez, 1977.

Plate II. (see page 88)

1. *Ooidium rossicum* Timofeev, 1957.
2. *Arbusculidium* (*iranica*) *iranense* Ghavidel-syooki, 1990.
3. *Arbusculidium filamentosum* (Vavrdová) Vavrdová, 1972.
4. *Timofeevia pentagonalis* (Vanguestainé) Vanguestainé, 1978.
5. *Stelliferidium gautieri* (Martin, 1972) Elouad-Debbaj, 1988.
6. *Dasydiacrodium obsonum* Martin in Martin and Dean, 1988.
7. *Stelliferidium cortinulum* (Deunff, 1961) emend. Deunff et al. 1974.
8. *Stelliferidium stelligerum* (Görka, 1967) emend. Deunff et al. 1974.
9. *Acanthodiacrodium achrasii* (Martin, 1973) Martin in Martin and Dean, 1988.
10. *Cymatiogalea cuvillieri* (Deunff) Deunff, 1964.
11. *Aureotesta clathrata clathrata* (Vavrdová, 1972) Brocke et al. 1998.

Plate III. (see page 89)

1. *Acanthodiacrodium rotundatum* Görka, 1967.
2. *Striatotheca transformata* Burmann, 1970.
3. *Multiplicisphaeridium bifurcatum* Staplin et al. 1965.
4. *Coryphidium bohemicum* (Vavrdová) Vavrdová, 1972.
5. *Stelliferidium furcatum* (Deunff, 1961) emend. Deunff et al. 1974.
6. *Coryphidium australe* Cramer and Diez, 1976.
7. *Stelliferidium barbarum* (Deunff, 1961) Elaoud-Debbaj, 1988.
8. *Acanthodiacrodium costatum* Burmann, 1968.
9. *Actinotodissus longitaleosus* Loeblich and Tappan, 1978.
10. *Arbusculidium iranense* (*A. iranica*) Ghavidel-syooki, 1990.
11. *Veryhachium subglobosum* Jardiné et al. 1974.
12. *Goniosphaeridium tener* (Timofeev) nov.comb., Elaoud-Debbaj, 1988.

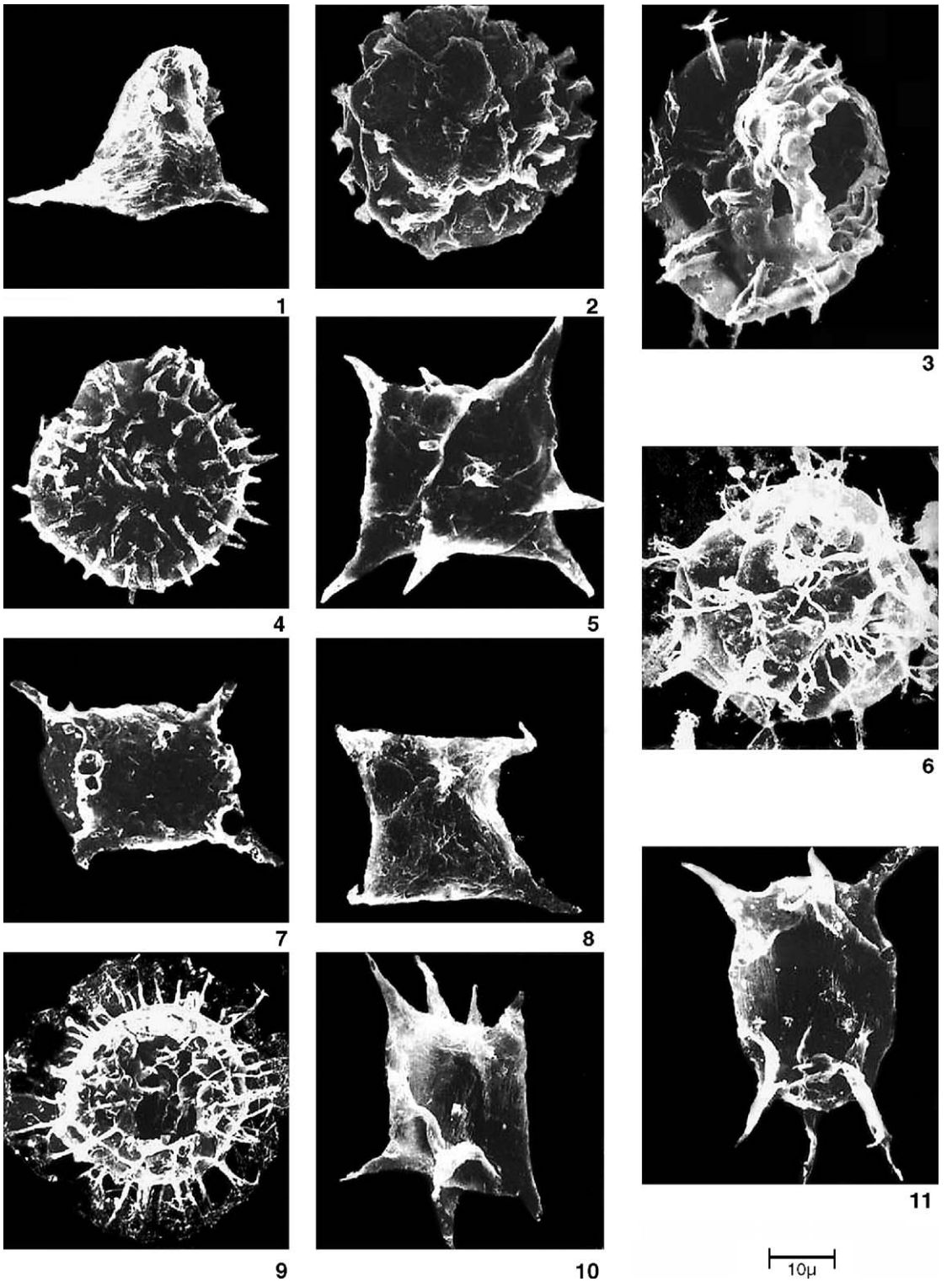


Plate I (*caption on page 86*).

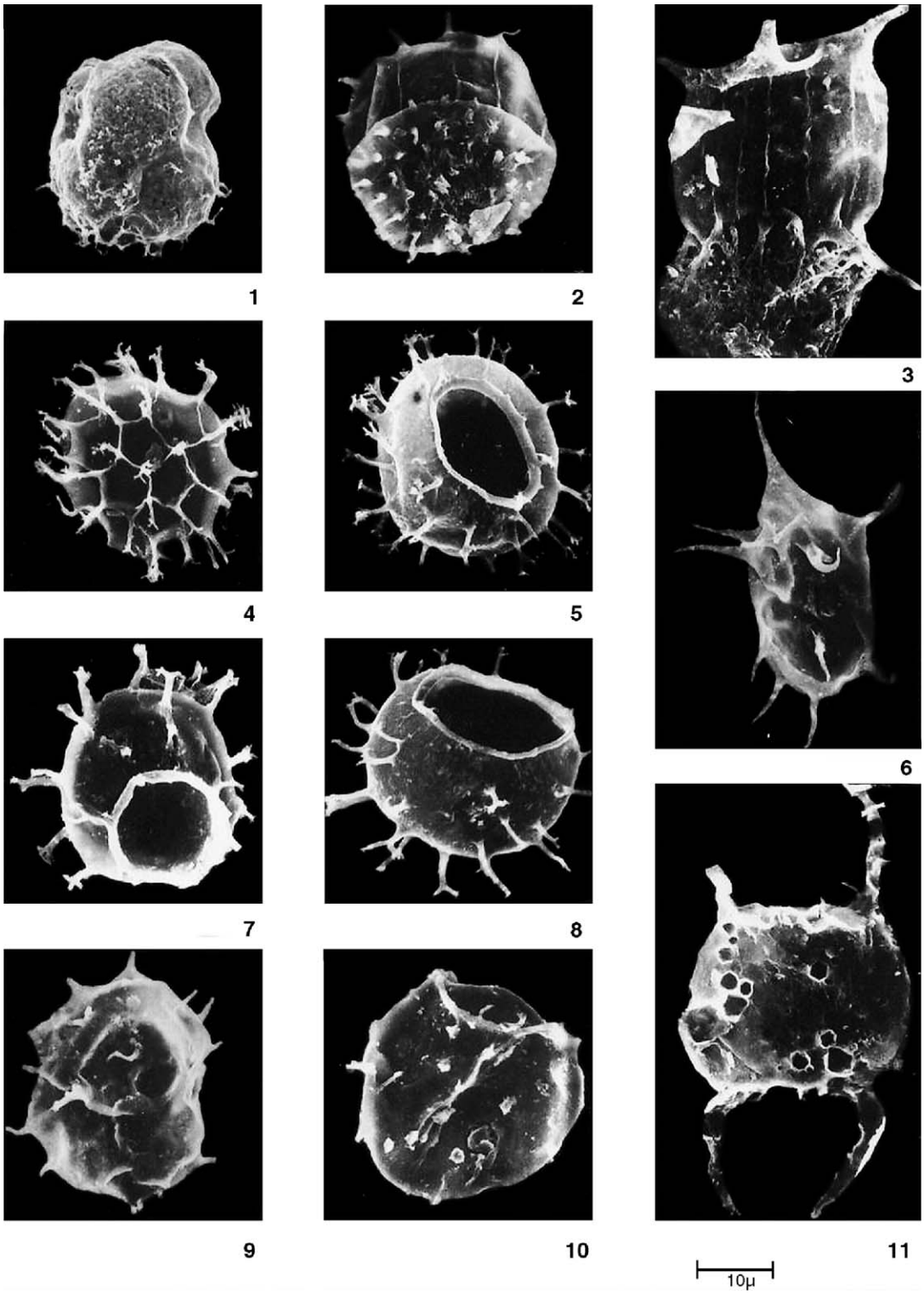


Plate II (*caption on page 86*).

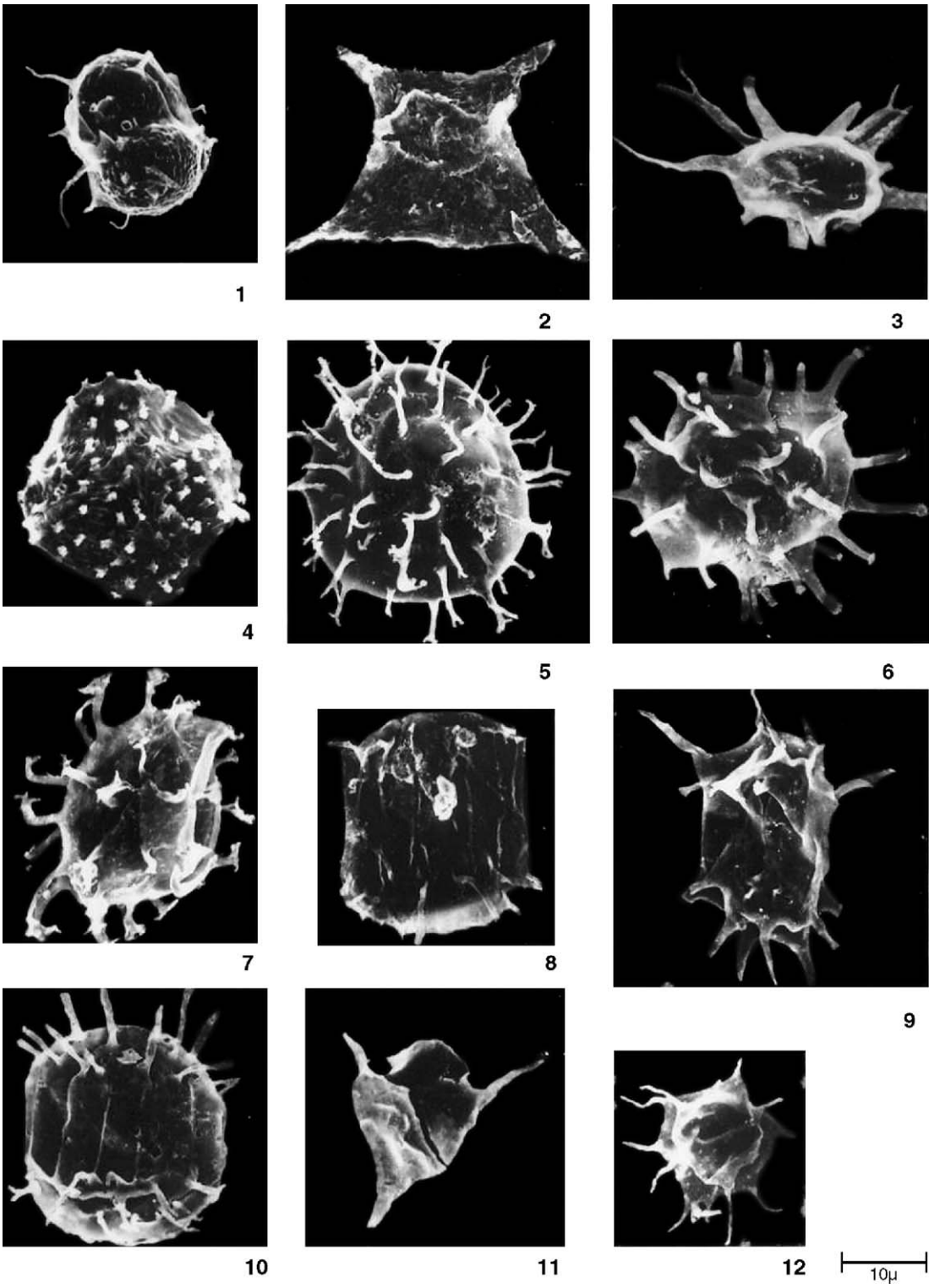
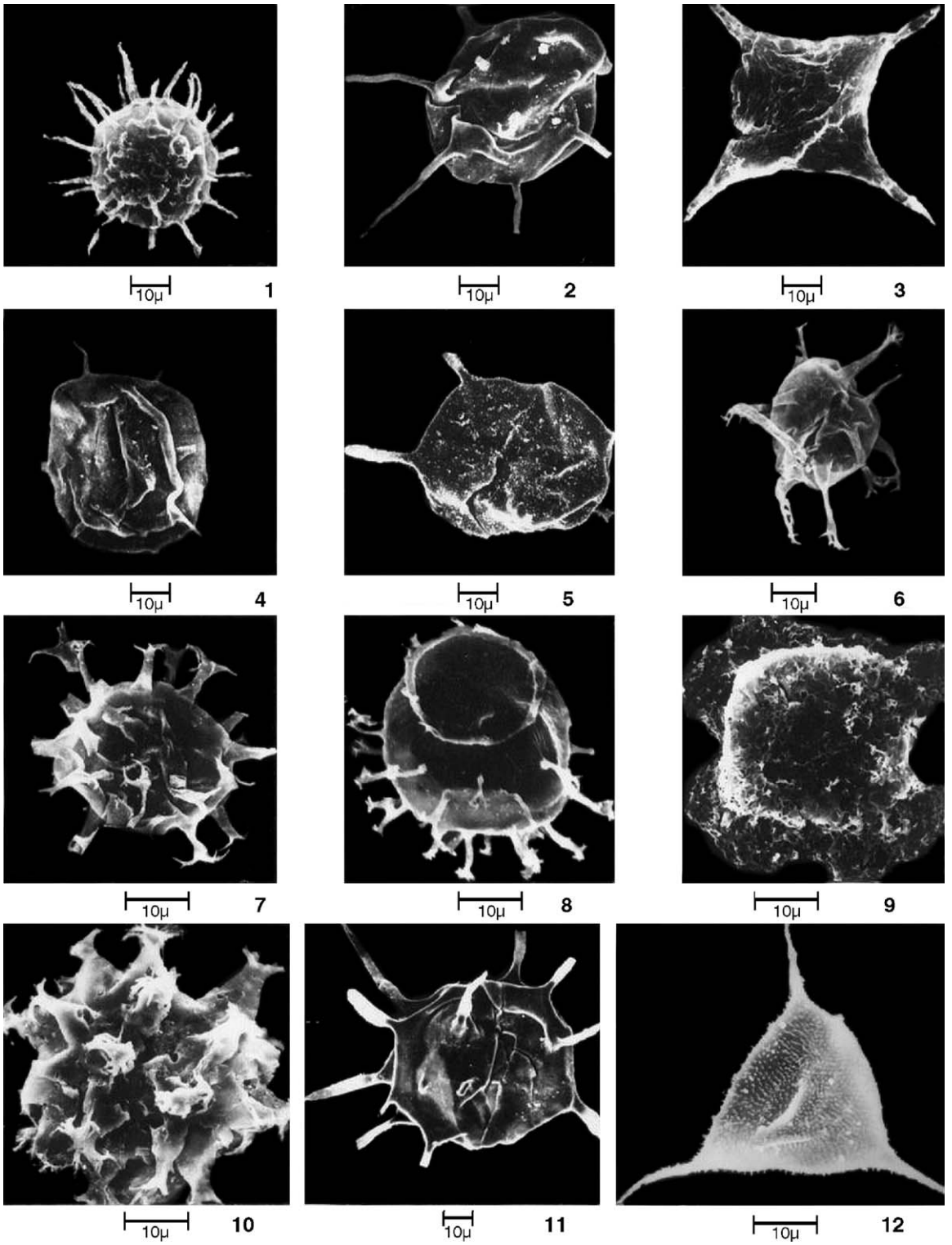


Plate III (*caption on page 86*).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All acritarch species of this assemblage of the Lashkarak Formation belong to the peri-Gondwana acritarch palaeoprovince (Vavrdová, 1974; Servais et al., 2003), especially *Striatotheca*, *Arbusculidium*, *Coryphidium* and *Aureotesta.* The presence of peri-Gondwana acritarch taxa in the Lashkarak Formation of Kuh-e-Kharbash suggests that this part of Iranian Platform has also been part of peri-Gondwana palaeocontinent along the southern shore of Tethys ocean during the Arenig.

4.4. Acritarch assemblage zone IV

This assemblage zone appears in the uppermost part of Lashkarak Formation and extends through 20 m of this rock unit (Fig. 2). The most characteristic acritarch species of this zone are *Acanthodiacrodium costatum*, *Multiplicisphaeridium multipugiunculatum*, *Peteinosphaeridium armatum* and *P. velatum.*

Among these acritarchs, *Peteinosphaeridium velatum* and *P. armatum* have been recorded in the Late Arenig strata of Sweden (Kjellström, 1971; Ribecai and Tongiorgi, 1995; Playford et al., 1995), Southern China (Tongiorgi et al., 1995) and Iran (Ghavidel-syooki, 1997, 2001, 2003). *Multiplicisphaeridium multipugiunculatum* has been recorded in the Late Arenig deposits of Morocco (Cramer et al., 1974; Cramer and Diez, 1977) and *Acanthodiacrodium costatum* has been reported in the Late Arenig sediments of Czech Republic (Vavrdová, 1972,1974 1997, 1990), Morocco (Cramer and Diez, 1977), Great Britain (Downie, 1984) and Iran (Ghavidel-syooki, 1997, 2001, 2003).

Based on the stratigraphic significance of the above-mentioned acritarch taxa, this part of the Lashkarak Formation is assigned to the Arenig age. It should be mentioned that some acritarch taxa of this assemblage have stratigraphical distribution in the late Arenig and Middle Ordovician, however this assemblage zone cannot include both late Arenig and Middle Ordovician strata since there is not any diagnostic acritarch species from Middle Ordovician in this zone. Therefore, the Middle Ordovician strata are not present in the studied stratigraphical column of Kuh-e-Kharbash.

4.5. Acritarch assemblage zone V

This assemblage zone begins in the lowermost part of Ghelli Formation and extends through a thickness of 209 m of the examined stratigraphic section (Fig. 2). This zone is marked by the disappearance of the Lower Ordovician species (Tremodoc–Arenig) and appearance of new acritarch species, consisting of *Actinotodissus longitaleosus*, *Baltisphaeridium dasos*, *B. longispinosum* subsp. *delicatum*, *Goniosphaeridium antiquum*, *G. splendens*, *Multiplicisphaeridium bifurcatum*, *M. irregulare*, *Multiplicisphaeridium* sp., *Ordovicidium elegantulum* and *Veryhachium lairdii.*

Amongst the acritarch species characteristic of this zone, *Veryhachium lairdii* has been reported to occur worldwide from the Middle Ordovician–Devonian (Turner, 1984), whereas the remainder belong to the Middle–Upper Ordovician. Some of the acritarch species from this zone such as *Gorgonisphaeridium antiquum*, *Multiplicisphaerdium bifurcatum*, *M. irregulare* and *Ordovicidium elegantulum* have been recorded in the Middle–Upper Ordovician strata of Sweden (Kjellström, 1971; Görka, 1987), England (Turner, 1985), the United States (Colbath, 1979; Loeblich and Tappan, 1971, 1978; Tappan and Loeblich, 1971), Czech Republic (Vavrdová, 1988), Saudi Arabia (Jachowicz, 1995), Canada (Jacobson and Achab, 1985) and Iran (Ghavidel-syooki, 2000, 2001, 2003). Likewise, the species *Baltisphaeridium longispinosum*, *B. dasos* and *Goniosphaeridium splendens* have only been recorded from the Caradoc sediments of Shropshire in England (Turner, 1984).

Based on these palynological data, this part of the Ghelli Formation is assigned to the Upper Ordovician (Caradoc).

Plate IV.

1. *Goniosphaeridium splendens* (Paris and Deunff) Turner, 1984.
2. *Baltisphaeridium longispinosum* subsp. *delicatum* Turner, 1984.
3. *Striatotheca principalis* Burmann, 1970.
4. *Dasydiacodium tremadocum* (Görka) emend. Tongiorgi *in* Bagnoli et al. 1988.
5. *Orthosphaeridium inflatum* Loeblich, 1970.
6. *Multiplicisphaeridium irregulare*Staplin et al. 1965.
7. *Ordovicidium elegantulum* Loeblich and Tappan, 1971.
8. *Stelliferidium cortinulum* (Deunff, 1961) emend. Deunff et al. 1974.
9. *Coryphidium persianense* Ghavidel-syooki, 1990.
10. *Multiplicisphaeridium multipugiunculatum* Cramer and Diez, 1977.
11. *Orthosphaeridium insculptum* Loeblich, 1970.
12. *Villosacapsulla setosapellicula* (Loeblich) Loeblich and Tappan, 1976.

4.6. Acritarch assemblage zone VI

This assemblage zone occurs in the upper part of Ghelli Formation and extends through 90 m of this rock unit (Fig. 2). This zone is characterized by co-occurrence of *Orthosphaeridium inflatum*, *Orthosphaeridium insculptum*, *Veryhachium subglobosum* and *Villosacapsulla setosapellicula.*

Among the above-mentioned acritarch species of this zone, *Villoscapsulla setosapellicula* has been recorded from Upper Ordovician deposits of the United States (Colbath, 1979; Loeblich, 1970; Miller, 1991; Wicander et al., 1999), England (Turner, 1984), Algeria (Jardiné et al., 1974; Vecoli, 1999), Saudi Arabia (Jachowicz, 1995) and Jordan (Keegan et al., 1990). Similarly, *Veryhachium subglobosum* has been recorded from the Ashgill strata of Jordan (Keegan et al., 1990), Saudi Arabia (Jachowicz, 1995), Algeria (Jardiné et al., 1974; Vecoli, 1999), Libya (Molyneux and Paris, 1985; Hill and Molyneux, 1988), Iran (Ghavidel-syooki, 1997, 2000, 2001, 2003). The two critical acritarch species of this assemblage are *Orthosphaeridium inflatum* and *Orthosphaeridium insculptum,* which have been associated with the *Dicellograptus complanatus* graptolite Zone in the Vauréal Formation (Ashgill) of Canada (Jacobson and Achab, 1985), the Upper Ordovician Sylvan Shale (Ashgill) of the United States (Loeblich, 1970; Wicander et al., 1999) and in Ashgill deposits of Jordan (Keegan et al., 1990), Saudi Arabia (Jachowicz, 1995) and Iran (Ghavidel-syooki, 2000, 2001, 2003).

Based on comparisons of the stratigraphic ranges of these species with those of elsewhere, the acritarch assemblage zone VI is also assigned to Upper Ordovician (Ashgill). The Ghelli Formation is disconformably overlain by the Geirud Formation (Fig. 2).

Based on palaeontological data, the Geirud Formation has been assigned to the Upper Devonian (Gaetani, 1965; Kimyai, 1972; Ghavidel-syooki, 1994) and therefore indicates a major hiatus between the Ghelli and Geirud formations in Kuh-e-Kharbash (near Deh-Molla). This hiatus encompasses the whole Silurian and Lower–Middle Devonian strata, possibly corresponding to the Caledonian Orogeny.

The same hiatus is true from Kuh-e-Kharbash towards the central and western Alborz Mountain Ranges, whereas the Silurian strata are well-developed toward eastern Alborz Mountain Range (Kopet–Dagh region).

5. Conclusions

The Mila, Lashkarak and Ghelli formations of Kuh-e-Kharbash of Deh-Molla area yielded 52 palynomorph taxa. The local stratigraphic distribution of these taxa is shown in Fig. 2. Assemblage I appears in the Mila Formation, suggesting the Upper Cambrian. The assemblages II through IV occur in the Lashkarak Formation, representing the Lower Ordovician (Tremadoc–Arenig). The assemblages V and VI are present in the Ghelli Formation, indicating the Upper Ordovician (Caradoc–Ashgill).

Comparison of the Lower Ordovician acritarch taxa with those of elsewhere indicates broad similarity with those from the peri-Gondwana acritarch palaeoprovince. This acritarch palaeoprovince includes southern Europe, North Africa, South America, eastern Newfoundland, southwestern China, the southern and central Iranian Basins and Saudi Arabia.

The presence of peri-Gondwana acritarch taxa in the Lashkarak Formation of Kuh-e-Kharbash (near Deh-Molla), suggests that the whole Alborz Mountain Range has been part of the peri-Gondwanan palaeocontinent, positioned along the southern shore of the palaeo-Tethys Ocean during the Lower Ordovician (Arenig).

The acritarch assemblages in the Ghelli Formation suggest broad similarity with those from the Upper Ordovician strata in Morocco, Algeria, Libya, Jordan, Saudi Arabia, England and Czech Republic. The palynomorphs and organic debris range in color from yellow to orange-brown, indicating a suitable thermal maturation for the organic materials of Mila, Lashkarak and Ghelli formations.

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