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Miospore assemblages from Late Ordovician (Katian-Hirnantian), Ghelli Formation, Alborz Mountain Range North-eastern Iran: Palaeophytogeographic and palaeoclimatic implications

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Abstract

Well-preserved miospore assemblages are recorded from the Late Ordovician (Katian-Hirnantian), Ghelli Formation in Pelmis-gorge at the north-eastern Alborz Mountain The palynomorphs were extracted from siliciclastic deposits which are well-dated by using of marine palynomorphs (acritarchs and chitinozoans). The encountered miospore assemblages consist of 14 genera (28 species: 26 cryptospores and 2 trilete spores). Six new cryptospore taxa are described: Rimosotetras punctata, Rimosotetras granulata, Dyadospora asymmetrica, Dyadospora verrucata, Segestrespora iranense and Imperfectotriletes persianense. The present findings contribute to improving knowledge of origin and onset of development of vegetative cover during the Late Ordovician. The recovery of diverse and abundant cryptospores in the Late Ordovician (Katian-Hirnantian) Ghelli Formation are probably related to increasing input of land-derived sediments during the global sea-level fall linked to the Late Ordovician glaciation, and tolerance of the primitive land plants in a wide range of climatic conditions. These miospore taxa were produced by earliest primitive land plants which probably grew close to the shoreline and washed in from the adjacent areas and produced high amount of miospores. The associated marine palynomorphs consist of acritarchs (13 genera and 18 species), chitinozoans (9 genera and 10 species), prasinophycean algae, scolecodonts and graptolite remains which are not discussed in detail herein. The established chitinozoan biozones of this part of Palaeozoic sequences are Armoricochitina nigerica, Ancyrochitina merga, Tanuchitina elongata and Spinachitina oulebsiri, suggesting the Late Ordovician (Katian-Hirnantian). These chitinozoan biozones are well-known only in peri-Gondwanan Domain, indicating that the study area has been part of this palaeo-continent during the Late Ordovician.

Keywords: Miospores; Late Ordovician; Palaeo-biogeography; Palaeo-climatology; Alborz Mountain Ranges.

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Introduction

The record and investigation on terrestrial sporomorphs of Palaeozoic strata (cryptospores and trilete spores) has a long history and goes back to several decades ago; in fact, our knowledge owes to many researchers in this field of geology [14, 20,21, 25, 33,31] ranging from Precambrian to Early Devonian strata. The study of cryptospores is important since land plant macrofossils have not been found in the sediments older than the Silurian in geological records and the cryptospores are thus oldest witnesses of earliest continental vegetation. It has been accepted now that cryptospores were produced by early primitive land plants which probably grew close to the shoreline and were washed in from the adjacent areas. In the Middle East, cryptospores and trilete spores have been recorded from the Middle-Upper Ordovician, Qasim Formation of Arabian Peninsula [23,25] Caradoc of the Hasirah Member of the Safiq Formation of Oman and Upper Ordovician-Silurian, south-eastern Turkey but up to now, there is only one published paper related to record of cryptospore assemblages below Devonian strata, especially Late Ordovician sediments in Iran Therefore, this paper is a complementary contribution to the knowledge of taxonomy and palaeophytogeography of cryptospores and trilete spores from Iranian Platform which was located at high palaeolatitudes (Peri-Gondwanan Domain) during the Upper Ordovician (Katian-Hirnantian). Herein, the cryptospore and spore assemblages are recorded from well-dated Ghelli Formation by means of independent fossil evidence such as acritarchs, chitinozoans, prasinophycean algae, conodonts and brachiopods.

1. Geological setting and Previous Studies

The study area is located, approximately 32 km southern Bojnourd city. The road from Bojnourd to Esfarayen is the main link to the region (Fig. 1). The measured and sampled stratigraphic section was chosen along this road (Fig. 2) since it cuts the whole Palaeozoic strata and is easily accessible for study. In this area, the Lower Palaeozoic strata is 1200m thick and in ascending stratigraphical order has been divided into the Mila (Cambrian), Lashkarak (Early-Middle Ordovician), Ghelli (Middle-Late Ordovician), and Niur (Early Silurian) formations . The study area falls within the Kopeh-Dagh region (northeastern Alborz Mountain Range), where the Lower Palaeozoic rock units extend towards the southern and eastern Caspian Sea. The Mila Formation consists mainly of medium to thick-bedded, cream-reddish brown limestones with poorly preserved megafossils (e. g. brachiopod and trilobites) which have not been identified at level of genera and species. Therefore, based on stratigraphic position, the Mila Formation has been assigned to the Middle and Late Cambrian. The Lashkarak Formation has a very distinctive sedimentary facies consisting of dark-gray shales, siltstones, and fine-grained sandstones which are interbedded with thin-bedded fossiliferous limestones (Fig. 2). In the study area, the Lashkarak Formation contains conodonts, brachiopods and acritarchs which have been assigned to the Tremadocian. The Ghelli Formation mainly consists of olive-gray silty shales,

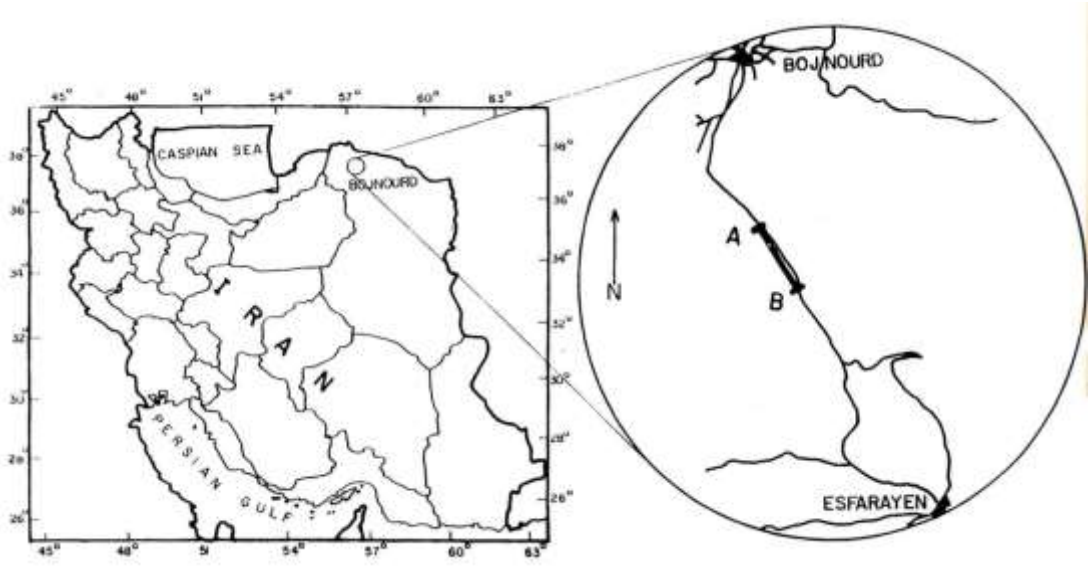

Figure 1. Location map of studied area (after Ghavidel-syooki 2001)

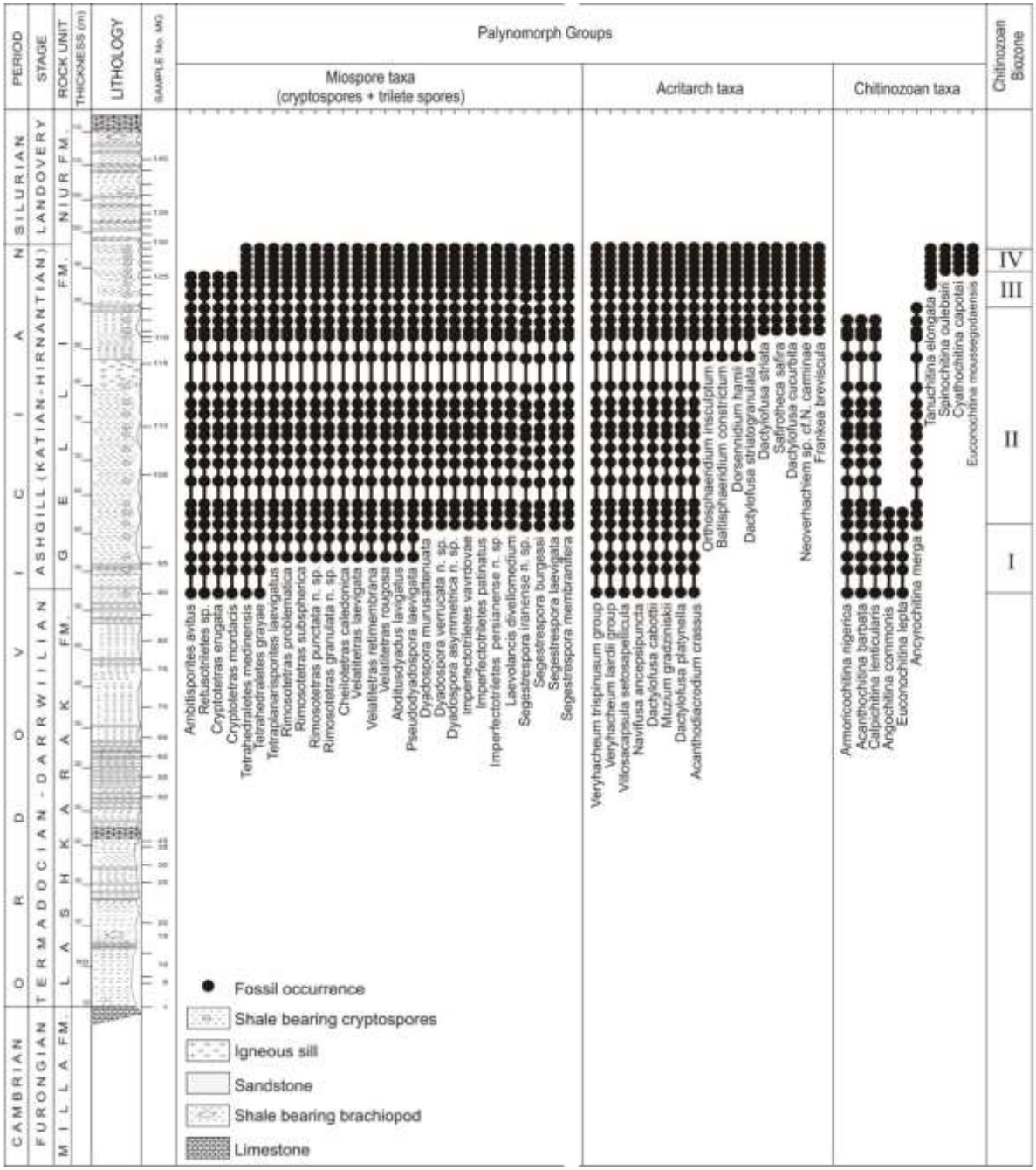

Figure 2. Stratigraphic distribution of different groups of palynomorph within the Ghelli Formation, in Pelmis- gorge, Northeastern Alborz Ranges.

micaceous siltstones and fine-grained sandstones which are cut with a thickness of 44m igneous rock (sill). The lower and upper contacts of Ghelli Formation are conformable with overlying and underlying formations (Fig. 2). Some intervals of this formation contain brachiopods, conodont and well-preserved chitinozoans which suggest Late Ordovician as its type section [8]. The Niur Formation, although well-developed in central Iran, was first described from the north-eastern Alborz Mountain Range. In the Pelmis-gorge area, this formation consists of mainly black shales, siltstones and sandstones with intercalations of fossiliferous limestones (Fig. 2). Herein, the Niur Formation contains abundant corals, brachiopods, crinoids, and palynomorphs (acritarchs and chitinozoans) which suggest an early Silurian [10].

Materials and Methods

A total of 140 surface samples were collected from the whole stratigraphic interval of Lower Palaeozoic strata (Mila, Lashkarak, Ghelli and Niur formations) in Pelmis-gorge, at eastern part of Kuh-e-Saluk, 32km southern Bojnourd city. The collected samples are indicated herein by the National Iranian Oil Company code number preceded by the prefix MG-1 to MG-140 (Fig. 2). Palynomorphs were extracted from shale, siltstone and fine-grained sandstone samples by using standard palynological procedures, including removal of carbonates and silicates by hydrochloric and hydrofluoric acids and density separation of the organic residues in 30 ml of saturated zinc bromide solution. Organic residues were then sieved through 15 μm nylon mesh sieves. Palynological residues were mounted on glass slides for optical as well as scanning electron microscopy examinations. All samples proved palyniferous and yielded well-preserved and abundant palynomorphs with dominating acritarch assemblages as well as rare algal clusters in the Mila Formation, chitinozoans, scolecodonts and chitinous graptolite remains in the Lashkarak and Ghelli formations. In addition to chitinozoans, acritarchs and scolecodonts, abundant cryptospores and rare trilete spores are present only in the Ghelli Formation (MG-90 to MG-130). The aforementioned palynomorph groups were counted and their percentages calculated, indicating samples MG-90 to MG-100 bearing miospores and their percentage is fairly higher than acritarchs and chitinozoans (see Table 1 and Fig. 3). Chitinozoan group is common in samples MG-90 to MG-104 and very rare to rare in the rest of the samples (Table 1 and Fig. 3). The results of palynological study of the area, consisting of acritarch and chitinozoan assemblages of Lower Palaeozoic rock units (Lashkarak, Ghelli and Niur formations) were previously published by [8]. Therefore, this paper has concentrated on the terrestrial palynomorph group of the Ghelli Formation (Katian-Hirnantian), although briefly diagnostic acritarch and chitinozoan taxa were discussed herein. The miospores and acritarchs range in colour from yellow to orange brown, indicating an intermediate degree of thermal maturity of the organic matter (Plate I to Plate VII). All slides pertaining to this study are housed in the palaeontological collections of the Exploration Directorate of the National Iranian Oil Company under samples number of MG-90 to MG-130.

Table 1. Relative percentage of different palynomorph groups of Late Ordovician in the Ghelli Formation, in Pelmis-gorge section, eastern Alborz Mountain Range.

Sample Number (MG)	Miospores (Cryptospores+Spores)%	Acritarchs%	Chitinozoans%	Scolecodonts%	Graptolite Remains%
90	15	69	14	2	**0**
94	27	21.5	46	5.5	**0**
96	19	40	38	2.5	**0.5**
98	17	42.5	35.5	4.15	**0.85**
99	31	38	24	7	**0**
100	21.5	40	33	5.5	**1**
101	56	24	11	7	**2**
104	52	13.5	24.5	5.5	**4.5**
106	46.5	42	4.5	6.5	**0.5**
107	63	27.5	6	1	**2.5**
109	74	21	0	3	**2**
110	75	21.5	0.5	2	**1**
111	80	6	10	3	**1**
112	58	41	0	1	**0**
113	61.5	37.5	1	0	**0**
116	33	65.5	1	0.5	**0**
119	59.4	40.6	0	0	**0**
120	37.5	60.5	1	1	**0**
121	57.5	40	2	0.5	**0**
122	76.4	23.4	0.2	0	**0**
123	54	46	0	0	**0**
124	65	35	0	0	**0**
125	66.5	33	0	0.5	**0**
126	54	45.5	0.2	0.3	**0**
127	65	34.5	0.2	0.3	**0**
128	72	27	1	0	**0**
129	65	16	9	10	**0**

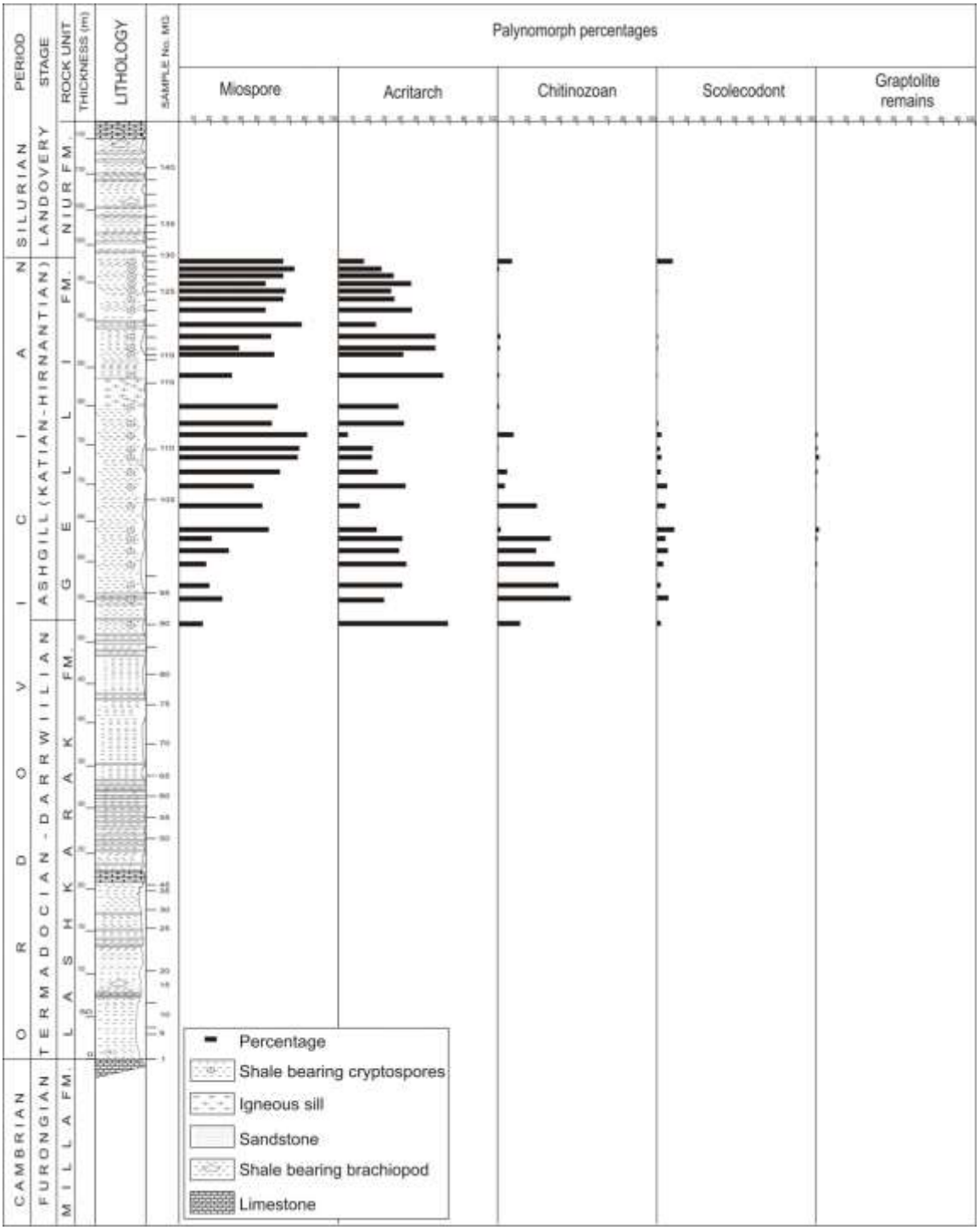

Figure 3. Quantative distribution of different groups of palynomorphs throughout the Ghelli Formation

2. Systematic palaeontology of palynomorphs

In this study, palynomorphs from the Ghelli Formation, especially miospores, are illustrated on plates I – VII, well-known acritarchs on plate VIII and chitinozoans on plate IX. Detailed descriptions are provided only for new miospore taxa (cryptospores and trilete spores). Dimensions, stratigraphic and palaeogeographic distributions are presented for all miospores (Table 2).

Table 2. Comparison of Late Ordovician (Katian-Hirnantian) miospore (cryptospores + trilete spores) taxa from the Ghelli Formation with other localities which contain a significant number of cryptospores in coeval geological time.

List of selected miospore Species (in this Study)	Saudi Arabia	Belgium	Turkey	Czech Republic	North Africa (Libya)	China	South America (Argentina)	UK	North America & Canada
Tetrahedraletes medinensis	+	+	+	+	+	+	+	+	+
Tetrahedraletes grayae	+	+	-	+	+	-	-	-	+
Tetraplanarisporites laevigatus	+	-	-	-	-	-	-	-	-
Rimosotetras problematica	+	-	+	-	+	-	+	+	+
Rimosotetras subspharica	+	-	+	-	-	-	-	-	-
Rimosotetras punctata n. sp.	-	-	-	-	-	-	-	-	-
Rimosotetras granulata n. sp.	-	-	-	-	-	-	-	-	-
Cheilotetras caledonica	+	-	-	-	-	-	-	-	+
Velatitetras laevigata	+	+	+	-	+	+	+	+	+
Velatitetras retimembrana	-	+	+	+	-	-	+	-	-
Velatitetras rugosa	+	+	+	+	+	+	+	+	+
Abditusdyadus laevigatus	+	+	-	-	-	-	+	+	+
Segestrespora membranifera	+	+	+	+	-	-	+	+	+
Segestrespora laevigata	+	+	+	-	+	-	+	+	+
Segestrespora burgessii	-	-	+	-	-	-	-	-	-
Segestrespora iranense n.sp.	-	+	-	-	-	-	-	-	-
Dyadospora murusattenuata	+	+	+	+	+	+	+	-	+
Dyadospora verrucata n. sp.	-	-	-	-	-	-	-		-
Dyadospora asymmetrica n. sp.	-	-	-	-	-	-	-		-
Pseudodyadospora laevigata	+	+	+	+	+	+	+	+	+
Imperfectotriletes vavrdovae	+	+	+	+	+	-	+	+	-
Imperfectotriletes persianense n. sp.	-	-	-	-	-	-	-	-	-
Imperfectotriletes patinatus	+	+	-	-	-	-	-	-	-
Cryptotetras erugata	+	-	-	-	-	-	-	-	-
Cryptotetras mordacis	+	-	-	-	-	-	-	-	-
Laevolancis divellomedium	+	+	+	-	+	+	+	+	+
Ambitisporites avitus	+	+	+	-	+	-	-	+	-
Retusotriletes sp. A.	+	-	-	-	-	-	-	-	-

2.1 Miospore group (cryptospores and trilete spores)

Miospores have been treated as non-marine palynomorphs. The cryptospores are without trilete or monolete marks and with or without contact features, consisting of tetrads, dyads and monads [31]. The trilete spores are formed in tetrads, but dispersed separately with either a trilete or monolete mark on proximal surfaces. The cryptospores can be divided into subgroups based on presence/absence of morphological features which have been proposed. The term "miospore" is used herein as a general term indicating all fossil plant spores smaller than 200μm, including both cryptospores and trilete spores. Based on presence or absence of morphological features which were

proposed by [31] the systematic palaeontology of miospores (cryptospores and trilete spores) is discussed below.

2. 1 A. *Anteturma CRYPTOSPORITES 104.*
2. 1 A-1. *Subgroup naked unfused tightly and loosely adherent cryptospore tetrads.* This subgroup has adherent tetrads which lines separate the four spores of the tetrad and it is without enclosing envelopes.

Genus ***Cryptotetras*** [25].

Cryptotetras erugata [25] (Plate I, 4;Plate II, 1, 11, 12; Plate III,8, 16, 17, 18; Plate V, 1, 2, 16).

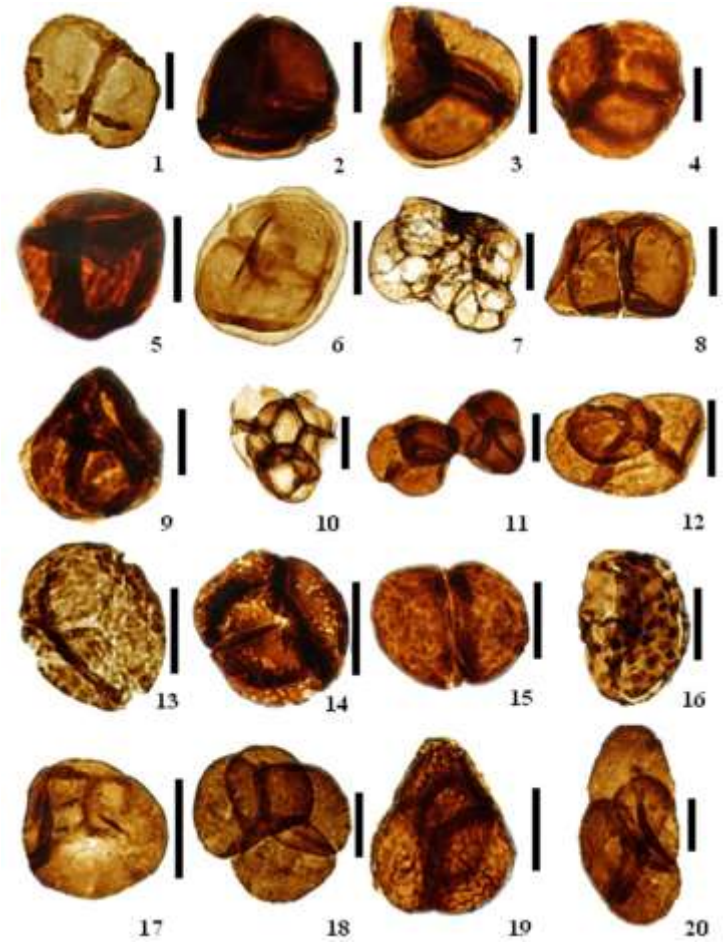

Plate I (Scale bare 10µ)
Fig. 1. *Dyadospora murusattenuata* [130] [14].
Figs. 2, 3. *Cheilotetras caledonica* [167].
Fig. 4. *Cryptotetras erugata* [134].
Figs. 5, 9. *Rimosotetras problematica* [13].
Fig. 6. *Segestrespora* (*Dyadospora*) *burgessii* [123].
Figs. 7, 10. *Retusotriletes* sp.
Fig. 8. *Abditusdyadus laevigatus*? [167].
Figs. 11, 18, 20. *Rimosotetras subspherica* [173].
Fig. 12. *Tetraplanarisporites laevigatus* [173].
Fig. 13. *Imperfectotriletes persianense* n. sp.
Fig. 14. *Rimosotetras punctata* n. sp.
Fig. 15. *Dyadospora verrucata* n. sp.
Fig. 16. *Segestrespora iranense* n. sp. (with dense granulate ornamentation).
Fig. 17. *Imperfectotriletes vavrdovae* [126].
Fig. 19. *Velatitetras retimembrana* [84] [123].

Dimensions: 13 (19) 25µm, two specimens were measured. The size range of Iranian specimens is smaller than those of Arabian Peninsula [25].

Occurrences: This species is present within the Ghelli Formation (samples MG-90 to MG-125), eastern Alborz Mountain Range.

Previous records: So far, this species has been recorded from Hanadir Shale Member of Qasim Formation, Ordovician (Darriwilian) of Arabian Peninsula [25].

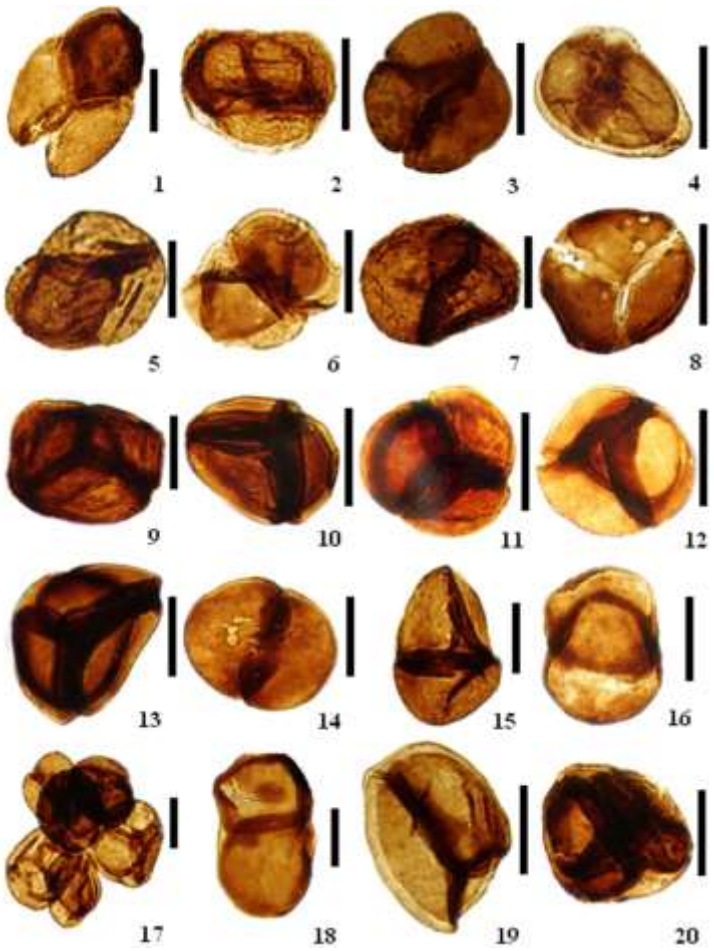

Plate II (scale bar 10µ)
Fig. 1. *Cryptotetras erugata* [134].
Fig. 2. *Velatitetras retimembrana* [84] [123].
Fig. 3. *Tetraplanarisporites laevigatus* [173].
Figs. 4, 19. *Segestrespora burgessii* [123].
Fig. 5. *Segestrespora laevigata* [13].
Fig. 6. *Abditusdyadus laevigatus* [167]. 7. *Velatitetras* (Nodospora) *rugosa* [123].
Fig. 8. Imperfectotriletes vavrdovae [126].
Figs. 9, 10. Tetrahedraletes grayae [131].
Figs. 11, 12. Cryptotetras erugata [134].
Fig. 13. Rimosotetras problematica [13].
Fig. 14. Dyadospora murusattenuata [130] [14].
Fig. 15, 16, 18. Dyadospora asymmetrica n. sp.
Fig. 17. Retusotriletes sp.
Fig. 20. Tetrahedraletes medinensis [132] emend. [167].

Cryptotetras mordacis [25] (Plate III, 9, 12).

Dimensions: 21 (24) 27µm, the Iranian specimens are smaller than those of Arabian Peninsula [25].

Occurrences: This species is common in the Ghelli Formation (samples MG-90 to MG-125).

Previous records: Hanadir Shale Member of Qasim Formation, Ordovician (Darriwilian) of Arabian Peninsula.

Genus ***Tetrahedraletes*** emend.

Type species: *Tetrahedraletes medinensis* emend.

Tetrahedraletes medinensis emend. (Plate III, 3, 4, 7, 10, 13; Plate V, 4, 13, 14, 15, 17, 18, 20; Plate VI, 5, 10, 11, 18, 20; Plate VII, 14)

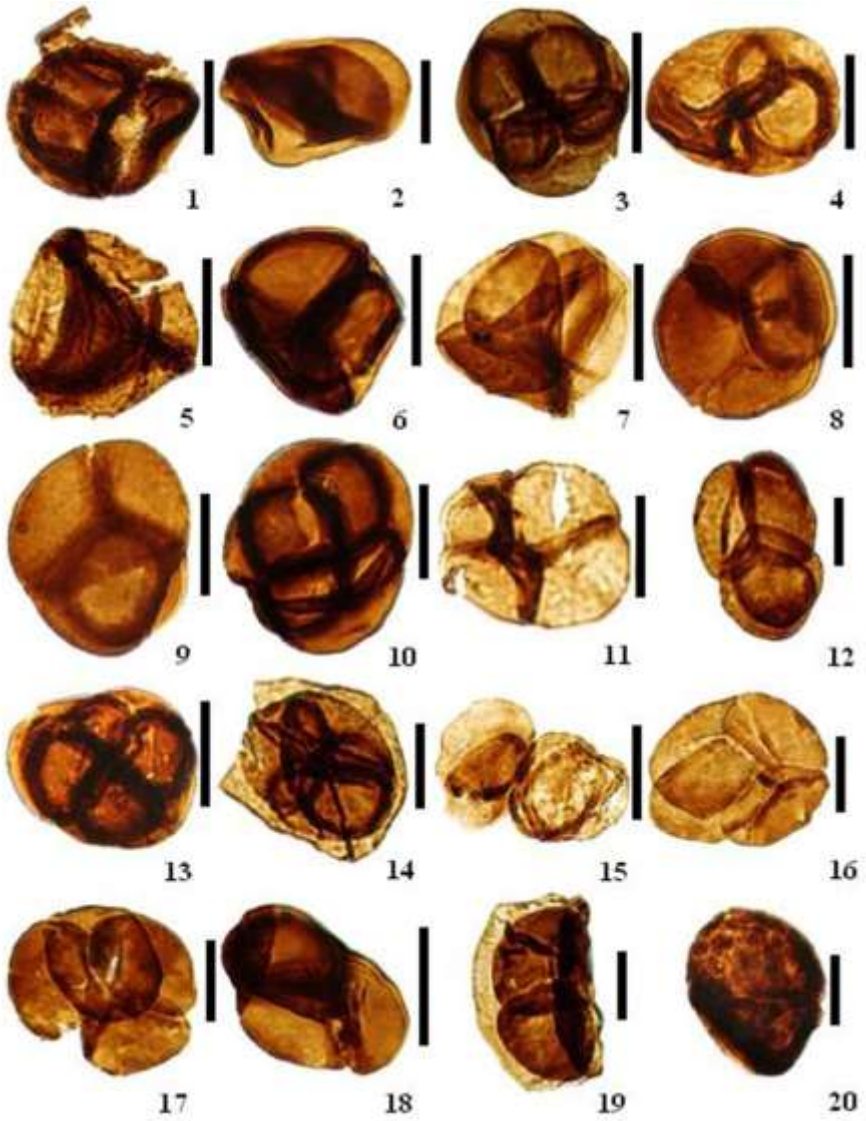

Plate III (scale bar 10µ)
Figs. 1, 5, 6. Rimosotetras problematica [13].
Figs. 2, 15. Segestrespora laevigata [130].
Figs. 3, 4, 7, 10, 13. Tetrahedraletes medinensis [132] emend. [167].
Figs. 9, 12. Cryptotetras mordacis [134].
Figs. 8, 16, 17, 18. Cryptotetras erugata [134].
Fig. 11. Tetraplanarisporites laevigatus [173].
Fig. 14. Velatitetras (Nodospora) rugosa [130] [123].
Fig. 19. Abditusdyadus laevigatus [167].
Fig. 20. Dyadospora verrucata n. sp.

Dimensions: 15 (30) 45µm, twenty specimens measured. The size range of Ghelli Formation's is smaller than those of Turkey , China and Canada and Estonia [31].

Occurrences: This species is present throughout the Ghelli Formation (samples MG-90 to MG-130), eastern Alborz Mountain Range (Fig. 2).

Previous records: So far, *Tetrahedraletes medinensis* has been recorded from the Caradoc type section, Shropshire, U. K. ; Upper Ordovician at Hlásná Třebaň, Czechoslovakia ; Upper Ordovician (Late Katian-Hirnantian), Bedinan Formation, southeastern Turkey ; Kalpintag Formation, South Xinjiang, China ; the Ordovician/Silurian boundary from the upper member of the Salar del Rincon Formation in the Puna region, North-west Argentina ; Hirnantian-Llandovery (*persculptus* graptolite Biozone - *turriculatus* graptolite Biozone), southwest Wales ; Latest Ashgillian, or earliest Llandovery(Rhuddanian), Cedaberg Formation, South Africa ; Upper Ordovician (Katian-Hirnantian) strata of Anticosti Island, Québec, Canada and Estonia [160]; Upper Ordovician (Katian-Hirnantian), Ghelli

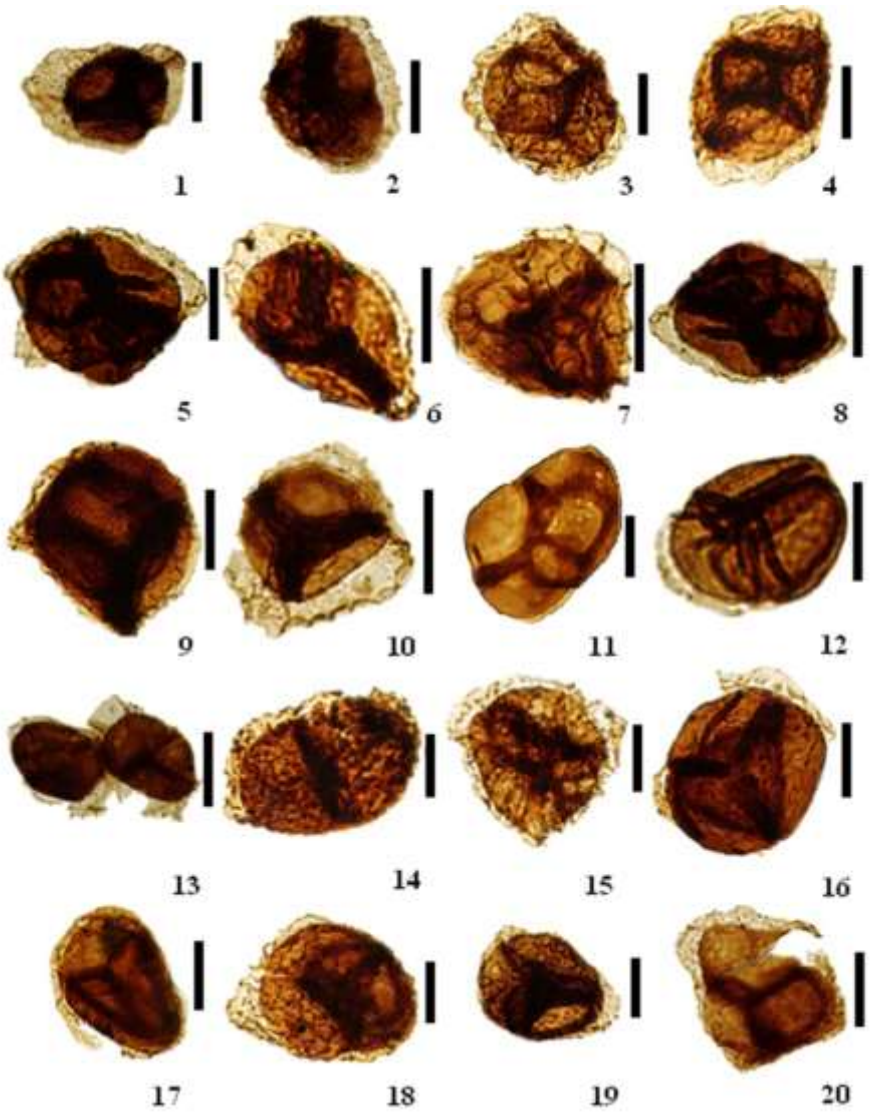

Plate IV (scale bar 10µ)
Figs. 1, 2, 8, 12, 17, 19. Velatitetras (Nodospora) rugosa [130[123].
Figs. 3, 4, 5, 6, 7, 9, 10, 15, 16, 18, 20. Velatitetras retimembrana [84] [123]
Fig. 11. Tetraplanarisporites laevigatus [173].
Fig. 13. Abditusdyadus laevigatus [167].
Fig. 14. Segestrespora membranifera [66] [12].

Formation, Khoshyeilagh area, northeastern Iran and Qusaiba-1 borehole, Sarah Formation, Latest Ordovician(Hirnantian), Arabian Peninsula, 488. 3ft [33], and Hanadir Shale Member of Qasim Formation, Ordovician (Darriwilian) of Arabian Peninsula [25].

Tetrahedraletes grayae [131] (Plate II, 9, 10; Plate V, 9).

Dimensions: 16 (19. 5) 23µm, three specimens measured. The size range of Ghelli Formation's specimens is less than those of China, Canada and Estonia [31]

Occurrences: *Tetrahedraletes grayae* is present in the whole studied samples of Ghelli Formation (MG-90 to MG-125), eastern Alborz Mountain Range (Fig. 2).

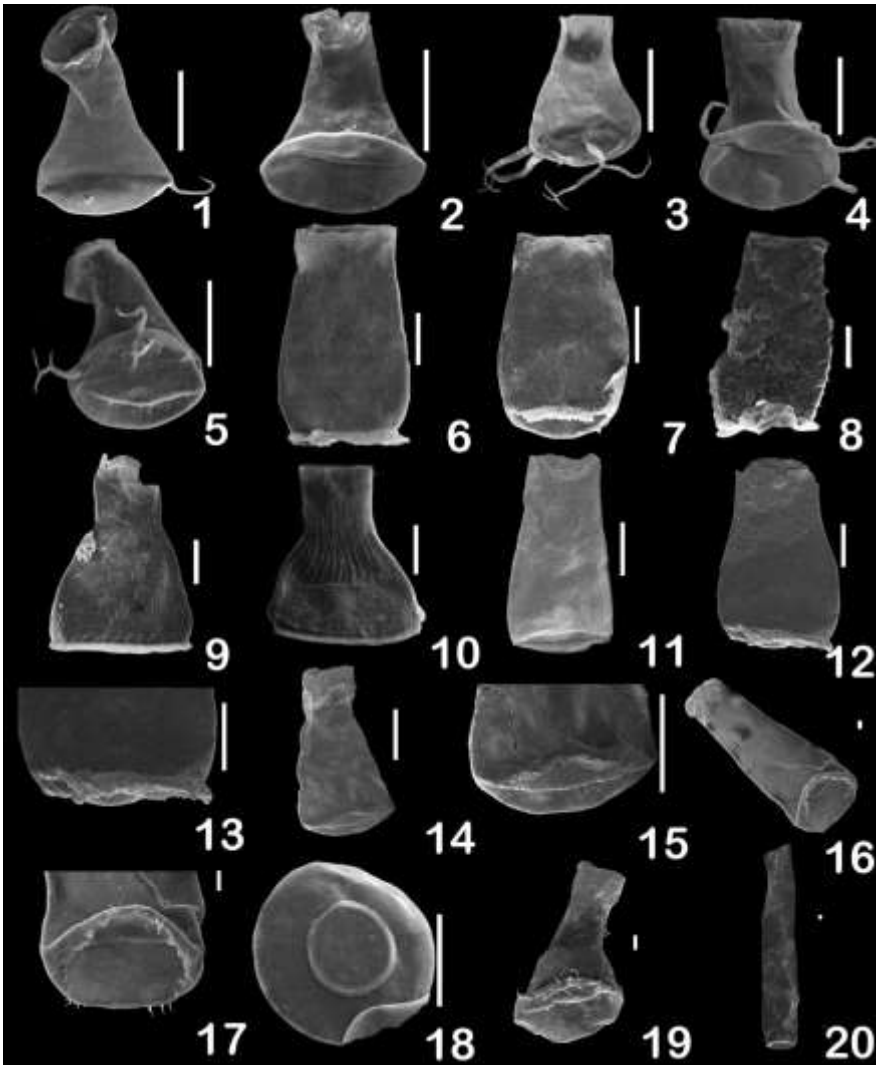

Plate IX (scale bar 10µ)
Figs. 1, 3, 4, 5. Ancyrochitina merga [65].
Fig. 2. Euconochitina lepta [65] [10].
Figs. 6, 7. Armoricochitina nigerica [9].
Fig. 8. Acanthochitina barbata [34].
Figs. 9, 10. Cyathochitina caputoi [24].
Figs.11, 14, 15. Euconochitina moussegoudaensis [74].
Figs. 12, 13. Armoricochitina nigerica [9]).
Figs. 16, 17. Spinachitina oulebsiri [95].
Fig. 18. Calpichitina lenticularis [9].
Fig. 19. Angochitina communis [64].

Previous records: Ashgill, Couches Fort Atkinson Dolomite, McQuokata Group, Illinois ; Oostduinkerke borehole, Brabant Massif, Belgium; Kosov Formation, Central Bohemia, Czech Republic; Upper Ordovician (Katian-Hirnantian) strata of Anticosti Island, Québec, Canada [31], Hanadir Shale Member of the Qasim Formation, Ordovician (Darriwilian), Arabian Peninsula [25] and Late Ordovician, Ghelli Formation, Khoshyeilagh area, eastern Alborz Mountain [16].

Genus ***Tetraplanarisporites*** [33]

Tetraplanarisporites laevigatus (Plate I, 12; Plate II, 3; Plate III, 11; Plate IV, 11; Plate V, 6; Plate, VII, 11, 17)

Dimensions: 31 (44) 57µm, seven specimens were measured. The size range of Iranian specimens is slightly larger than those of Saudi Arabia [33].

Occurrence: This species is present throughout the Ghelli Formation (MG-98 to MG-130).

Previous records: Qusaiba-1 borehole, Sarah Formation (Baqa Shale Member, Baqa Sandstone Member and Quwarah Member), Late Ordovician (Hirnantian) Saudi Arabia [33]

Genus ***Rimosotetras***

Type species: *Rimosotetras problematica*

Rimosotetras problematica (Plate I, 9; Plate II, 13; Plate III, 1, 6)

Dimensions: 17.5 (30) 42.5µm, ten specimens measured. The size range of Iranian specimens is smaller than those of Turkey , Canada and Estonia [31] and Saudi Arabia [25].

Occurrences: This species is present throughout the studied samples of Ghelli Formation (MG-98 to MG-130), eastern Alborz Mountain Range (Fig. 2).

Previous records: This species has a long stratigraphic range, from Late Ordovician through Silurian[31]. Likewise, *Rimosotetras problematica* has been recorded from Silurian deposits elsewhere[22]. The species has also been recorded from Early Devonian (Lochkovian) strata of the Tawil Formation in the Arabian Peninsula. This cryptospore species has been recorded from Hanadir Shale Member of the Qasim Formation, Ordovician (Darriwilian), Arabian Peninsula [25] and finally, this species has been recorded from Upper Ordovician (Katian-Hirnantian), Ghelli Formation, Khoshyeilagh area, northeastern Iran [16]

Rimosotetras subspherica [25] (Plate I, 11, 18, 20; Plate V, 14; Plate VI, 16, 19; Plate VII, 13)

Dimensions: 19 (32) 45µm, eleven specimens were measured. The size range of Ghelli's specimens is bigger than those of Hanadir Shale Member of Qasim Formation of Arabian Peninsula [25].

Occurrences: This species is present in the whole thickness of Ghelli Formation (MG-98 to MG-129), eastern Alborz Mountain Range.

Previous records: This species has been recorded from the Hanadir Shale Member (Darriwilian) of Arabian Peninsula [25].

***Rimosotetras punctata* n. sp.** (Plate V, 3, 5; Plate I, 14)

Holotype: Plate I, fig. 14

Type stratum: Ghelli Formation, sample number MG-100, 32km, southern Bojnourd city, eastern flank of Kuh-e-Saluk, northeastern Alborz Mountain Range.

Derivation of name: From the Greek punctatus, bearing pores, the name considered to be feminine.

Dimensions: 15 (16) 17µm, fifteen specimens were measured.

Occurrences: This species is present (MG-98 to MG-130) throughout the Ghelli Formation, eastern Alborz Mountain Range.

Description: Loosely permanent tetrads, individual spore-member circular to subcircular in outline, walls of spore members uniformly thin, perforated with numerous pits which penetrate the entire walls.

Remarks: This species differs from other species of *Rimosotetras* in perforated walls of spores.

Rimosotetras granulata n. sp. (Plate V, 8, 11)

Holotype: Plate V, Fig. 11

Type stratum: Ghelli Formation, sample number MG-100, 32km, southern Bojnourd city, eastern flank of Kuh-e-Saluk, northeastern Alborz Mountain Range.

Dimensions: 20 (24. 5) 29µm, twenty specimens were measured.

Occurrences: This species is present within the Ghelli Formation (MG-98 to MG-130), eastern Alborz Mountain Range.

Derivation of name: Refers to granulate - echinate ornamentation which is distributed on the whole surface of each spore member of tetrads.

2. 1 A- 2. *Subgroup naked fused cryptospore tetrads*

Genus ***Cheilotetras***

Type species: *Cheilotetras caledonica*

Cheilotetras caledonica (Plate I, 2, 3; Plate VII, 1, 2)

Dimensions: 17 (24) 31µm, five specimens measured

Occurrences: This species is present in the Ghelli Formation (MG-98 to MG-130), eastern Alborz Mountain Range.

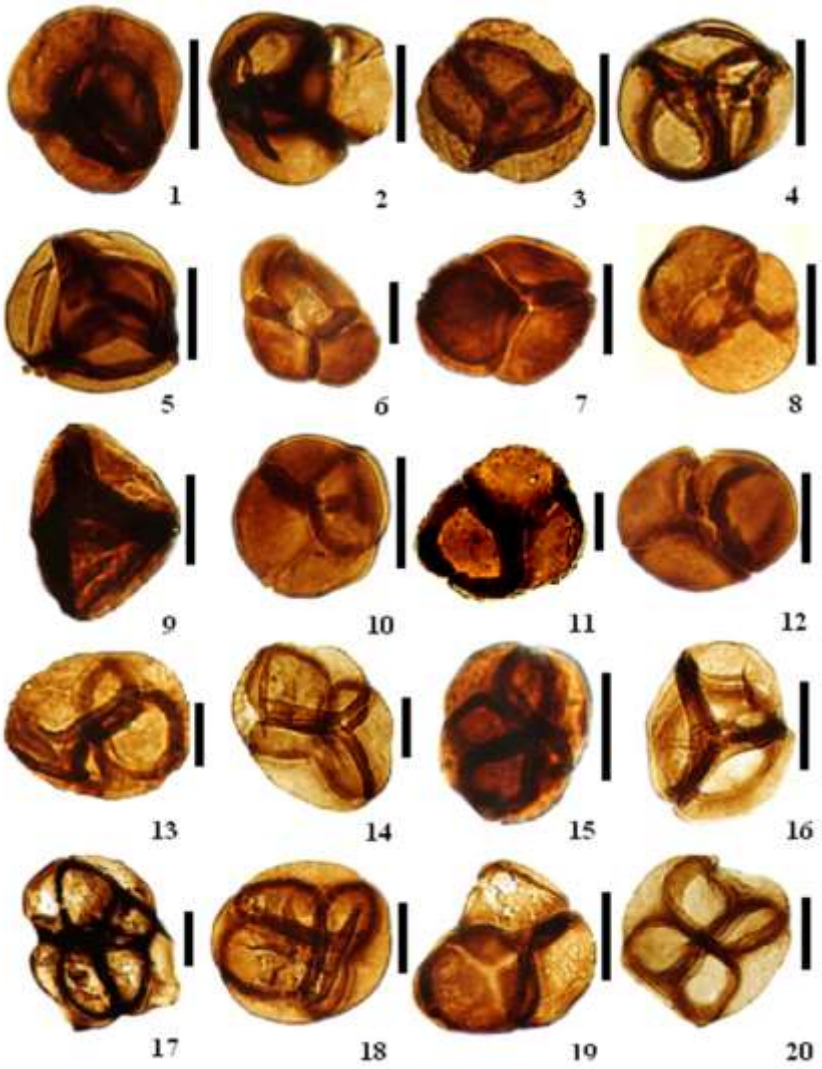

Plate V (scale bar 10µ)
Figs. 1, 2, 16. Cryptotetras erugata [134].
Figs. 3, 5. Rimosotetras punctata n.sp.
Fig. 6. Tetraplanarisporites laevigatus [173].
Fig. 14. Rimosotetras subspherica [134].
Figs. 4, 13, 15, 17, 18, 20. Tetrahedraletes medinensis [132]) emend. [167].
Fig. 9. Tetrahedraletes grayae [102].
Figs. 8, 11. Rimosotetras granulata n. sp.
Fig. 19. Imperfectotriletes patinatus [126].

Previous records: Based on literature review, *Cheilotetras caledonica* has been previously reported mostly from post-Ordovician strata worldwide, ranging from Early-Late Silurian strata [19] to Early Devonian. This species has been described from Upper Ordovician (Katian- Hirnantian) strata of Canada and Estonia [31] and Upper Ordovician (Katian-Hirnantian), Ghelli Formation, Khoshyeilagh area, northeastern Iran [34, 16].

2. 1 A-3. *Subgroup envelope- enclosed unfused cryptospore tetrads*

Genus ***Velatitetras***

Type species: *Velatitetras laevigata*

Velatitetras laevigata (Plate III, 14)

Dimensions: 20 (22) 24µm, fifteen specimens measured. The Iranian specimens are much larger than those from Turkey, and more or less similar to those of Canada and Estonia.

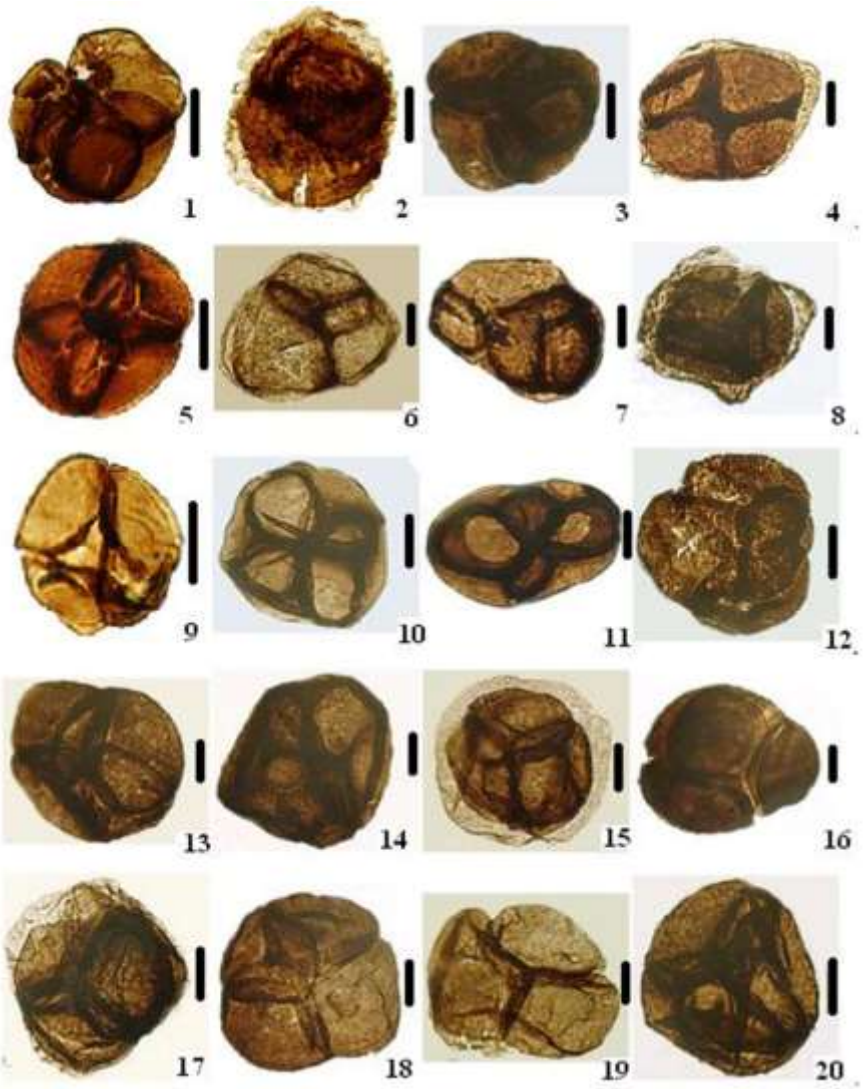

Plate VI (scale bar 10µ)
Figs. 1, 3. Imperfectotriletes patinatus [126].
Fig. 2. Velatitetras retimembrana [84] [123].
Figs. 4, 6, 8, 12, 15. Velatitetras (Nodospora) rugosa [130] [123].
Figs. 5, 10, 11, 18, 20. Tetrahedraletes medinensis [130] emend. [167].
Figs. 7, 13, 14. Imperfectotriletes patinatus [126].
Fig. 9. Cryptotetras erugata [134].
Figs. 16, 19. Rimosotetras subspherica [134].
Fig. 17. Velatitetras retimembrana [84] [123].

Occurrences: This species is present in the Ghelli Formation (MG-98 to MG-130), eastern Alborz Mountain Range in Iran (Fig. 2).

Previous records: This species has been mainly documented from Ashgill (Late Katian-Hirnantian) to Llandovery, worldwide. Only one record from Lochkovian of Saudi Arabia has been recorded. Some relevant occurrences are reported here as follows: Caradoc-Ashgill, Bedinan Formation, Turkey; Ashgill, Oostduinkerke borehole, Brabant Massif, Belgium Upper Ordovician (Katian-Hirnantian) Canada and Estonia [31] ; Kalpintag Formation, Southern Xinjiang, China; Upper Caradoc- Lower Telychian: subsurface of northeastern Libya: Llandovery, Salar del Rincón Formation, Puna Region, Argentina Qusaiba Mb., Nuayyim-2 and Hawiyah-152 boreholes, Saudi Arabia.

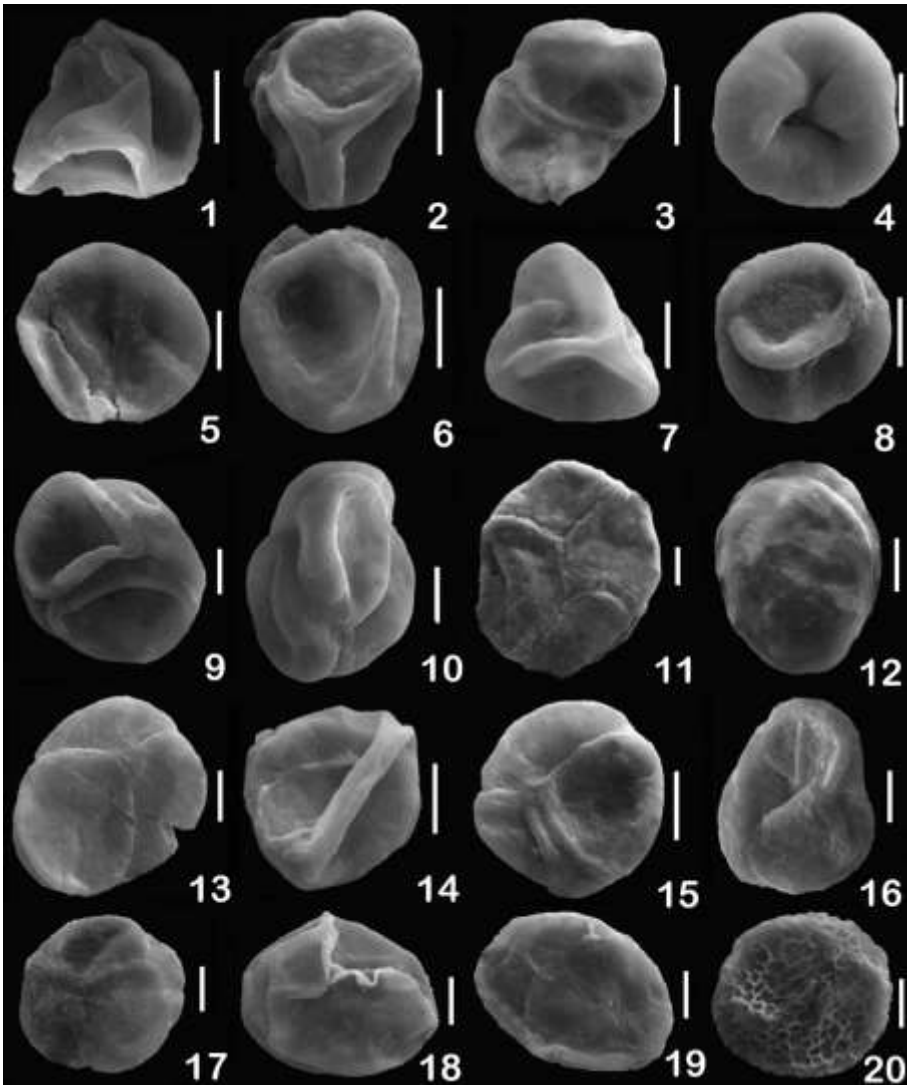

Plate VII (scale bar 10µ)
Figs. 1, 2. Cheilotetras caledonica [167].
Fig. 3. Dyadospora murusattenuata [130] emend [14].
Figs. 4, 18. Imperfectotriletes vavrdovae [126].
Figs. 5, 19. Laevolancis divellomedium [14].
Figs. 6, 7, 8, 16. Pseudodyadospora laevigata [66].
Figs. 9, 15. Rimosotetras problematica [13].
Figs. 11, 17. Tetraplanarisporites laevigatus [173].
Fig. 12. Segestrespora burgessii [123].
Fig. 13. Rimosotetras subspherica [134].
Fig. 14. Tetrahedraletes medinensis [130] emend. [167].
Fig. 20. Velatitetras rugosa [130] [123].

Dadas Formation, Turkey Tanezzuft and Acacus formations, Tunisia, and Upper Ordovician-Lowermost Silurian of Qusiaba-1, Arabian Peninsula [33].

Velatitetras retimembrana (Plate I, 19; Plate II, 2; Plate IV, 3, 4, 5, 6, 7, 9, 10, 15, 16, 18, 20;Plate VI, 2, 17).

Dimensions: 17 (27. 5) 38µm, width of envelope 3-4µm with clear reticulation, fourteen specimens measured. The Iranian specimens are more or less similar to those of Turkey.

Occurrences: This species is present in the Ghelli Formation (MG-98 to MG-130), eastern Alborz Mountain Range of Iran (Fig. 2).

Previous records: *Velatitetras retimembrana* has

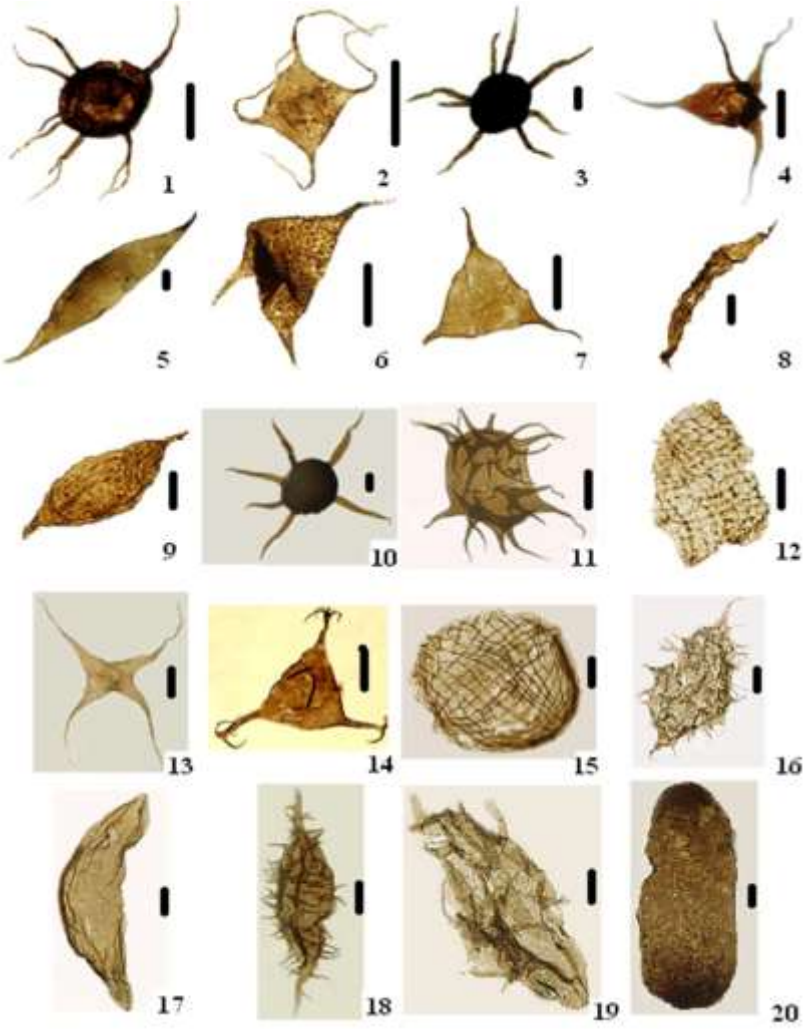

Plate VIII (scale bar 10µ)
Fig. 1. Orthosphaeridium insculptum [77].
Fig. 2. Veryhachium lairdii group [120].
Figs. 3, 10. Baltisphaeridium constrictum [68].
Fig. 4. Dorsennidium hamii [77] [79].
Fig. 5. Dactylofusa platynetrella [79] [24].
Fig. 6. Villosacapsula setosapellicula [77] [78].
Fig.7. Veryhachium trispinosum [120].
Fig. Fig. 8. Dactylofusa striatogranulata [63].
Fig. 9. Dactylofusa cucurbita [63].
Fig. 11. Acanthodiacrodium crassus [79] [123].
Fig. 12. Muzivum graziniskii [178].
Fig. 13. Neoveryhachium sp. cf. N. carminae [20].
Fig. 14. Frankea breviscula [15] (reworked).
Fig. 15. Dactylofusa cabottii [21] [42].
Figs. 16, 18, 19. Safirotheca safira [150].
Fig. 17. Dactylofusa striata [122] [42].
Fig. 20. Navifusa ancepsipuncta [77].

been previously recorded from Late Ordovician, Bedinan Formation, southeastern Turkey; Ashgillian-Llandovery Wales area, UK; Llandovery (Rhuddanian-Aeronian), Niagara Gorge, Lewiston, New York, USA; Llandovery (Rhuddanian), Tuscarora, Central Pennsylvania, USA; Ashgillian, Drakes Formation,

Ohio, USA; late Llandovery, Jupiter Formation, Anticosti Island, Quebec, Canada Llandovery (Rhuddanian-Aeronian), North-east Libya and Late Ordovician, Kosov Formation, Hlásná Třebaň, Czech Republic.

Velatitetras rugosa Plate II, 7; Plate III, 14; Plate IV, 1, 2, 8, 12, 17; Plate VI, 4, 6, 8, 12, 15; Plate VII, 20) [31]

Dimensions: 20 (32. 5) 45µm, fifteen specimens measured. The Iranian specimens are smaller than those of Turkey, as well as Canada and Estonia [31].

Occurrences: This species is present in the Ghelli Formation (MG-96 to MG-130), the eastern Alborz Mountain Range in Iran (Fig. 2).

Previous records: This species has been already recorded from Ashgillian (Hirnantian), Velleda Mb. of Ellis Bay Formation Anticosti Island [19]. Other occurrences are as follows: Caradoc-Hirnantian, Bedinan Formation, Turkey. Ashgillian, Oostduinkerke borehole, Brabant Massif, Belgium; Ashgill-Early Llandovery: Hlásná Třebaň, Czechoslovakia. Early Llandovery (Rhuddanian), Bronydd. Llandovery-Ludlow, Allenport, Pennsylvania, USA [3] Ludlow, uppermost Pitinga Formation, Urubu River area, western Amazon Basin, Brazil [23]. Ludlow-Lochkovian, Tanezzuft, Acacus, Tadrart formations, Ghadamis basin, MG-1 borehole, Tunisia [22] Upper Ordovician (Katian-Hirnantian) strata of Canada and Estonia [31].

2. 1. A- 4. *Subgroup envelope-enclosed unfused cryptospore dyads. This subgroup is characterized by true dyads enclosed within a smooth ornamented envelope.*

Genus ***Abditusdyadus***

Type species: *Abditusdyadus histosus*

Abditusdyadus laevigatus [26] (Plate I, 8; Plate II, 6; Plate III, 19; Plate IV, 13)

Dimensions: 18 (23. 5) 29µm, four specimens measured.

Occurrence: This species is present in the Ghelli Formation (MG-98 to MG-30).

Previous records: Ashgillian (late Katian-Hirnantian), Oostduinkerke Brabant Massif, Belgium Early Llandovery (Rhuddanian), Qusaiba member of Qalibah Formation, Saudi Arabia; Lochkovian, Lower Old Red Sandstone, Lorne, Scotland Upper Ordovician (Katian-Hirnantian) strata of Canada and Estonia [31] and Upper Ordovician (Katian-Hirnantian), Ghelli Formation, Khoshyeilagh area, northeastern Iran [13].

2. 1 A-5. *Subgroup envelope-enclosed fused cryptospore dyads. This subgroup is characterized by pseudodyads within an envelope.*

Genus ***Segestrespora*** 13

Type species: *Segestrespora membranifera*

Segestrespora membranifera [8] (Plate IV, 14)

Dimensions: 21 (27) 33µm, three specimens measured. The size range of Iranian species is bigger than those of Turkey.

Occurrences: This species is rare to common and present in the Ghelli Formation (MG-100 to MG-130).

Previous records: This species has a wide geographical distribution that stratigraphically ranges from Upper Ordovician to Lower Silurian (Llandovery). It has so far been recorded from Late Ordovician, Bedinan Formation, southeastern Turkey, Ashgillian, Oostduinkerke borehole, Brabant Massif, Belgium, Latest Ashgillian (Hirnantian), Earliest Silurian (Rhuddanian) from Scach to Bronydd Formation, Ashgillian-Rhuddanian type Llandovery area, southwestern Wales, U. K; *persculptus* - *acinaces* graptolite Biozone, Ashgillian, Hlásná Třebaň, Kosov Formation, *bohemicus* graptolite biozone, Czechoslovakia, Llandovery: Qusaiba Member of Qalibah Formation, Saudi Arabia; Upper Ordovician and Lowermost Silurian of Qusaiba-1, Qasim region, central Saudi Arabia [33], Upper Ordovician of Libya [1], Salar del Rincón Formation, Puna Region, Argentina and Upper Ordovician (Katian-Hirnantian) strata of Anticosti Island, Québec, Canada, and Estonia [31]

Segestrespora laevigata 13 (Plate II, 5; Plate III, Figs. 2, 15)

Dimensions: 12 (16. 5) 21µm, three specimens measured (each spore is 13µm long and 9µm wide). The size range of Iranian specimens is smaller than those of Turkey.

Occurrences: This species is rare and present in the Ghelli Formation (MG-100 to MG-130).

Previous records: This species has wide geographical distribution and stratigraphically ranges from Late Ordovician-Rhuddanian. This species has so far been recorded from Late Ordovician (Caradoc-Hirnantian), Bedinan Formation, southeastern Turkey Ashgillian, Oostduinkerke borehole, Brabant Massif, Belgium, latest Ashgillian (Hirnantian) - earliest Silurian (Rhuddanian) from Scach to Bronydd Formation, type Llandovery area, southwestern Wales, Llandovery, Qusaiba Member of Qalibah Formation, Saudi Arabia, Upper Ordovician-lowermost Silurian, Qusaiba-1, Qasim region, central Saudi Arabia (Katian-Hirnantian; [33] and Upper Ordovician (Katian-Hirnantian) strata of Anticosti Island, Québec, Canada, and Estonia [31].

Segestrespora burgessii (Plate I, 6; Plate II, 4, 19).

Dimensions: 19 (29) 39µm, four specimens measured

(enclosed-envelope of 1-3µm). The size range of Ghelli Formation specimens is bigger than those of Turkey.

Occurrences: This species is rare but is present in the Ghelli Formation (MG-100 to MG-129).

Previous records: This species has so far been recorded from latest Ashgillian (Hirnantian) - earliest Silurian (Rhuddanian) from Scach to Bronydd Formation, type Llandovery area, southwestern Wales and Late Ordovician, Bedinan Formation, southeastern Turkey.

***Segestrespora iranense* n. sp**. (Plate I, 16)

Holotype: Plate I, Fig. 16

Type stratum: Ghelli Formation, samples numbered MG-100 to MG-124, 32km, southern Bojnourd city, eastern flank of Kuh-e-Saluk, northeastern Alborz Mountain Range.

Dimensions: 18 (20) 22µm, twenty specimens were measured.

Occurrences: This species is present within the Ghelli Formation (MG-100 to MG-130), eastern Alborz Mountain Range.

Derivation of name: Refers to Iran, the country in which the species was first recorded.

Diagnosis: *Segestrespora iranense* n. sp. is a fairly small cryptospore species with elliptical outline. The whole spore-like cells are ornamented by granules, or connate spinae. This cryptospore species is 30µm long and 15µm wide.

Description: *Segestrespora iranense* n. sp. is dyad to pseudodyad, with elliptical outline which is entirely enclosed within an uniform envelope. The whole cryptospore is covered by granules, or connate spinae. Individual spore-like cells are kidney shape which is 30µm long and 15µm wide. The envelope is firmly adherent to the enclosed spore-like cells. The annular ring is 2-3µm wide and encircles the spore-like cells at their junction. *Segestrespora iranense* n. sp. differs from other species of *Segestrespora* in having granules throughout the whole cryptospore surface.

2. 1 A-6. *Subgroup unfused naked cryptospore dyads (true dyads). This subgroup comprises dyads, which readily separate into two alete spores.*

Genus ***Dyadospora*** emend.

Type species: *Dyadospora murusattenuata* emend.

Dyadospora murusattenuata emend. (Plate II, 14; Plate VII, 3)

Occurrences: This species is present in the Ghelli Formation, Eastern Alborz Mountain Range of Iran (MG-100 to MG-130).

Dimensions: 19 (27) 35µm, four specimens measured. The size range of Iranian specimens is smaller than those of Libya [1].

Previous records: Based on literature review, *Dyadospora murusattenuata* has a long stratigraphic range (Ordovician-Devonian) and has a common worldwide distribution. So far, this species has been recorded from Upper Caradoc-Upper Ashgill, E1-1 borehole, Libya; Llandovery: Qusaiba Mb., Qalibah Formation, Saudi Arabia Ordovician and Silurian, Bedinan Formation, southeastern Turkey; Ashgillian, Kalpintag Formation, Southern Xinjiang, China; Ashgillian, Kosov Formation, Hlásná Třebaň, Czech Republic; Hirnantian, Oostduinkerke borehole, Brabant Massif, Belgium; Hirnantian, Salar del Rincón Formation, Puna Region, Argentina; Upper Ordovician (Katian-Hirnantian) strata of Anticosti Island, Québec, Canada, and Estonia [31] and Upper Ordovician (Katian-Hirnantian), Ghelli Formation, Khoshyeilagh area, northeastern Iran [16].

***Dyadospora asymmetrica* n. sp**.

Holotype: Plate II, Figs. 15, 16, 18.

Type stratum: Ghelli Formation, sample number MG-100, 32km, southern Bojnourd city, eastern flank of Kuh-e-Saluk, northeastern Alborz Mountain Range.

Derivation of name: Derived from two unequal spore cells.

Dimensions: 16 (22) 28µm, fifteen specimens were measured.

Occurrences: This species is present (MG-100 to MG-130) throughout the Ghelli Formation, eastern Alborz Mountain Range.

Description: loosely tetrads, individual spore-member circular to subcircular in outline. Walls of each spore granulate, or echinata. The walls of spore are uniformly thick.

Remarks: This species differs from other species *Dyadospora* in thick wall, loosely attached, two unequal cells .The surface of dyad is smooth and sometime with one shrunken cell contents (cytoplasm) in each spore member.

***Dyadospora verrucata* n. sp.**

Holotype: Plate I, 15; Plate III, 20.

Type stratum: Ghelli Formation, from samples numbered MG-100 to MG-130, in 32km, southern Bojnourd city, eastern flank of Kuh-e-Saluk, northeastern Alborz Mountain Range.

Derivation of name: From verrucate ornamentation which covers both dyad spores.

Dimensions: 20 (22) 24µm, fifteen specimens were measured.

Occurrences: This species is present (MG-100 to MG-129) throughout the Ghelli Formation, eastern Alborz Mountain Range.

Description: Loosely attached dyads; Dyads elliptical consist of two unequal spores. The walls of dyads are

fairly thick and covered by verrucate ornamentations

Remarks: This species differs from other species *Dyadospora* in thick wall and verrucate ornamentation.

2. 1 A-7. *Subgroup naked fused cryptospore dyads (pseudodyads). This group consists of dyads, which are not enclosed within an envelope, and does show a recognizable line of attachment.*

Genus ***Pseudodyadospora***

Type species: *Pseudodyadospora laevigata*

Pseudodyadospora laevigata (Plate VII, 6, 7, 8, 16)

Dimensions: 22 (30) 38µm, four specimens measured. The size range of Iranian specimens is smaller than those of Turkey.

Occurrences: *Pseudodyadospora laevigata* is present within the Ghelli Formation at Pelmis gorge, Eastern Alborz Mountain Range (MG-100 to MG-130).

Previous record: So Far, *Pseudodyadospora laevigata* has been recorded from Ashgill-early Llandovery, Kosov Formation, Hlásná Třebaň, Czech Republic; Ashgill, Kalpintag Formation, Southern Xinjiang, China; early Llandovery (Rhuddanian), Qalibah Formation and Qusaiba Mb., Saudi Arabia; Ordovician and Silurian, Bedinan Formation, southeastern Turkey; Hirnantian, the Velleda Member of the Ellis Bay Formation, Anticosti Island, Quebec, Canada; Ludlow-Pridoli, Dadas Formation, southeastern Turkey; Ludlow-Lochkovian, Tanezzuft, Acacus, Tadrart formations, Ghadames Basin, MG-1 borehole, southern Tunisia; Upper Ordovician (Katian-Hirnantian) strata of Anticosti Island, Québec, Canada, and Estonia [31]; Upper Ordovician and lowermost Silurian, Qusaiba-1, Qasim region, Central Saudi Arabia [33].

2. 1 A-8. *Spores physically separated from cryptospore polyads*

Genus ***Imperfectotriletes***

Imperfectotriletes vavrdovae (Plate I, 17; Plate II, 8; Plate VII, 4, 18)

Occurrence: Imperfectotriletes vavrdovae is present in the Ghelli Formation, at eastern Alborz Mountain Range (MG-100 to MG-130).

Dimensions: 16 (28) 40µm, Twenty specimens measured. The size range of Iranian specimens is smaller than those of Libya [1].

Previous records: Ashgillian - lower Telychian, UK, Czech Republic, south-eastern Turkey, Saudi Arabia, Libya, USA, North-west Argentina and Upper Ordovician of Northern Chad and south-eastern Libya [15].

Imperfectotriletes patinatus (Plate V, 19; Plate VI, 7, 13, 14)

Type species: Imperfectotriletes vavrdovae

Occurrences: This cryptospore species is present in the Ghelli Formation, eastern Alborz Mountain Range (MG-100 to MG-130).

Dimensions: 21 (32. 5) 44µm, three specimens were measured. The size range of Ghelli Formation's is almost the same as those of Turkey .

Previous records: Ashgillian from the Oostduinkerke borehole, Brabant Massif, Belgium; Upper Ordovician and lowermost Silurian of Qusaiba-1, shallow core Hole, Qasim region, central Saudi Arabia [33].

Imperfectotriletes persianense **n. sp.** (Plate I, 13; Plate VI, 9)

Holotype: Plate I, 13

Type stratum: Ghelli Formation, sample number MG-100, 32km, southern Bojnourd city, eastern flank of Kuh-e-Saluk, northeastern Alborz Mountain Range.

Derivation of name: From the Latin Persia, referring to the ancient name of Iran.

Dimensions: 18 (19) 20µm, ten specimens were measured.

Occurrences: This species is present (MG-100 to MG-130) throughout the Ghelli Formation, eastern Alborz Mountain Range.

Description: Amb subtriangular to elliptical with rounded apices. Exine of spore is usually folded and irregularly covered by verrucate sculpture. Trilete-mark is distinct with opening on proximal pole.

Remarks: This species differs from other species of Imperfectotriletes by verrucate sculpture.

2. 1 A-9. *Subgroup Hilate cryptospores*

Genus ***Laevolancis***14

Type species: *Laevolancis divellomedium* 14

Laevolancis divellomedium

(Plate VII, 5, 19)

Dimensions: 30 (35. 5) 41µm, five specimens measured. The size range of Ghelli Formation is bigger than those of Libya [1].

Occurrences: *Laevolancis divellomedium* is present within the Ghelli Formation, at eastern Alborz Range (MG-98 to MG-125).

Previous records: Caradoc in Southern Britain, Rhuddanian in Saudi Arabia, uppermost Ordovician in southern Xinjiang, China and Upper Ordovician/ Silurian of north-west Argentina.

2. 1 B. *Anteturma sporites*

Turma Triletes

Subturma zonotriletes

Infraturma crassiti

Genus ***Ambitisporites***

Type species: *Ambitisporites avitus*

Ambitisporites avitus sensu (Plate II, 8)

Occurrences: This species is present within the Ghelli Formation, eastern Alborz Mountain Range of Iran (MG-90 to MG-125).

Dimensions: 14 (15) 16µm, two specimens measured. The specimens of Ghelli Formation are smaller than those of type species

Previous records: This species is known throughout the Silurian and is widely distributed all over the world. So far, It has been recorded from Late Ordovician and Late Silurian, Bedinan and Dadas formations, Turkey; lower Silurian (Aeronian) from *sedgwickii* graptolite Biozone, southwestern Wales. However, it could have appeared in the latest Ordovician.

Genus *Retusotriletes*

Type species: *Retusotriletes warringtonii*

***Retusotriletes* sp.** (Plate I, 7, 10; Plate II, 17)

Description: This species occurs in the Ghelli Formation and extends from samples MG-90 to MG-125. Size range of this species is 12-16µm (with distinct curvature perfectae). Amb subcircular to triangular with convex sides and rounded apices. Exine is smooth and homogenous. Trilete mark is distinct and each spore radius merges into curvature perfectae and sometimes coincides with equatorial outline. This species is similar to *Retusotriletes* cf. *minor* Kedo, 1963, but the latter differs from Iranian specimens in presence of thinner area at proximal pole and larger size.

2. 1 A-9. Cryptospore biostratigraphy

The recovery of miospores provides another opportunity for independent age assessment of Ghelli Formation, in the study area. The encountered cryptospores are critical since they have limited stratigraphic range from Middle Ordovician to lower Silurian interval elsewhere. Our cryptospores findings are important in this formation since marine palynomorph assemblages suggest an Ashgillian (Katian-Hirnantian) age for the Ghelli Formation. The outcrop samples of Ghelli Formation (MG-90 to MG-130) resulted in 14 genera [6] miospore species: cryptospores and 2 trilete spores), consisting of *Abditusdyadus laevigatus*, *Cryptotetras erugata*, *Cryptotetras mordacis*, *Tetrahedraletes medinensis*, *Tetrahedraletes grayae*, *Cheilotetras caledonica*, *Dyadospora murusattenuata*, *Dyadospora verrucata* n. sp., *Dyadospora asymmetrica* n. sp., *Laevolancis divellomedium*, *Pseudodyadospora laevigata*, *Rimosotetras problematica*, *Rimosotetras subspherica*, *Rimosotetras punctata* n. sp., *Rimosotetras granulata* n. sp., *Segestrespora* (*Dyadospora*) *burgessii*, *Segestrespora membranifera*, *Segestrespora iranense* n. sp., *Segestrespora laevigata*, *Tetraplanarisporites laevigatus*, *Velatitetras retimembrana*, *Velatitetras* (*Nodospora*) *rugose*, *Velatitetras laevigata*,*Imperfectotriles vavrdovae*, *Imperfectotriletes patinatus*, Imperfectotriltes persianense n.sp., *Ambitisporites avitus* and *Retusotriletes* sp. (Plate I-VII and Table 2). There are many proposals for cryptospore biozonations e. g. [31], but one cannot see any agreement in this respect. This could have resulted either by paucity cryptospore data or heterogeneity data on assemblages of one time interval. For instance, there are a few papers which concern only on Late Ordovician (Katian-Hirnantian), and the majority of contributions are on the Ordovician/Silurian boundary. However, as illustrated in Figure 2, three local events can be marked by miospores within the Ghelli Formation. The first event is characterized by appearance of *Ambitisporites avitus*, *Retusotriletes* sp., *Cryptotetras erugata*, *Cryptotetras mordacis*, *Tetrahedraletes medinensis* and *Tetrahedraletes grayae*, corresponding to sample MG-90 and their presence in succeeding events of Ghelli Formation (Fig. 2). The occurrences of these miospores are correlatable with appearance of diagnostic chitinozoan taxa such as *Armoricochitina nigerica*, *Acanthochitina barbata*, *Calpichitina lenticularis*, *Angochitina communis* and *Euconochitina lepta*, suggesting early to middle Katian for this event / assemblage (see Fig. 2). The second event corresponds to sample MG-98 and is defined by the onset of many cryptospore taxa such as *Tetraplanarisporites laevigatus*, *Abditusdyadus laevigatus*, *Rimosotetras subspherica*, *Rimosotetras punctata* n. sp., *Rimosotetras granulata* n. sp., *Rimosotetras problematica*, *Cheilotetras caledonica*, *Velatitetras retimembrana*, *Velatitetras* (*Nodospora*) *rugosa*, *Velatitetras laevigata*, and *Pseudodyadospora laevigata*, correlating with first appearance of *Ancyrochitina merga*, suggesting late Katian age for this event (Fig. 2). The third event is marked by the first appearance of cryptospore taxa such as *Imperfectotriletes vavrdovae*, *Imperfectotriletes patinatus*, *Imperfectotriletes persianense* n.sp., *Dyadospora murusattenuata*, *Dyadospora verrucata* n. sp., *Dyadospora* asymmetrica n. sp., *Laevolancis divellomedium*, *Segestrespora burgessii*, *Segestrespora laevigata*, *Segestrespora membranifera* and *Segestrespora* iranense n. sp., at MG-100 of the Ghelli Formation, corresponding to *Ancyrochina merga* biozone and their continuation within *Tanuchitina elongata* and *Spinachitina oulebsiri* chitinozoan biozones, representing Hirnantian age (Fig. 2). For palaeobiography evaluations of cryptospores, the author has selected the Coefficient Similarity (CS) because it was successfully used when evaluated the provincialism of the lower palaeozoic conodonts. This Coefficient of

Similarity is expressed as: CS = 2v/a+ b where v is the number of species in common between the two compared areas; a and b are respectively the total number of species recorded in each area. This CS was applied for the encountered miospores of this study and previously published assemblages of coeval age from elsewhere (e. g. Belgium, Turkey, Czech Republic, Libya, China, Argentina, the United Kingdom, Estonia and Canada) (Table 2). By using the Coefficient of Similarity, the identified cryptospore species of Ghelli Formation are 83% in common with Saudi Arabia, 67% in common with Turkey; 70% with Belgium; 60% with Argentina; 56% with UK; 56% with Libya; 60% with Estonia and Canada; 44% with Czech Republic and 35% with China. The CS values show high similarity between the studied area and selected assemblages of other countries, representing primitive land plants which produced cryptospores, were cosmopolitan and tolerated a wide range of climatic conditions during the global sea-level fall linked to the Late Ordovician glaciation. Herein, the Ghelli Formation is considered to be deposited in shallow marine environment (littoral) since the high amount of terrestrial miospores and low amount of marine palynomorphs (acritarchs and chitinozoans and marine algae), indicate that the earliest land plants which produced cryptospores grew on adjacent areas and then washed in and constitute 15% in MG-90, 72% in MG-128 and 80% in MG-111, respectively (Table 1). Such high proportions of land derived palynomorphs indicate that primitive land plants were close to depositional environment. It should be mentioned that relative percentage of different palynomorphs change from MG-90 to MG-130 alternatively (Table 1), but in general from bottom to the top of this formation, the terrestrial palynomorph content increases (Table 1), possibly indicating decrease of distance from onshore. This is consistent with presence of *Dactylofusa cabottii* as well as *Musivium gradzinskii* [34] in the Ghelli Formation, which suggest shallow-water, nearshore, marine conditions .

2. 2. Acritarchs

The following acritarch taxa were identified (Plate VIII):

Group Acritarcha Evitt, 1963
Genus *Acanthodiacrodium* emend.
Acanthodiacrodium crassus (Plate VIII, 11)
Genus *Baltisphaeridium* emend.
Baltisphaeridium constrictum (Plate VIII, 3, 10).
Genus *Dactylofusa*
Dactylofusa cucurbita Pate VIII, 9)
Dactylofusa striata (Plate VIII, 17).
Dactylofusa platynetrella (Plate VIII, 5)
Dactylofusa cabottii (Plate VIII, 15).
Dactylofusa striatogranulata(Plate VIII, 8)
Genus *Dorsennidium* emend.
Dorsennidium hamii (PlateVIII, 4).
Genus *Frankea* emend.
Frankea breviuscula (Plate VIII, 14)
Genus *Musivium*
Musivium gradzinskii (PlateVIII, 12)
Genus *Navifusa*
Navifusa ancepsipuncta (Plate VIII, 20)
Genus *Neoveryhachium*
Neoveryhachium carminae (Plate VIII, 13)
Genus *Orthosphaeridium* emend.
Orthosphaeridium insculptum (Plate VIII, 1)
Genus *Safirotheca*
Safirotheca safira (Plate VIII, 16, 18, 19)
Genus *Veryhachium* emend.
Veryhachium lairdii group (Plate VIII, 2)
Veryhachium trispinosum group (Plate VIII, 7)
Genus *Villosacapsula*
Villosacapsula setosapellicula (Plate VIII, 6)

2. 3. Acritarch biostratigraphy

In this study, a total of 13 genera (18 species) of Late Ordovician acritarch taxa were identified. These are associated with reworked Early-Middle Ordovician acritarch taxa (e. g. *Frankea breviuscula*) which probably originated from neighbouring areas with short transport distance since they have a good preservation. Amongst the aforementioned acritarch taxa, the Late Ordovician acritarch species of *Villosacapsula setosapellicula* has been recorded from the Richmondian (Katian) of Oklahoma, Missouri, Algerian Sahara, Libya; the Katian of Canada; the Upper Ordovician of Morocco and Jordan. *Orthosphaeridium insculptum* has also been recorded from the Katian Sylvan Shale of Oklahoma, USA; the Katian Maquoketa Shale, Northeastern Missouri, U. S. A; Katian Vaureal Formation of the Anticosti Island, Québec, Canada; the Upper Ordovician of Czech Republic; the Ashgill deposits of Portugal and Morocco; the Upper Ordovician(Katian – Hirnantian), Seyahou Formation of the Zagros Mountains, Southern Iran [12], and the Upper Ordovician(Katian-Hirnantian) , Ghelli Formation, Kopeh-Dagh Region, Northeastern Alborz Mountain Range of Iran. The acritarch species of *Baltisphaeridium constrictum*, *Navifusa ancepsipuncta*, *Dactylofusa striatogranulata*, *Dactylofusa platynetrella* and *Acanthodiacrodium crassus* are typical acritarch taxa which have been recorded from the Late Ordovician of Czech Republic, North America Portugal and North Africa, Iran [12] and Iraq [2]. The acritarch species of *Dactylofusa cucurbita* is recorded for the first

time from the Ghelli Formation in Iran. It has been previously recorded from the Late Ordovician of Algerian Sahara, Libya [1] and Czech Republic. Likewise, the acritarch species of *Safirotheca safira* has so far been reported from the Late Ordovician of Czech Republic and Iranian platform [12] Furthermore, some of the acritarch species of Ghelli Formation, such as *Veryhachium lairdii* group, *Veryhachium trispinosum* group, *Dactylofusa cabottii* and *Frankea breviuscula* have been recorded from the Middle-Upper Ordovician strata of Sweden , England, the United States, Czech Republic, North Africa, Saudi Arabia, China and Iran [11,12]. *Dactylofusa cabottii* has widespread distribution and ranges from Caradocian to Ludlow. It should be mentioned that *Dactylofusa cabottii* is a common palynomorph in the Late Ordovician - Silurian shallow-water, nearshore, marine strata. Because of its occurrence in various non-marine deposits, they considered that it may be a possible euglenoid that represented the oldest freshwater protozoan. Whether *Dactylofusa cabottii* is euglenoid or not, is beyond the scope of this paper. On the other hand, because we are not sure of the biological affinity of *D. cabottii* and based on its widespread occurrence in nearshore, marine strata, it is placed in the acritarch group. Furthermore, *Musivium gradzinskii* [34] is another common palynonomorph in the Ghelli Formation. This species has been recorded from the Devonian, the Holy Cross Mountain and Radom-Lublin region of Poland and has been assigned to Family Hydrodictyaceae of the Chlorophyta, based on its coenobial habit and comparison with extant Hydrodictyaceae which are found only in fresh to brackish water. The depositional environment of *Musivium gradzinskii* is interpreted as a very nearshore to off shore-shelf [34]. On the other hand, based upon acritarch biostratigraphy of the *Dicellograptus complanatus* graptolite zone from the Katian Vaureal Formation of Anticosti Island, Québec Canada and the Katian, Maquoketa Shale of Northeastern Missouri, all acritarch species of Ghelli Formation, indicating Late Ordovician age (Katian-Hirnantian). Finally, the reworked acritarch taxa of Upper Ordovician(Katian-Hirnantian) sediments which are found in the Ghelli Formation are similar to those found in Saudi Arabia, Libya, Morocco, Algeria, Turkey and Zagros basin of Iran [13]. Herein, it should be mentioned that a few acritarch species such as *Dactylofusa cucurbita* and *Safirotheca safira* are restricted to peri-Gondwanan palaeo-province and the remaining acritarchs are cosmopolitan.

2. 4. Chitinozoans

The following chitinozoan taxa were identified (Plate IX):

Order Operculifera
Family Desmochitinidae, emend.
Subfamily Desmochitinidae
Genus *Calpichitina*
Type species: *Calpichitina scabiosa*
Calpichitina lenticularis (Plate IX, 18)
Subfamily Pterochitininae
Genus *Armoricochitina*
Armoricochitina nigerica (Plate IX, 6, 7, 12, 13)
Subfamily Ancyrochitininae
Genus *Ancyrochitina*
Ancyrochitina merga (Plate IX, 1, 3, 4, 5)
Genus *Angochitina*
Angochitina communis (Plate IX, 19)
Subfamily Belonechitininae
Genus *Acanthochitina* emend.
Acanthochitina barbata (Plate IX, 8)
Order Prosomatifera
Subfamily Conochitininae
Genus *Euconochitina* , emends
Euconochitina moussegoudaensis (Plate IX, 11, 14, 15)
Euconochitina lepta emend. (Plate IX, 2)
Subfamily Tanuchitininae
Genus *Tanuchitina* emend.
Tanuchitina elongata (Plate IX, 20)
Order Prosomatifera
Subfamily Spinachitininae
Genus *Spinachitina* emend.
Spinachitina oulebsiri (Plate IX, 16, 17)
Subfamily Cyathochitininae
Genus *Cyathochitina* emend.
Type species: *Conochitina campanulaeformis*
Cyathochitina caputoi
(Plate IX, 9, 10)

The distribution of the above-mentioned chitinozoan taxa in the study section (Fig. 2), allows recognition of four well-known chitinozoan biozones which are discussed in brief herein.

2 5. Chitinozoan biostratigraphy

Although some samples of the Ghelli Formation contain a good percentage of chitinozoan amongst other palynomorphs (MG-90 to MG-100), the remaining samples have very rare percentage of this group (see Table1). In this study, nine chitinozoan genera (ten species) were recognized that are well-known, biostratigraphically and Palaeogeographically. Based on the presence of these diagnostic chitinozoan taxa, the Ghelli Formation is assigned to the *Armoricochitina nigerica*, *Ancyrochitina merga*, *Tanuchitina elongata* and *Spinachitina oulebsiri* chitinozoan biozones,

suggesting the Late Ordovician (Katian-Hirnantian; Fig. 2). All chitinozoan species found in the Late Ordovician of the Pelmis-gorge area have been recorded from the North Gondwana domain, including North Africa (Morocco, Algeria, Tunisia, Libya, and Nigeria), the Middle East (Saudi Arabia, Syria, Jordan, and Iran), southwestern Europe (Italy, France, Spain, and Portugal) and Central Europe (Czech Republic). In particular, *Armoricochitina nigerica*, *Ancyrochitina merga*, *Tanuchitina elongata*, and *Spinachitina oulebsiri* have never been recorded outside the North Gondwana domain. Accordingly, the study area belongs to peri-Gondwanan palaeo-content during the Late Ordovician time.

Results and Discussion

The present study is restricted to the Ghelli Formation. The investigated palynomorphs assemblages come from 27 samples which were collected from an outcrop section at Pelmis-gorge, 32km southern Bojnourd city, NE Iran. All samples yielded abundant and well-preserved acritarchs, chitinozoans and miospores. The acritarch and chitinozoan taxa are characteristic of Late Ordovician that is associated with reworked acritarch species of Lower and Middle Ordovician, probably derived from adjacent areas. The identified acritarch and chitinozoan taxa of Ghelli Formation show strong affinity with Ashgillian assemblages from peri-Gondwanan landmass including North Africa (Morocco, Algeria, Tunisia, Libya, and Nigeria), the Middle East (Saudi Arabia, Syria, Jordan, and Iran), southwestern Europe, (Italy, France, Spain, Portugal), Central Europe (Czech Republic) and to some extent with China. Several acritarch and chitinozoan species are known from different palaeogeographic realms. However, only local biozonations have been established with acritarchs for the Upper Ordovician North Gondwanan domain [12,13]. In contrast, chitinozoan assemblages have been well documented from North Africa, particularly in Morocco and Algeria. A standard biozonation has been established for the region that can precisely be used for the present work. The significant acritarch taxa of this study from the Ghelli Formation consist of *Orthosphaeridium insculptum*, *Dorsennidium hamii*, *Dactylofusa striatogranulata*, *Dactylofusa cucurbita*, *Dactylofusa platynetrella*, *Baltisphaeridium constrictum*, *Dactylofusa striata*, *Acanthodiacrodium crassus*, *Navifusa ancepsipuncta*, *Safirotheca safira*, *Villosacapsula setosapellicula* and *Neoveryhachium carminae*. Amongst these acritarch taxa, some are long ranging species, extending from Ordovician through Silurian (e. g. *Frankea breviscula*; *Neoveryhachium carminae*), but the remaining acritarch taxa are indicative of Late Ordovician age. A few acritarch species of Ghelli Formation consisting of *Dactylofusa striata*, *Dactylofusa platynetrella*, and *Safirotheca safira*, *Dactylofusa striatogranulata*, and *Dactylofusa cucurbita* are diagnostic acritarch taxa for Late Ordovician and are restricted to Ashgill. Likewise, the acritarch species of *Dactylofusa striatogranulata*, *Dactylofusa cucurbita* and *Safirotheca safira* seem to be restricted to the peri-Gondwanan landmass. So far, these species have been described from the Upper Ordovician glacial marine deposits of Algerian Sahara biozone , Bohemia, Libya [1] and Iran [13]. *Neoveryhachium carminae* is well present in the samples of Ghelli Formation. This species is characteristic of the Silurian and has been primarily recorded from fragments Formation in Normandy which is now assigned to the upper Ashgillian. Furthermore, this species has been recorded from Upper Ordovician deposits of Tunisia and Late Ordovician, marine glacial deposits of Dargaz Formation in Zagros Mountain Ranges [12] Of the chitinozoans of the productive samples of Ghelli Formation (MG-90 to MG-130), the most important identified species are *Armoricochitina nigerica*, *Ancyrochitina merga*, *Tanuchitina elongata*, *Angochitina communis*, *Euconochitina moussegoudaensis*, *Euconochitina lepta*, *Calpichitina lenticularis* and *Spinachitina oulebsiri*. Based on the presence of these diagnostic chitinozoan taxa, the siliciclastic sequence of Ghelli Formation is assigned to the *Armoricochitina nigerica*, *Ancyrochitina merga*, *Tanuchitina elongata* and *Spinachitina oulebsiri* chitinozoan Biozones, suggesting Late Ordovician age (Katian-Hirnantian; Fig. (2). All chitinozoan species found in the Ghelli Formation of the Pelmis-gorge area have been recorded from the North Gondwanan domain. Therefore, the study area was part of the peri-Gondwanan palaeo-continent during the Late Ordovician. Hence the stratigraphic position of cryptospore assemblages of Ghelli Formation and the level of the oldest trilete spore of *Ambitisporites avitus* can be assigned to Ashgillian (Katian-Hirnantian).

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