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# Palynostratigraphy and Palaeogeography of the Cambro-Ordovician strata in southwest of Shahrud (Kuh-e-Kharbash), North 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 paleontologically 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. Fifty two 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 through the entire succession. Comparison of the acritarch recorded taxa 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; Palaeobiogeography; Northern Iran.*

## Introduction

The study area is called Kuh-e Kharbash, which is located near Deh-Molla, approximately 20 km 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 this area.

The study area is part of the Central Alborz Mountain Range, located near 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 progressively disappeared from the Kuh-e-Kharbash towards the Central Alborz Range and the whole Ordovician and Silurian strata are not present in the western Alborz Range, whereas Upper Ordovician and Silurian deposits are present and well-developed toward the eastern Alborz Range.

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.

## 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).

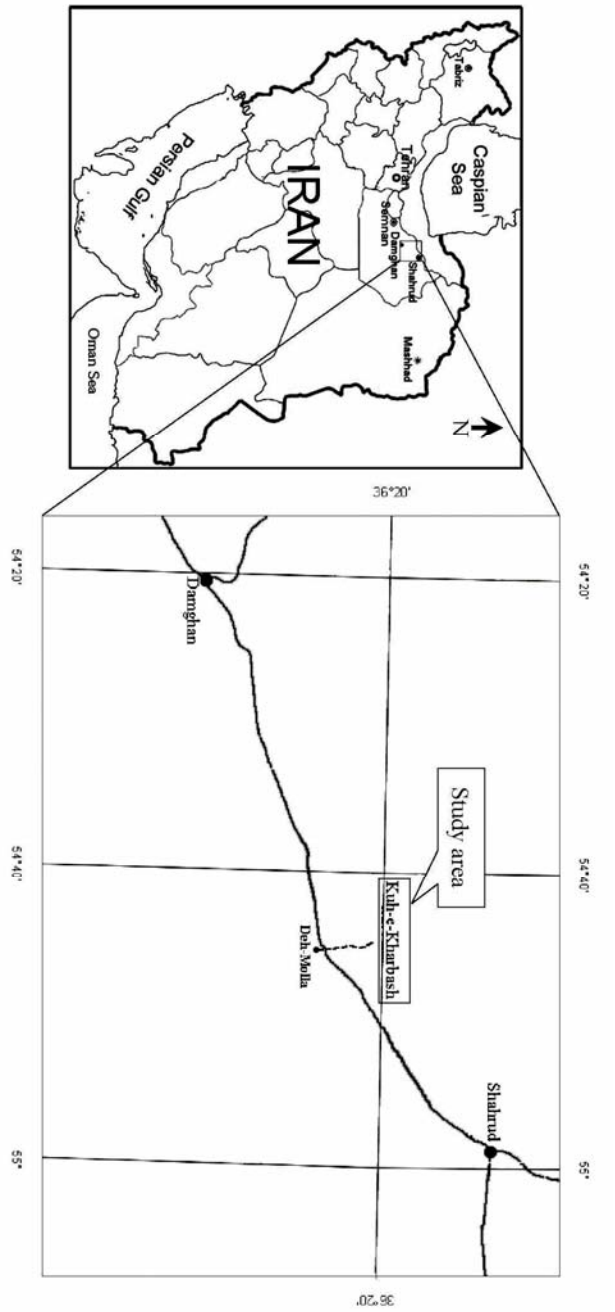


**Figure 1- Location map of the studied area.**

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 29.5m 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 & 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).

## Materials and Methods

Paleontological 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, scole-codonts and rare small trilete spores).

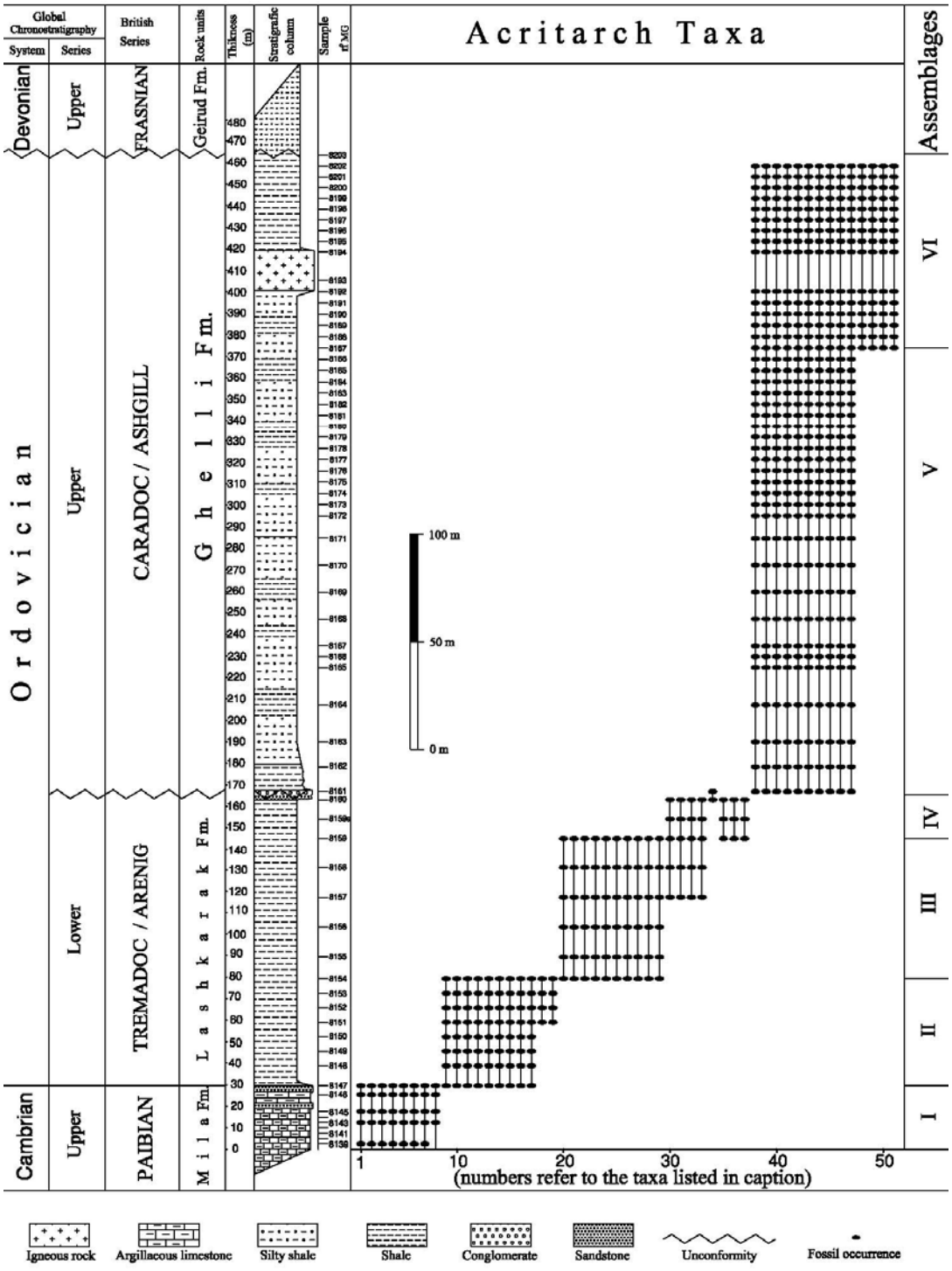


**Figure 2- Stratigraphical distribution of selected acritarch taxa in the Late Cambrian-Ordovician strata, southwest of Shahrud city (Deh-Molla area) northeastern Iran. The recorded taxa are listed below (numbers refer to the corresponding columns in the figure).**

1= *Ooidium rossicum* Timofeev, 1957; 2=*Timofeevia pentagonalis* (Vanguestainé) Vanguestainé, 1978; 3= *Dasydiacrodium obsonum* Martin in Martin & Dean 1988; 4= Algal cluster (coenobium); 5= *Dasydiacrodim caudatum* Vanguestainé 1973; 6= *Acanthodiacrodium achrasii* (Martin) Martin & Dean 1988; 7= *Vulcanisphaera turbata* Martin *in* Martin & 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* (Gorká) 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* (Górka) emend. Tongiorgi *in* Bagnoli *et al.* 1988; 19= *Acanthodiacrodium rotundatum* Górka 1967; 20= *Arbusculidium filamentosum* (Vavrdová) Vavrdová 1972; 21= *Arbusculidium iranense(A. iranica)* Ghavidel-syooki 1990; 22= *Coryphidium bohemicum* (Vavrdová) Vavrdová 1972; →

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.

## 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 and 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 micrographs were prepared for all selected acritarch taxa and illustrated on Plate I-IV.

### Acritarch assemblage zone 1

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 & Stephenson 1989, Miller & 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. The above-mentioned acritarch taxa suggest Upper Cambrian for the Upper part of Mila Formation (Fig. 2). the acritarch species of this assemblage have been recorded in the Late Cambrian strata of Canada(Martine and Dean, 1981, 1988, Parson & Anderson 2000), the United states (Wood and Stephenson, 19890, Sweden (Bagnoli *et al.* 1988), Norway (Welsch 1986) Belgium (Vanguestainé 1973, 1978) Belgium and northern France (Ribecai & Vanguestainé 1993), Russia (Volkova 1990), North Africa (Jardiné *et al.* 1974, Vecoli 1999) and southern Iran (Ghavidel-syooki 1977).

### 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*, *Vulcanisphaera cirrita* and *V. africana.*

Figure 2- (continued). 23. *Coryphidium persianense* (*A. persica*) Ghavidel-syooki 1990. 24. *Barakella fortunata* Cramer & Diez 1977. 25. *Coryphidium australe* Cramer & Diez 1976. 26. *Polygonium gracile* Vavrdová 1966. 27. *Polygonium* sp. 28. *Aureotesta clathrata* var. *simplex* (Cramer *et al*. 1974) emend. Bracke *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 & Diez 1977. 37. *Peteinosphaeridium armatum* Tongiorgi *et al.*1995. 38. *Peteinosphaeridium velatum* Kjellström 1971. 39. *Baltisphaeridium dasos* Colbath 1979. 40. *Ordovicidium elegantulum* Loeblich & Tappan 1971. 41. *Baltisphaeridium longispinosum* subsp. *delicatum* Turner 1984. 42. *Gorgonisphaeridium antiquum* Loeblich & Tappan 1978. 43. *Goniosphaeridium splendens* (Paris & Deunff) Turner 1984. 44. *Actinotodissus longitaleosus* Loeblich & 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 & Tappan 1976. 51. *Orthosphaeridium inflatum* Loeblich 1970. 52. *Orthosphaeridium insculptum* Loeblich 1970.

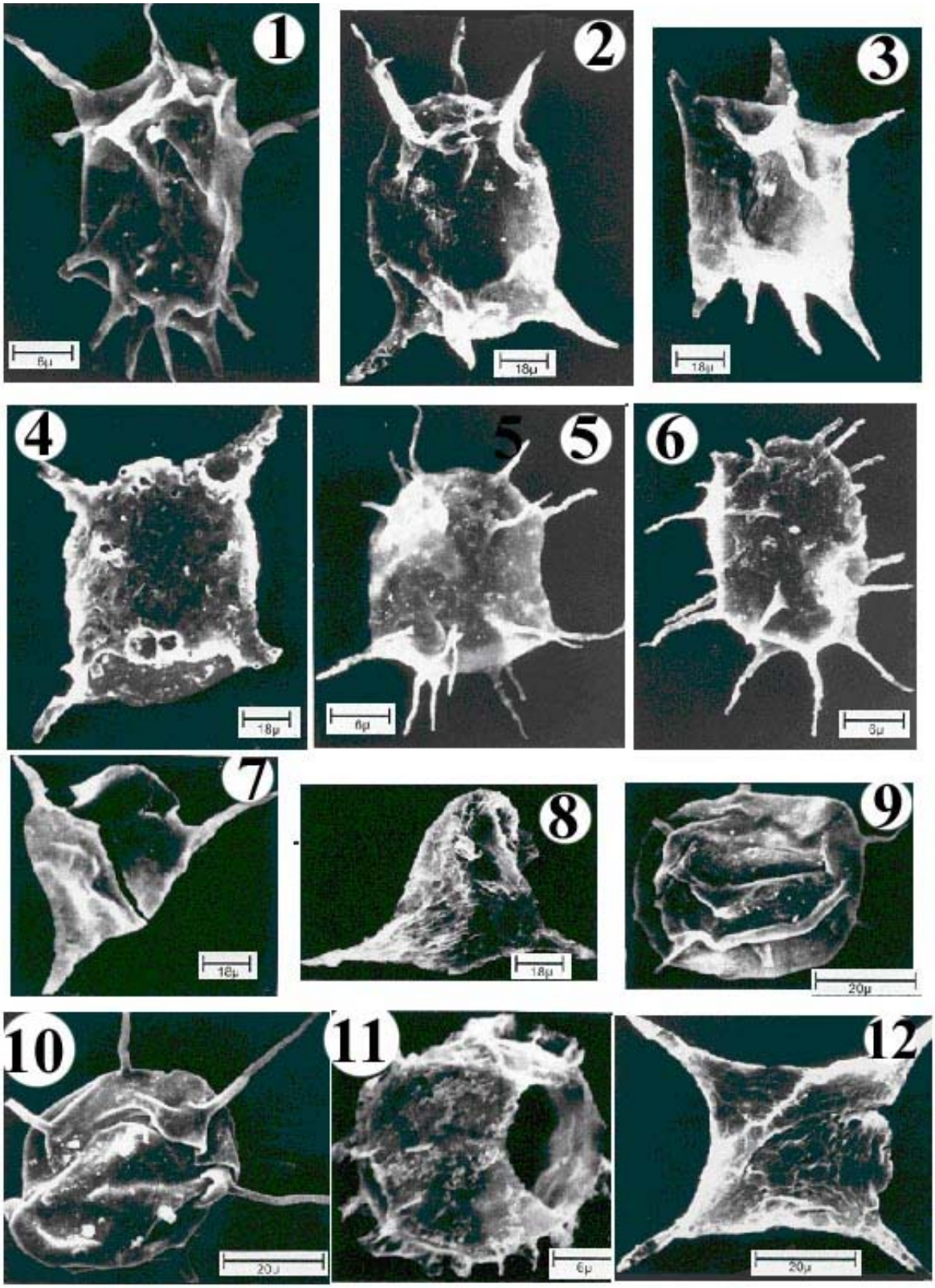


**Plate I: 1. *Actinotodissus longitaleossus* Loeblich & Tappan 1978. 2. *Barakella fortunata* Cramer & Diez 1977. 3. *Striatotheca trapezformis* Burmann 1970. 4. *Aureotesta clathrata simplex* (Cramer *et al.* 1974) Brocke *et al.* 1998. 5. *Dasydiacrodium obsomum* Martin in Martin & Dean 1988. 6. *Acanthodiacrodium achrasii* (Martin 1973) Martin in Martin & Dean 1988. 7. *Veryhachium subglobosum* Jardine *et al.* 1974. 8. *Arkonia triangulata* (Cramer *et al.* 1974) Varvrdoda 1978. 9. *Dasydiacrodium tremadocum* (Gorka) emend. Tongiorgi in Bagnoli *et al.* 1988. 10. *Baltisphaeridium longispinsoum* subsp. *delicatum* Turner 1984. 11. *Cymatiogalea cristata* (Downie) Rauscher 1973. 12. *Striatotheca principalis* Burmann 1970.**

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 & Higgs 1999), France (Rauscher 1974, Martin 1973), Poland (Górka 1967), Spain (Cramer 1964), Italy (Pittau 1985), Germany (Servais & Molyneux 1997), Austria (Reitz & Höll 1991), North Africa (Combaz 1967, Laoud-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).

**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, Aureotesta 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 & Dean 1988) has recorded *Arbusculidium 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, 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, *Arbusculidium filamentosum* is frequently associated with *Coryphidium bohemicum* in Arenig deposits (Vavrdová 1972, 1974, 1997, 1990, Rauscher 1974, Burmann 1968, 1970). The species of *Coryphidium bohemicum* has likewise been recorded in the Arenig deposits of England and it has co-occurrence with graptolites biozones of Arenig (Molyneux & 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.* 1997). The acritarch species of this assemblage have also been recorded in the Arenig deposits of North Africa (Cramer & Diez 1974, Cramer *et al.* 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 & Molyneux 1997) and Argentina (Rubinstein *et al.* 1999).

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.

**Acritarch assemblage zone IV**

This assemblage zone appears in the uppermost part of Lashkarak Formation and extends through 20m 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 & 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 & Diez 1977) and *Acanthodiacrodium costatum* has been reported in the Late Arenig sediments of Czech Republic (Vavrdová 1972, 1974,

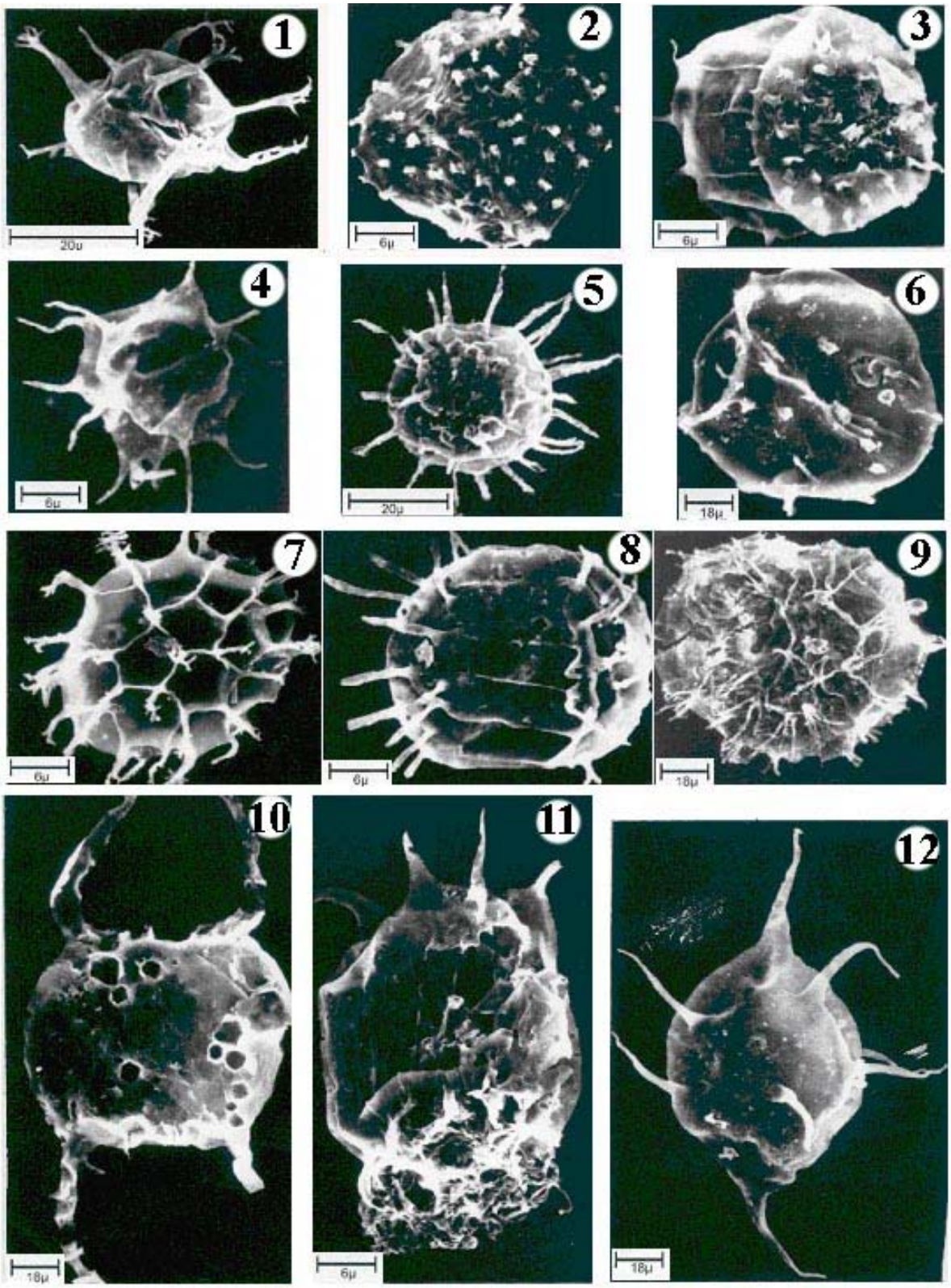


**Plate II- 1. *Multisphaeridium irregulare* Staplin et al. 1965. 2. *Coryphidium bohemicum* (Vavrdová) Vavrdová. 3. *Arbusculidium* (*iranica*) *iranense* Ghavidel-syooki 1990. 4. *Gonisphaeridium tener* (Timofeev) Elouad-Debbaj 1988. 5. *Gonisphaeridium splendens* (Paris & Deunff) Turner 1984. 6. *Cymatiogalea cuvillieri* (Deunff) Deunff 1964. 7. *Timofeevia pentagonalis* (Vanguestainé) Vanguestainé 1978. *8. Arbusculidium* (*iranica*) *iranense* Ghavidel-syooki 1990. *9. Vulcanisphaera turbata* Matin in Matin & Dean 1981. 10. *Aureotesta clathrata clathrata* (Vavrdová 1972) Brocke *et al.* 1998. 11. *Arbusculidium filamentosum* (Vavrdová) Vavrdová 1972. 12. *Dasydiacrodium caudatum* Vanguestainé 1973.**

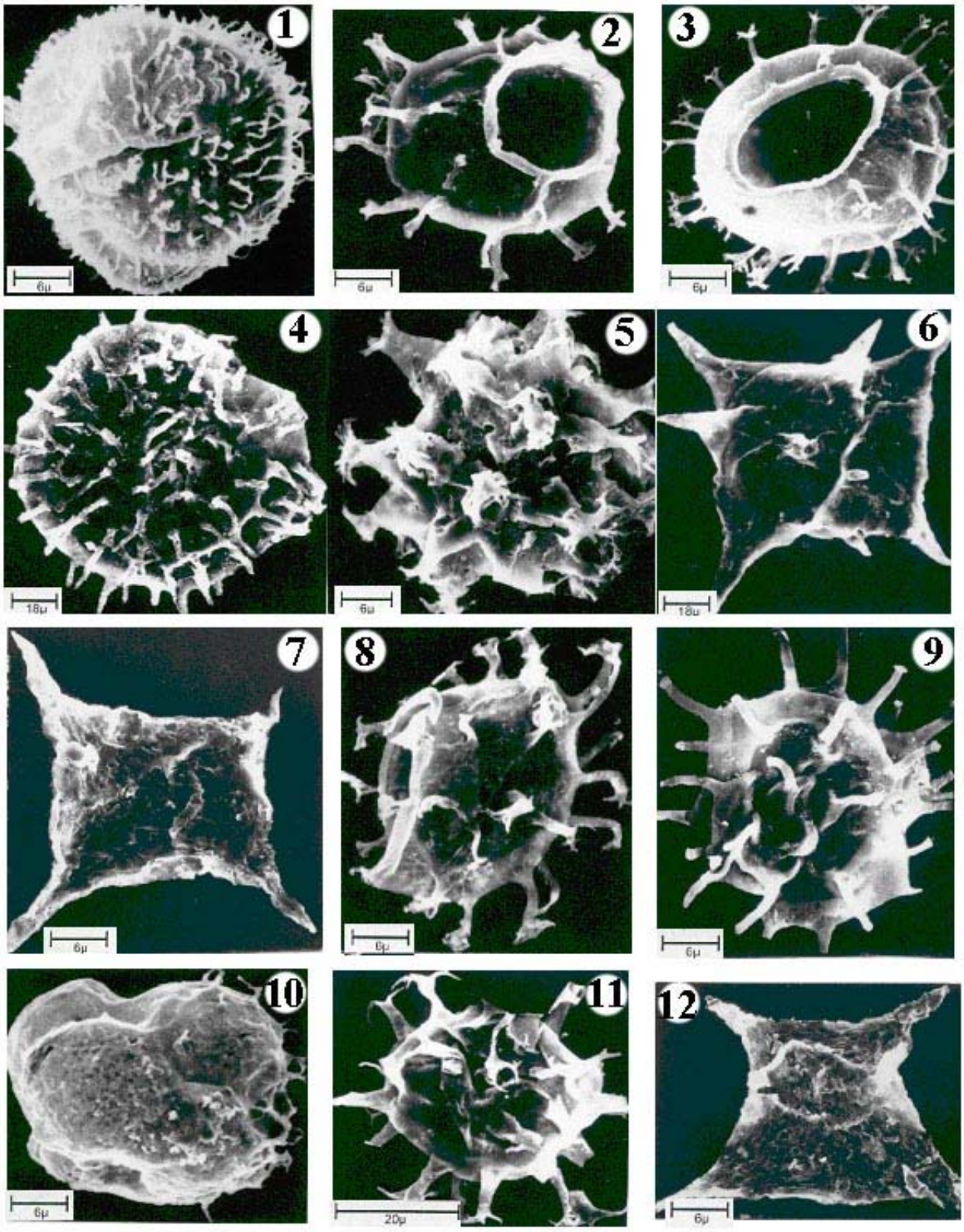


**Plate III- 1. *Gorgonisphaeridium antiquum* Loeblich & Tappan 1978. 2. *Stelliferidium cortinulum* (Deunff 1961) emend. Deunff *et al.* 1974. 3. *Stelliferidium gautieri* (Matin 1972) Elouad-Debbaj 1988. *4. Baltisphaeridium dasos Colbath 1979.* 5. *Multiplicisphaeridium multipugiunculatum* Cramer & Dietz 1977. 6. *Polygonium sp*. 7. *Striatotheca frequens* Burmann 1970. 8. *Stelliferidium barbarum* (Deunff 1961) Elouad-Debbaj 1988. 9. *Coryphidium australe* Cramer & Diez 1976. 10. *Ooidium rossicum* Timofeev 1957. 11. *Ordovicidium elegantulum* Loeblich & Tappan 1971. 12. *Striatotheca transformata* Burmann 1970.**

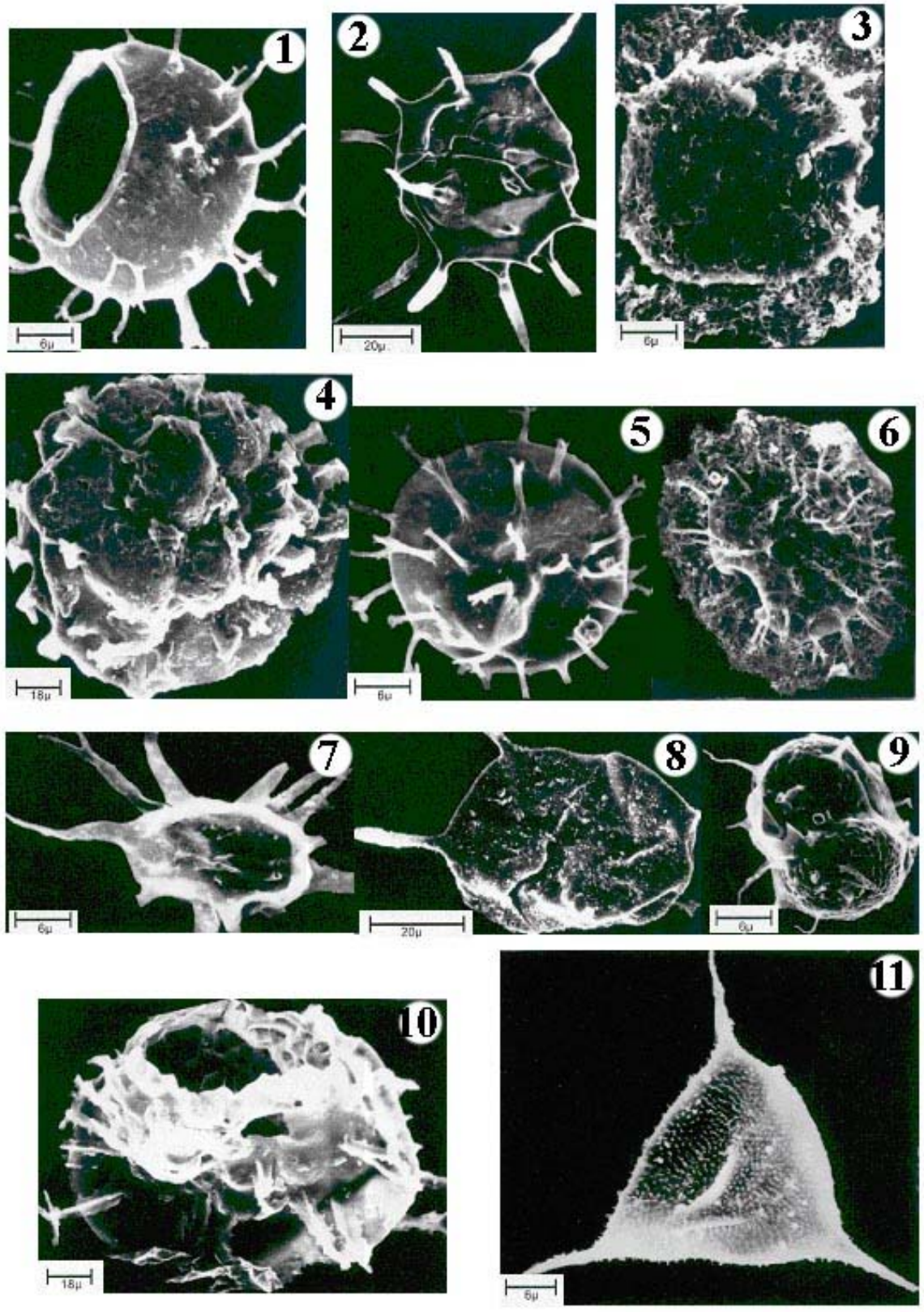


**Plate IV- 1. *Stelliferidium steligerum* (Górka 19617) emend. Deunff *et al.* 1974. 2. *Orthosphaeridium insculptum* Loeblich 1970. 3. *Coryphidium persianense* Ghavidel-syooki 1990. 4. *Peteinosphaeridium velatum* Kjellström 1971. 5. *Goniosphaeridium splendens* (Paris & Deunff) Turner 1984. 6. *Vulcanisphaera cirrita* Rasul 1976. 7. *Multiplicisphaeridium bifurcatum* Staplin *et al.* 1965. 8. *Orthosphaeridium inflatum* Loeblich 1970. 9. Acanthodiacrodium rotundatum Górka 1967. 10. *Peteinosphaeridium armatum* Tongiorgi et al. 1995. 11. *Villosacapsulla setosapellicula* (Loeblich) Loeblich & Tappan 1976.**

1997, 1990), Morocco (Cramer & 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 can not 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.

**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; Górka 1987), England (Turner 1985), the United States (Colbath 1979; Loeblich & Tappan 1978), 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), possibly corresponding to the Caledonian Orogeny.

**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 & Paris 1985, Hill & 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 & 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. 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).

## 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 assemb-lages 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 palaeo-province includes southern Europe, North Africa, South America, eastern Newfoundland, south-western 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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