The first report of cryptospore assemblages of Late Ordovician in Iran, Ghelli Formation, Eastern Alborz

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Abstract

For the first time, an assemblage of cryptospores, which includes 10 species belonging to nine genera, from the Upper Ordovician strata, is being reported, in Iran. These cryptospore assemblages were recovered from the upper part of Ghelli Formation., from the eastern Alborz Mountain range. These peri-Gondwanan cryptospores have been classified based on their morphology (monad, true dyad, pseudodyad, true attached, and loose tetrads). The results of the present study support previous findings that there are no significant differences between similar-aged cryptospore assemblages of the peri-Gondwanan, Baltic provinces and other parts of the world. Based on the presence of the chitinozoan index of the northern Gondwana (*Spinachitina oulebsiri*), the index acritarchs, and the present cryptospores, a late Hirnantian (Late Ordovician) age is proposed to the top of the Ghelli Formation. The cryptospores seem to be transported from an adjacent land area and the lack of land-derived elements in the up-section may indicate an increased distance offshore.

Keywords: *Cryptospore, Late Ordovician, Ghelli Formation, Eastern Alborz, Iran.*

Introduction

The study area is located about 80 km north-east of the city of Shahroud and east of the Khosh-Yeilaghi village (N 36° 49' 24" to 36° 53' 04" and E 55° 14' 14" to 55° 24' 12") (Fig. 1). Ghavidel-Syooki *et al*. (2011a), studied the acritarchs and chitinozoans from this formation, but could identify only the cryptospore *Tetrahedraletes* sp. In this study, in addition to the investigations on acritarch and chitinozoan assemblages, we identified cryptospores following the morphological classification of Wellman and Richardson (1993). We focused only on the top part of the Ghelli Formation, that is, the beginning of the green shale (as a key bed), which was approximately equivalent to the first occurrence of the chitinozoan index *S. oulebsiri* of the late Katian age.

Geological setting

The Khosh-Yeilaghi area is considered as a part of the eastern Alborz zone (Stocklin, 1968) and Alborz zone (Alavi, 1979, 1991). On the basis of Khosh–Yeilaghi geological map (Jafarian, 2004; scale 1:100000), the rock units of the Paleozoic and Mesozoic rocks comprise of Ghelli, Soltan-Meydan, Padeha, Khosh Yeilagh, Mobark, Doroud, Ruteh, Nesen, Elika and Shemshak formations (Fig. 1).

The Ghelli Formation (Abarsaj formation) was first introduced by Shahrabi (1990) in the Gorgan geological map (scale 1:250000). This formation comprises of alternate beds of gray and olive green shale and siltstones, having thin to moderate thickness, very thin and uncommon layers of grayish micaceous sandstone, and an interlayer of split basalts lying near the top (Figs. 2, 3). The lower part of the Ghelli Formation has been cut by a fault and is conformably overlain by the Soltan-Meydan volcanic Formation of the Silurian age (Ghavidel-Syooki *et al.*, 2011a). A Late Ordovician age has been assigned to the Ghelli Formation, on the basis of palynological studies (Chateaneuf *et al*., 1978; Sabouri, 2003; Ghavidel-Syooki *et al*., 2011a; Mahmoudi *et al*., 2011; Mahmoudi, 2011). In the present study, the top (110 m) of the Ghelli Formation is sampled for a palynological study.

Materials and Methods

Twenty-three samples from the upper Ghelli Formation were collected and palynological slides were prepared as the standard processing methodology, at the palynological laboratory of the Geological Survey of Iran, and kept there as an archive. The slides were then subjected to an optical study. The blackish/opaque color of some of the cryptospores (especially monad forms) made it

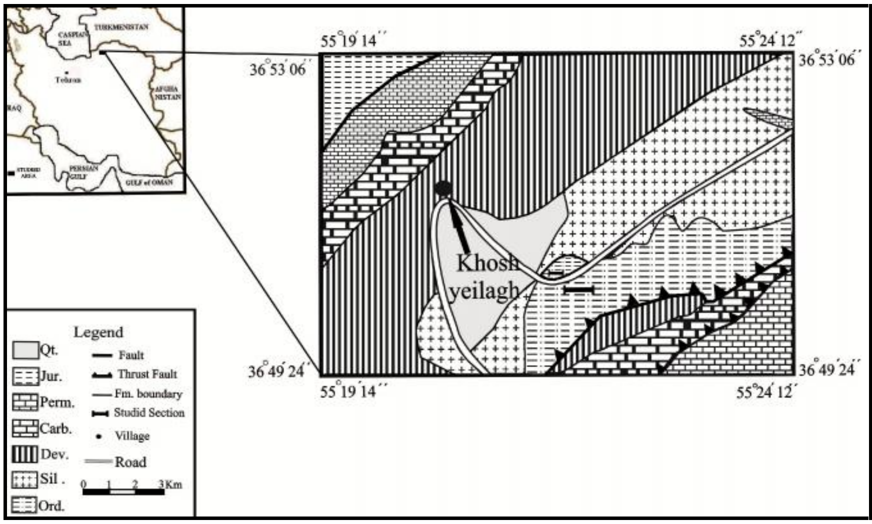


Figure 1. The sketch of geological map of the study area

difficult to identify them under light microscopy. For better brightness, we treated the samples with liquid bleach ($NaClO+K_2Cr_2O_7$+DeIonized water), but the result was not useful. Therefore, Scanning Electron Microscopy (SEM) was applied to study these specimens. The SEM instrument, model Wegall Tescan, with High Vacuum, based at the Research Institute of Razi, has been used for identification of the palynomorphs.

Figure 2. Field photography of the studied section (by Mahmoudi, 2011)

The previous studies on cryptospores in the world

Wellman & Gray (2000) proposed that these microfossils were derived from Bryophyte-like parental plants. The cryptospores and phytodebris were the first evidence of land plants that were recovered from the Llanvirnian (Darriwilian; Middle Ordovician) (Wellman & Gray, 2000). The first true spore (Embryophyte) was also reported from the Middle Llanvirnian (Darriwilian; Middle Ordovician) of Saudi Arabia (Strother *et al*., 1996).

In general, the cryptospores of Late Ordovician (Katian-Hirnantian) showed low diversity and abundance at the generic and species levels, and researchers were convinced that the glaciation of the Hirnantian age had no effect on these cryptospore assemblages (Vecoli *et al*., 2011). Recent findings revealed that the cryptospore assemblages of the Baltic and peri-Gondwana provinces (especially Turkey) were very similar to each other (Steemans, 2000; Vecoli *et al*., 2011). In some of the previous palynological articles on Late Ordovician of Iran, the cryptospores were considered as a whole or described only at the two generic and two species levels (Ghavidel-Syooki & Khosravi, 1994; Ghavidel-Syooki, 1995; Ghavidel-Syooki, 2006; Ghavidel-Syooki & Hosseinzadeh Moghadam, 2010; Ghavidel-Syooki *et al*., 2011a; Ghavidel-Syooki *et al*., 2011b). Also Ghavidel-Syooki *et al*., (2010) introduced an assemblage of cryptospores from the Silurian of north east of Iran, without any morphological classification.

Discussion and Results

The cryptospores are moderately preserved and show moderate diversity and abundance (Table 1).

In this study, for the first time in Iran, an assemblage of cryptospores belonging to nine genera (10 species) have been identified from the Late Ordovician, Ghelli Fm., in north eastern Alborz, Iran. These are as follows:

Abditus Dydus laevigatus, Cheilotetras caledonica,

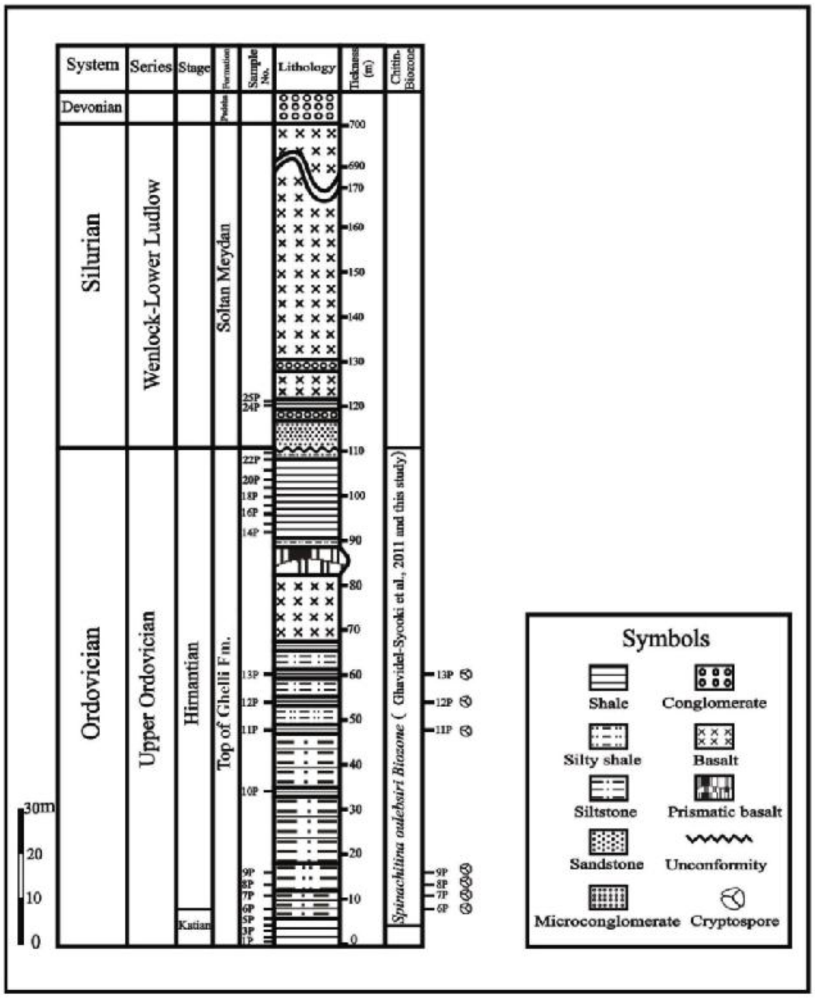


Figure 3. The stratigraphical column of the studied section

Table 1. The occurrence of cryptospores at the top of the Ghelli Fm. section

Abditusdyadus laevigatus	*Tetrahedralete s medinensis*	*Rimosotetras problematica*	*Dyadospora murusdens*	*Segestrespora rogusa*	*Dyadospora murusattenuat*	*Hispanaediscu sp.*	*Gneudnaspora divellomedi*	*Rugosphaera cerebra*	*Cheilotetras caledonica*	**Sample**
	■	■	■	■	■	■	■	■	■	**Kh/6P/2011**
	■	■	■				■			**Kh/7P/2011**
			■							**Kh/8P/2011**
■										**Kh/9P/2011**
	■	■	■	■	■	■				**Kh/11P/2011**
	■									**Kh/12P/2011**
	■	■	■							**Kh/13P/2011**

Dyadospora murusdensa, *D. murusattenuata*, *Gneudnaspora divellomedia*, *Hispanaediscus* sp., *Rimosotetras problematica*, *Rugosphaera cerebra*, *Segestrespora rugosa*, *Segestrespora* sp. cf. *S. rugosa*, *Tetrahedraletes medinensis*, *Tetrahedraletes* sp. cf. *T. medinensis*.

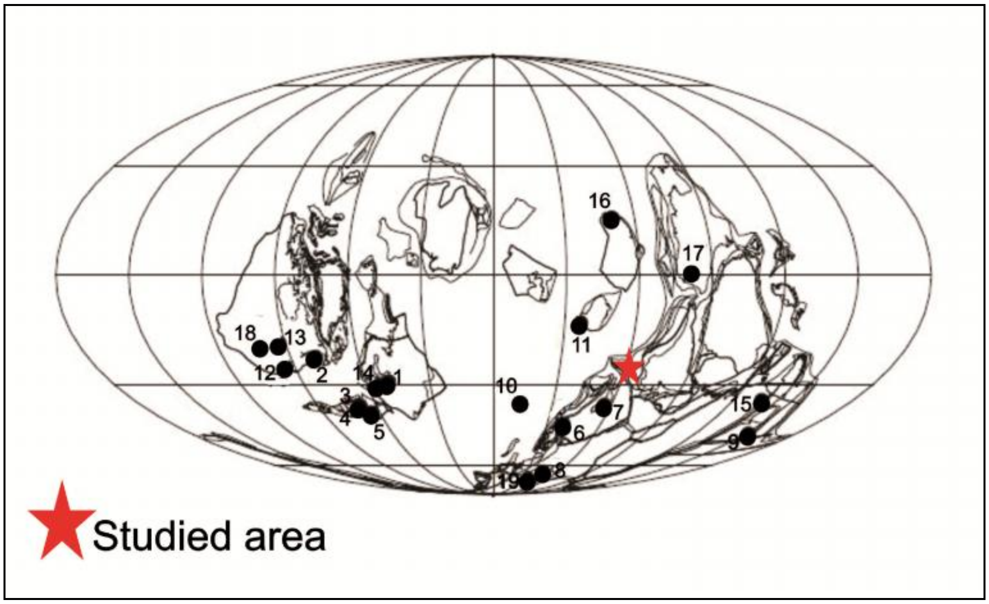


Figure 4. Location map of reported Late Ordovician (Katian- Hirnantian) cryptospore assemblages (Vecoli *et al*., 2011) plotted on palaeogeographical reconsruction (Torsvik, 2009), at 445 My. 1. Valga-10 drillcore, Estonia (Vecoli *et al*., 2011); 2. Anticosti Island (Vecoli *et al*. 2011); 3. Southwest Wales (Burgess, 1991); 4. Southern Britain (Wellman, 1996); 5. Belgium (Steemans, 2001); 6. Southeastern Turkey (Steemans *et al*., 1996); 7. Saudi Arabia (Steemans *et al*., 2009); 8. Northeast Libya (Richardson, 1988); 9. Northwest Argentina (Rubinstein, 2005; Rubinstein & Vaccari, 2004); 10. Czech Republic (Vavrdová, 1988, 1989); 11. South China (Wang *et al*., 1997); 12. USA (Gray 1988); 13. Canada (Gray 1988); 14. Sweden (Gray, 1988); 15. South Africa (Gray *et al*., 1986); 16. North China (Yin and He 2000); 17. Australia (Foster & Williams 1991); 18. USA (Strother, 1991); 19. Western Libya (Gray *et al*., 1982). The star mark indicates the paleoposition of the study area assigned to the North Gondwana province.

The morphological classification of Wellman and Richardson (1993) has been applied to their classification.

In this classification, the cryptospores are divided into five groups: Unfused permanent tetrads, fused permanent tetrads, true dyad, pseudodyads, and hilate cryptospores, which include only monads.

Ghavidel-Syooki *et al*., (2010) reported Silurian cryptospore assemblages from the northeast of Iran without any morphological classification.

Vecoli *et al*., (2011), concluded that there is no significant difference between cryptospore assemblages of the world in Late Ordovician and our data in this article are in agreement with them. With reference to the identified cryptospores (Plates 1 and 2), and the presence of biostratigraphy and palaeogeography indices, the chitinozoa species, *Spinachitina oulebsiri* (Paris, 1990; Paris *et al*., 2000, 2007), which is assigned to the Late Ordovician of northern Gondwana (Ghavidel-Syooki *et al*. 2011a; this study: Plate 3, Fig. 12), and also the reported index acritarchs of Late Ordovician (Ghavidel-Syooki *et al*., 2011a; this study: Plate 3, Figs. 1-11) a Late Ordovician age (late Hirnantian) is proposed for the top of the Ghelli Fm., (Fig. 5) (Ghavidel- Syooki *et al*. 2011a; this study).

The presence of peri- Gondwanan palaeobiogeographical index acritarchs (Delabroye *et al*., 2010; Ghavidel-Syooki *et al*., 2011a) and Plate 3, Figures 9-11 of this study, indicate that eastern Alborz was in the peri-Gondwanan province during the Late Ordovician (Mahmoudi *et al*., 2011; Mahmoudi, 2011).

Palaeoenvironment significance

In the studied samples, the *Veryhachium tripinosom* species appear to be abundant and the *Baltisphaeridium*, *Villosocapsula*, *Leiofusa*, *Multiplicisphaeridium*, *Ordovicidium*, *Orthosphaeridium*, *Actinotodissus* genera are common; the *Dorsennidium*, *Safirotecha*, *Peteinosphaeridium* genera are rare and the *Frankea*, *Navifusa*, *Pirea*, *Riptosocherma* genera are very rare, respectively (Table 2b).

In general, the marine elements (acritarchs, prasinophytes and occasionally chitinozoans) are present throughout the section (110 m), but the

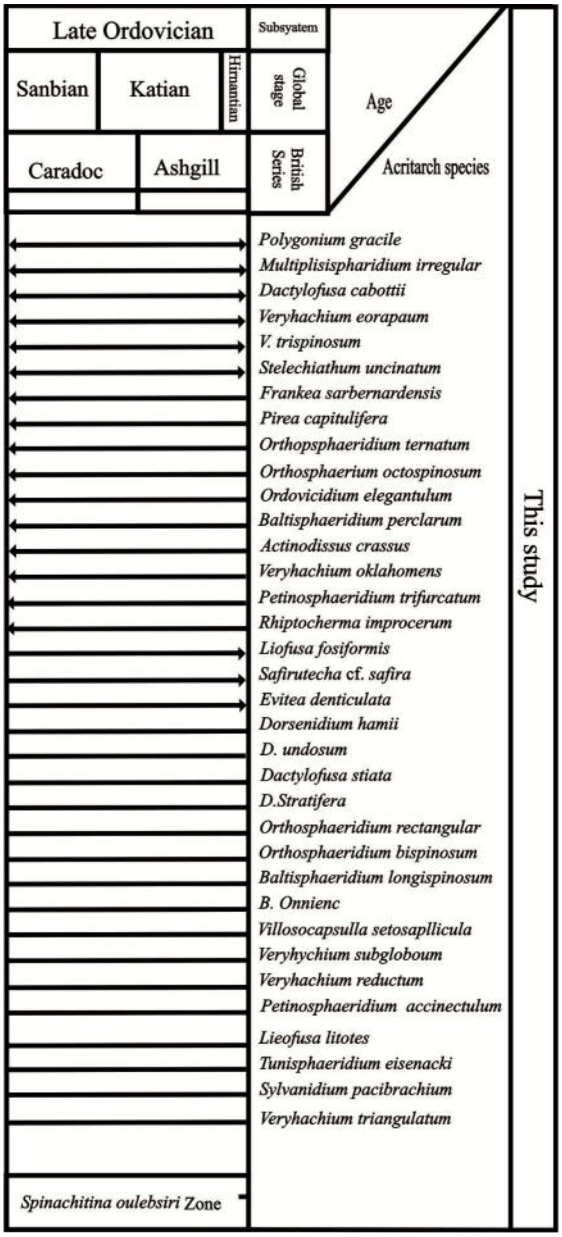


Figure 5. Stratigraphical distribution of some of the index acritarchs and chitinozoa at the top of the Ghelli Fm.

terrestrial elements (cryptospores), recovered only from samples No. 6 to 13 (8 to 60 m from the base of the section), constitute 7% (Table 2a) of the palynomorph assemblage. The admixture of land-derived and marine palynomorphs in the Ghelli Fm. materials (interval of 52 m), clearly indicate a continental influx. The cryptospores seem to be transported from an adjacent land area. The lack of land-derived elements in the up-section may indicate an increased distance offshore. This type of paleoenvironmental conclusion is well-explained by Rubinstain & Vaccari 2004 and Le Herisse *et al*. 2013.

Nine genera (10 species) have been recovered from the Ghelli Formation of the Upper Ordovician strata of the eastern Alborz Mountain range, Iran. These cryptospores are classified morphologically and their assemblages have systematically revealed that there are no significant differences between similar-aged cryptospore assemblages of the peri-Gondwanan region, Baltic provinces, and other parts of the world.

The cryptospores seem to be transported from an adjacent land area, which is not so close-by. The lack of land-derived elements in the up-section may indicate an increased distance offshore

Systematic cryptospores

The authors followed the subdivision and terminology proposed by Wellman and Richardson (1993, 1996) and Richardson (1996a, b) and for comprehensive synonymy listings Strother (1991), Wellman and Richardson (1996), and Vecoli *et al*. (2011) can be referred to Anteturma Cryptosporites Richardson, Ford & Parker 1984.

True Tetrads

Naked fused cryptospore tetrads

This group comprises of tetrads, where the spores are without outer envelopes and are fused together, and appear without lines of attachment that mark the position of the planes of attachment between the spores.

Genus *Cheilotetras* Wellman & Richardson1993

Cheilotetras caledonica Wellman & Richardson 1993

Pl. 1, Fig. 8; Pl. 2, Fig. 5

Dimensions. 30 (35) 40 µm.

Description. Fused permanent tetrads, outline circular, an individual 'spore' without an invaginated distal surface. The junction is entirely fused and no line of attachment is evident. The distal exine over the spores is laevigate.

Occurrence. Late Ordovician (Katian–Hirnantian), Anticosti Island, Québec, Canada, and Estonia (Vecoli *et al*., 2011); Early Silurian (Llandovery): Scotland (Molyneux *et al*., 2008); Middle Silurian (Wenlock): Scotland (Wellman & Richardson 1993; 1996; Molyneux *et al*., 2008); Middle to Late Silurian (Wenlock– Ludlow): Scotland (Wellman, 1993); Middle to Late Silurian

(Wenlock– Peridoli): Southern Wales (Burgess & Richardson, 1995); Early Devonian (Lochkovian): Saudi Arabia (Steemans *et al*., 2007).

Naked unfused cryptospore tetrads

This group of permanent tetrads comprises of tetrads that remain permanently attached, with lines of attachment on the tetrads surface that mark the position of the planes of attachment between the spores. Unfused tetrads are naked, or enclosed within the laevigate or variously ornamented envelopes.

Genus *Rimosotetras* Burgess 1991

Rimosotetras problematica Burges 1991

Pl. 1, Fig. 9; Pl. 2, Figs. 6&7

Dimensions. 20 (25) 30 μm.

Description. Unfused permanent tetrads. Circular-sub circular in outline, with lines of attachment on the tetrads surface that mark the position of the planes of attachment between the spores. The distal exine over the spores is laevigate.

Occurrence. Long stratigraphic range, having been frequently recorded in strata across the Late Ordovician, through Silurian (Vecoli *et al*., 2011), such as in the: Late Ordovician (Katian–Hirnantian): Northwest Argentina (Rubinstein & Vaccari, 2004); Late Ordovician (Katian–Hirnantian): Anticosti Island, Québec, Canada, and Estonia (Vecoli *et al*., 2011); Late Ordovician to Early Silurian (Caradoc– late Llandovery): North Africa (Richardson, 1988); Late Ordovician to Early Silurian (late Ashgill– early Telychian): Libya (Hill *et al*., 1985); Late Ordovician to Middle Silurian (Caradoc– Ludlow): Southeast Turkey (Steemans *et al*., 1996); Early Silurian (Llandovery): Saudi Arabia (Steemans *et al*., 2000; Wellman *et al*., 2000; Steemans *et al*., 2007); Early Silurian (Llandovery): Brazil (Le Herisse *et al*., 2001); Middle Silurian (Wenlock): Shropshire, England (Burgess & Richardson, 1991); Middle Silurian (Wenlock): Scotland (Wellman & Richardson, 1993); Early to Late Silurian (Telychian– Ludfordian): Pennsylvania, USA (Beck & Strother 2008); Late Silurian (Ludlow): Southern Tunisia (Vecoli *et al*., 2009).

Table 2. Relative abundances of individual genera and species, derived from counts 23 specimens per sample from the top of the Ghelli Fm. in the studied area, based on the reported frequency of Playford & Wicander 2006, are specified as follows: V, very abundant (>25% of the total acritarch/ prasinophyte content); A, abundant (>10–25%); C, common (>5–10%); U, uncommon (1–5%); R, rare (<1%) and (-) barren. a) Cryptospores and Chitinozoa; b) Acritarchs and Prasinophytes

a

Palynomorphs Taxa		Samples Number (Ord. Kh/1-23P)																						
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Cryptospores Taxa	*Abditusdyadus laevigatus*	–	–	–	–	–	–	–	–	C	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Cheilotetras caledonica	–	–	–	–	–	C	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Dyadospora murusdensa	–	–	–	–	–	C	C	C	–	–	C	–	C	–	–	–	–	–	–	–	–	–	–
	Dyadospora murusattenuata	–	–	–	–	–	C	–	–	–	–	C	–	–	–	–	–	–	–	–	–	–	–	–
	Rimosotetras problematica	–	–	–	–	–	C	C	–	–	–	C	–	C	–	–	–	–	–	–	–	–	–	–
	Rugosphaera cerebra	–	–	–	–	–	C	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Tetrahedraletes medinensis	–	–	–	–	–	C	C	–	–	–	C	C	C	–	–	–	–	–	–	–	–	–	–
	Monads Cryptospores	–	–	–	–	–	C	C	C	C	–	C	C	C	–	–	–	–	–	–	–	–	–	–
Chitinozoa Taxa	*Ancyrochitina* spp.	–	–	–	–	–		–	–	UC	–	UC	UC	UC	–	UC	–	–	–	–	–	–	–	–
	Conochitina spp.	–	–	–	C	–	C	–	–	–	–	–	UC	–	–	–	–	–	–	–	–	–	UC	–
	Desmochitina minor	–	–	–	–	–	–	–	–	–	UC	–	–	–	–	–	–	–	–	–	–	–	–	–
	Rhabdochitina usitata	–	–	–	–	–	UC	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Spinachitina oulebsiri	–	–	–	–	–	UC	–	–	UC	–	–	UC	–	–	–	–	–	–	–	–	–	–	–
	Undetermined Chitinozoa	–	–	–	C	C	–	–	–	UC	–	–	UC	UC	–	UC	–	–	–	–	UC	–	–	–

b

Acritarchs & Prasinophyte Taxa	Sample Numbers (Ord. Kh/ 1-23P)																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Actinotodissus crassus	C	C	–	–	–	–	–	–	–	C	C	–	R	–	–	R	–	–	–	–	–	–	–
Baltisphaeridium longispinosum	C	A	C	C	C	C	R	C	C	C	C	C	C	–	–	C	–	–	–	–	–	–	–
B. onniense	UC	UC	–	UC	C	UC	C	UC	UC	–	UC	–	–	–	–	–	–	–	–	–	–	–	–
B. perclarum	R	C	R	R	–	–	–	–	R	C	C	–	R	–	R	–	–	–	–	–	–	–	–
Dactylofusa cabottii	C	UC	–	UC	R	UC	R	UC	C	–	–	–	–	–	–	–	–	–	–	–	–	–	–
D. striata	C	C	–	C	C	–	–	C	C	–	–	–	–	–	–	R	–	–	–	–	–	–	–
D. Striatifera	–	–	–	–	–	–	–	–	R	–	–	–	–	–	R	–	–	–	–	–	–	–	–
Dorsennidium hamii	–	–	–	–	–	–	–	–	UC	–	R	–	UC	–	–	–	–	R	–	–	–	–	–
D. undosum	–	–	–	–	–	–		–	R		R	–	–	–	–	–	–	–	–	–	–	–	–
Evittia denticulata denticulata	UC	UC	UC	C	–	C	–	UC	–	C	UC	C	C	–	UC	C	–	–	–	–	–	–	–
Frankea sartbernardensis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	VR	–	–	–	–	–
Leiofusa bispinosoides	–	–	–	–	–	–	–	R	–	R	R	–	–	–	–	–	–	–	–	–	–	–	–
L. fosiformis	UC	UC	UC	C	UC	C	–	UC	–	C	UC	–	C	UC	–	–	–	–	–	–	–	UC	–
L. litotes	–	–	UC	–	–	–	–	–	UC	UC	C	–	–	–	–	–	–	–	–	–	–	–	–
Multiplicisphaeridium irregular	UC	C	UC	C	C	UC	–	C	C	C	C	C	UC	C	UC	C	–	–	–	–	–	–	R
Navifusa similis	–	–	–	R	R	–	–	–	–	–	R	–	–	–	–	–	–	–	–	–	–	–	–
Ordovicidium elegantulum	C	C	–	C	–	–	R	R	C	R	C	R	C	C	C	C	–	–	–	–	–	–	R
Orthosphaeridium bispinosum	R	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–	–	–	–	–	–
O. octospinosum	R	C	R	C	–	–	–	R	C	C	R	–	–	–	–	–	–	–	–	–	–	–	–
O. rectangulare	–	R	–	–	R	R	–	–	–	C	R	–	–	–	C	R	–	–	–	–	–	–	–
O. ternatum	–	–	–	–	–	–	–	–	–	R	R	–	R	–	–	–	–	–	–	–	–	–	–
Peteinosphaeridium accinctulum	–	–	–	R	–	–	–	–	–	–	–	R	–	R	–	–	–	–	–	–	–	–	–
P. septuosum	–	–	–	–	R	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pirea capitulifera	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	VR
Polygonium gracile	R	R	R	–	–	UC	–	R	–	R	–	R	R	UC	–	–	R	–	UC	–	–	–	–
Riptosocherma improcera	–	–	–	–	–	–	–	–	–	VR	–	–	–	–	–	–	–	–	–	–	–	–	–
Safirotheca sp. cf. *S. safira*	–	–	R	–	–	–	–	–	R	–	–	–	–	–	R	–	–	–	–	–	–	–	–
Stellechinatum uncinatum	UC	R	–	–	–	UC	–	–	–	–	UC	–	R	–	–	R	–	–	–	–	–	–	–
Sylvanidium paucibrachium	–	–	–	–	–	–	–	–	–	–	UC	UC	R	–	–	–	–	–	–	–	–	–	–
Tunisphaeridium eisenackii	–	–	–	–	–	VR	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Veryhachium eurapaum	R	R	C	C	C	C	R	R	C	C	C	R	C	R	C	R	–	–	–	–	–	–	R
V. oklahomens	R	UC	C	C	C	R	UC	R	C	R	UC	R	C	R	C	UC	–	–	–	–	C	C	C
V. reduatum	–	–	–	–	R	–	–	–	–	–	–	R	–	–	–	–	–	–	–	–	–	–	–
V. subglobosom	–	–	–	–	R	–	–	R	R	R	C	C	–	–	–	–	–	–	–	–	–	–	–
V. triangulatum	R	–	–	R	–	–	–	R	–	R	R	–	–	–	–	–	–	–	–	–	–	–	–
V. trispinosom	A	A	C	A	A	A	A	A	A	A	A	A	A	A	A	A	–	–	–	–	–	A	A
Villosacapsula setosapellicula	C	–	C	C	C	–	C	C	C	C	C	C	–	C	C	C	C	–	–	–	–	–	C
Tylotopalla sp.	R	R	–	–	–	–	–	–	–	R	R	–	–	–	–	R	–	–	–	–	–	–	–

Genus *Tetrahedraletes* Strother & Traverse emend. Wellman & Richardson 1993

Tetrahedraletes medinensis Strother & Traverse emend. Wellman & Richardson 1993

Pl. 1, Figs.11&12; Pl. 2, Figs. 9&11

Dimensions. 20 (25) 30 µm.

Description. Permanent tetrahedral tetrads, subcircular to subtriangular in outline. Within the tetrads, individual 'spores' have a subtriangular to subcircular equatorial outline. The walls are not very thick. The spores appear within the line of attachment, are clearly visible on the tetrad surface, and are without an enclosing envelope.

Occurrence. This species has been recorded worldwide and ranges from Ordovician (Caradoc) to Devonian (Vecoli *et al*., 2011). Some selected previous occurrences are as follows: Late Ordovician (Caradoc– Ashgill; late Katian– Hirnantian): Sudan (Gray, 1988; Le Herisse, 1989); Late Ordovician (Hirnantian): Wales (Burgess 1991); Late Ordovician (Caradoc– Ashgill; late Katian– Hirnantian): Australia (Forster & Williams 1991); Late Ordovician (Caradoc; late Katian): (Wellman, 1996); Late Ordovician (Caradoc– Ashgill; late Katian–Hirnantian): Southeast Turkey (Steemans *et al*., 1996); Late Ordovician (Katian– Hirnantian): Southern Xinjiang, China (Wang *et al*. 1997); Late Ordovician (Katian– Hirnantian): Pennsylvania (Taylor, 2002); Late Ordovician (Katian– Hirnantian): Anticosti Island, Québec, Canada, and Estonia (Vecoli *et al*. 2011); Late Ordovician to Early Silurian (late Asgill–ealy Llandovery): Saudi Arabia (Gray *et al*. 1986); Early Silurian (early Aeronian; middle Llandovery): North America (Miller & Eames 1982; Johnson 1985); Early Silurian (early Wenlock): Shropshire, England (Burgess & Richardson 1991); Early Silurian (Llandovery) Saudi Arabia (Steemans *et al*., 2007); Middle Silurian to Late Silurian (Sheinwoodian; early Wenlock)–(Ludfordian; late Ludlow): Pennsylvania, USA (Beck & Strother 2008) Late Silurian: South China; (Wang *et al*. 2005).

Tetrahedraletes grayae Strother 1991
Pl. 2, Fig. 8

Dimensions. 25 (35) 40 µm.

Description. Three-dimensionally preserved permanent tetrad of alete sporomorphs in arranged tetrahedral configuration; individual spore bodies subtriangular to subspherical in outline; Walls thin, surfaces psilate to somewhat microgranular depending upon the preservation, sutures between spore bodies visible, but without a well-developed thickened ring in the margin.

Occurrence. Late Ordovician (Katian–Hirnantian): Belgium (Steemans, 2001); Late Ordovician (Ashgill): Central Bohemia, Czech Republic (Vavrdová, 1989); Late Ordovician–Early Silurian (late Caradoc– early Telychian): northeastern Libya (Richardson, 1988); Early Silurian (Llandovery): Anticosti Island, Québec, Canada (Duffield, 1985); Early Silurian (Llandovery): Niagara Gorge, Lewiston, New York (Miller & Eames, 1982); Early Silurian: central Ohio, USA (Taylor, 2002).

True dyad

This group comprises of dyads in which two distinct spores are present with a clear plane of attachment forming a line of attachment on the surface of the dyad. The true dyads are usually naked, or enclosed within an envelope.

Unfused naked cryptospore dyads

This group comprises of dyads that readily separate into two alete spores.

Genus *Dyadospora* Strother & Traverse 1979
emend. Burgess & Richardson 1991

Dyadospora murusdensa Strother & Traverse 1979
emend. Burgess & Richardson 1991
Pl. 1, Fig. 5; Pl. 2. Figs. 1&4

Dimensions. 15 (22) 30 µm.

Description. Dyads, usually isomorphic, subcircular to elliptical in equatorial view, with an oblique compression. Individual 'spores' distally convex. A darkened equatorial crassitude, 1–2 µm thick is present. Exine laevigate.

Occurrence. Late Ordovician (Katian– Hirnantian): Southern British (Wellman, 1996); Late Ordovician (Hirnantian): Turkey (Steemans *et al*., 1996); Late Ordovician (Ashgill; Middle Katian–Hirnantian): Southern Xinjiang, China (Wang *et al*., 1997); Late Ordovician (Hirnantian): Argentina (Rubinstein & Vaccari, 2004); Late Ordovician–Early Silurian (Caradoc–Rhuddanian): Northeast Libya (Richardson 1988); Early Silurian (early Aeronian; middle Llandovery): North America (Miller & Eames, 1982); Early Silurian (Rhuddanian; early Silurian): North America (Johnson, 1985); Middle Silurian (Homerian; late Wenlock): Shropshire, England (Burgess & Richardson 1991); Early Silurian (Llandovery): Saudi Arabia (Steemans *et al*., 2000); Middle to Late Silurian (Late Wenlock–Early Ludlow): Peninsula (Taylor, 2002); Late Silurian: South China (Wang *et al*., 2005); Silurian: Sudan (Steemsns *et al*., 2010).

Dyadospora murusattenuata Strother & Traverse emend. Burgess and Richardson 1991
Pl. 2, Fig. 2

Dimensions. 15 (17) 20 µm.
Description. Dyads, usually isomorphic, subcircular in equatorial view, preserved in oblique compression. Individual "spores" distally convex. There is a crassitude at the point of contact between the two cryptospores. There is a cleft between the crassitudes of each 'spore'.
Occurrence. This species has a long stratigraphic range (Ordovician–Devonian) and common worldwide distribution (Vecoli *et al*., 2011). Some selected occurrences are as follows: Late Ordovician (late Caradoc– late Ashgil; Katian"Hirnantian): Libya (Richardson 1988); Late Ordovician (Ashgill; middle Katian): Czech Republic (Vavrdova, 1988; 1989); Late Ordovician (Katian–Hirnantian): Southeast Turkey (Steemans *et al*., 1996); Late Ordovician (Katian–Hirnantian): Southern Xinjiang, China (Wang *et al*., 1997); Late Ordovician (Katian– Hirnantian): Southwest Belgium (Rubinstein & Vaccari, 2004; Rubinstein, 2005); Late Ordocian (Katian–Hirnantian) Anticosti Island, Québec, Canada, and Estonia (Vecoli *et al*., 2011); Silurian: Sudan (Steemans *et al*., 2010); Early Silurian (Llandovery) Saudi Arabia (Steemans *et al*., 2007); Middle Silurian (Homerian; late Wenlock): Shropshire, England (Burgess & Richardson, 1991); Late Silurian: South China; (Wang *et al*., 2005).

Envelope-enclosed unfused cryptospore dyads
Group characterized by true dyads enclosed within a variously ornamented envelope.

Genus *Abditusdyadus* Wellman & Richardson 1996
Abditusdyadus laevigatus Wellman & Richardson 1996
Pl. 2, Fig. 3

Dimensions. 15–20 µm.
Description. Dyads of two lavigate hilate cryptospores enveloped within thick walls.
Occurrence. Late Ordovician (Katian–Hirnantian): Belgium (Steemans, 2001); Late Ordovician (Katian–Hirnantian): Anticosti Island, Québec, Canada, and Estonia (Vecoli *et al*., 2011); Early Silurian (Llandovery): Brazil (Mizusaki *et al*., 2002); Early Silurian (Rodanian; early Llandovery): Saudi Arabia (Steemans *et al*., 2000; Wellman *et al*., 2000); Ealy Devonian (Lochkovian): Scotland (Wellman & Richardson 1996).

Pseudodyads
Envelope-enclosed fused cryptospore dyads
This group comprises of dyads in which two permanently fused spores are joined by an encircling thickened band without a plane of attachment and line of attachment. Pseudodyads occur in a naked form or enclosed within an envelope.

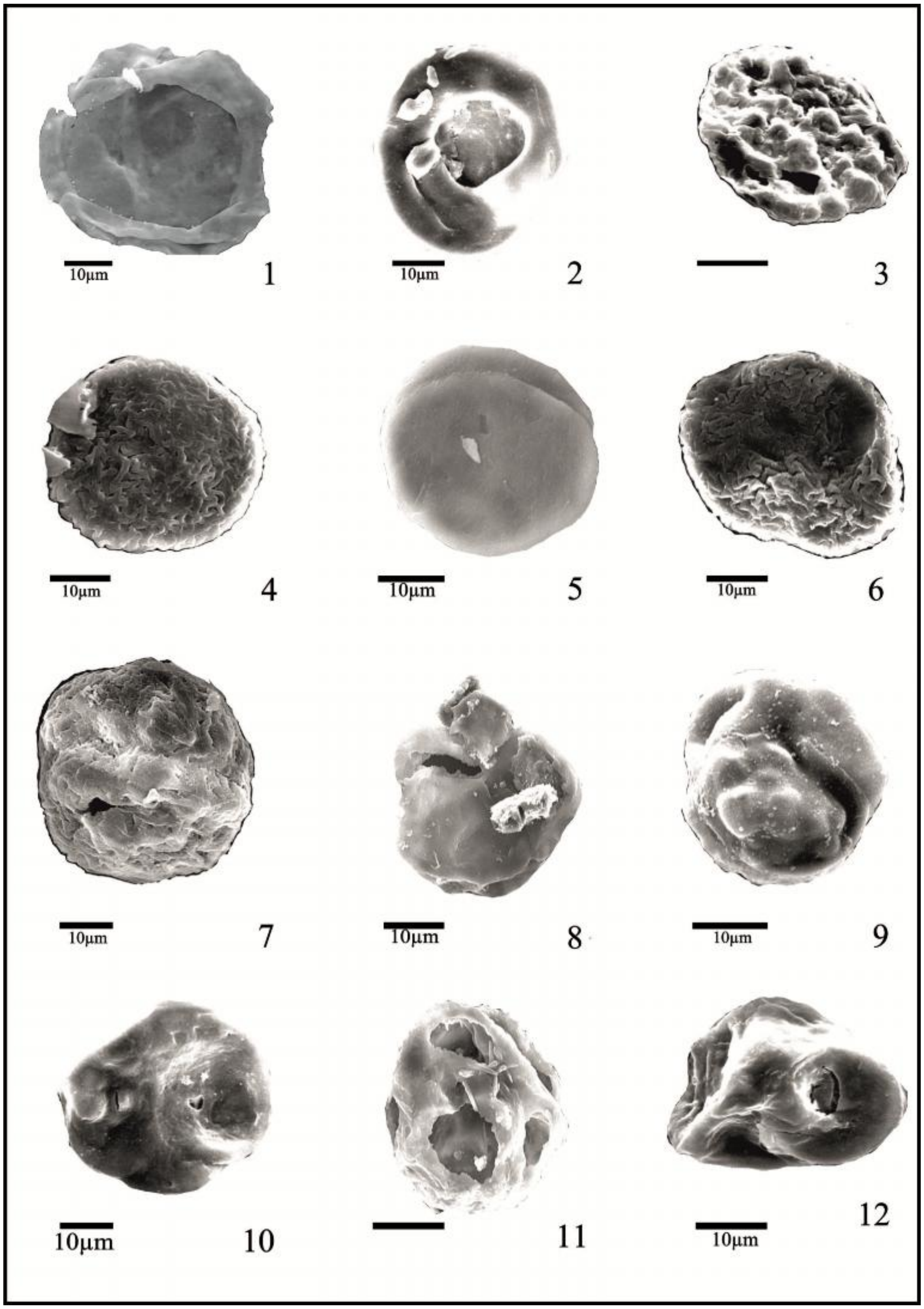
Genus *Segestrespora* Burgess 1991
Segestrespora rugosa (Johnson 1985) Burgess 1991
Pl. 1, Fig. 6

Dimensions. 30 (35) 40 µm.
Description. Pseudodyads, subcircular to elliptical in equatorial view, and totally enclosed within an envelope. Distal exine is ornamented with a closely spaced microrugulate.
Occurrence. This species has a wide geographical distribution, stratigraphically ranging from the late Ordovician to the Llandovery (Vecoli *et al*. 2011). Some selected occurrences are as follows: Late Ordovician (Katian– Hirnantian): Northeast Libya (Richardson, 1988); Late Ordovician (Katian–Hirnantian): Southwest Wales (Burgess 1991); Late Ordovician (Katian– Hirnantian): Southeast Turkey (Steemans *et al*., 1996); Late Ordovician (Katian–Hirnantian): Belgium (Steemsns, 2001); Late Ordovician (Katian– Hirnantian): Anticosti Island, Québec, Canada, and Estonia (Vecoli *et al*., 2011); Early Silurian (Llandovery): SW Wales (Burgess 1991); Early Silurian (early Llandovery): Saudia Arabia (Steemans *et al*., 2000; Wellman *et al*., 2000).

Hilate cryptospores
These forms consist of alete monad spores, hemispherical in longitudinal view, with a hilum, and an equatorial thickening. The exine may be laevigate or variously ornamented. Closely similar monads have been observed, partly united at the contact area as loose dyads.

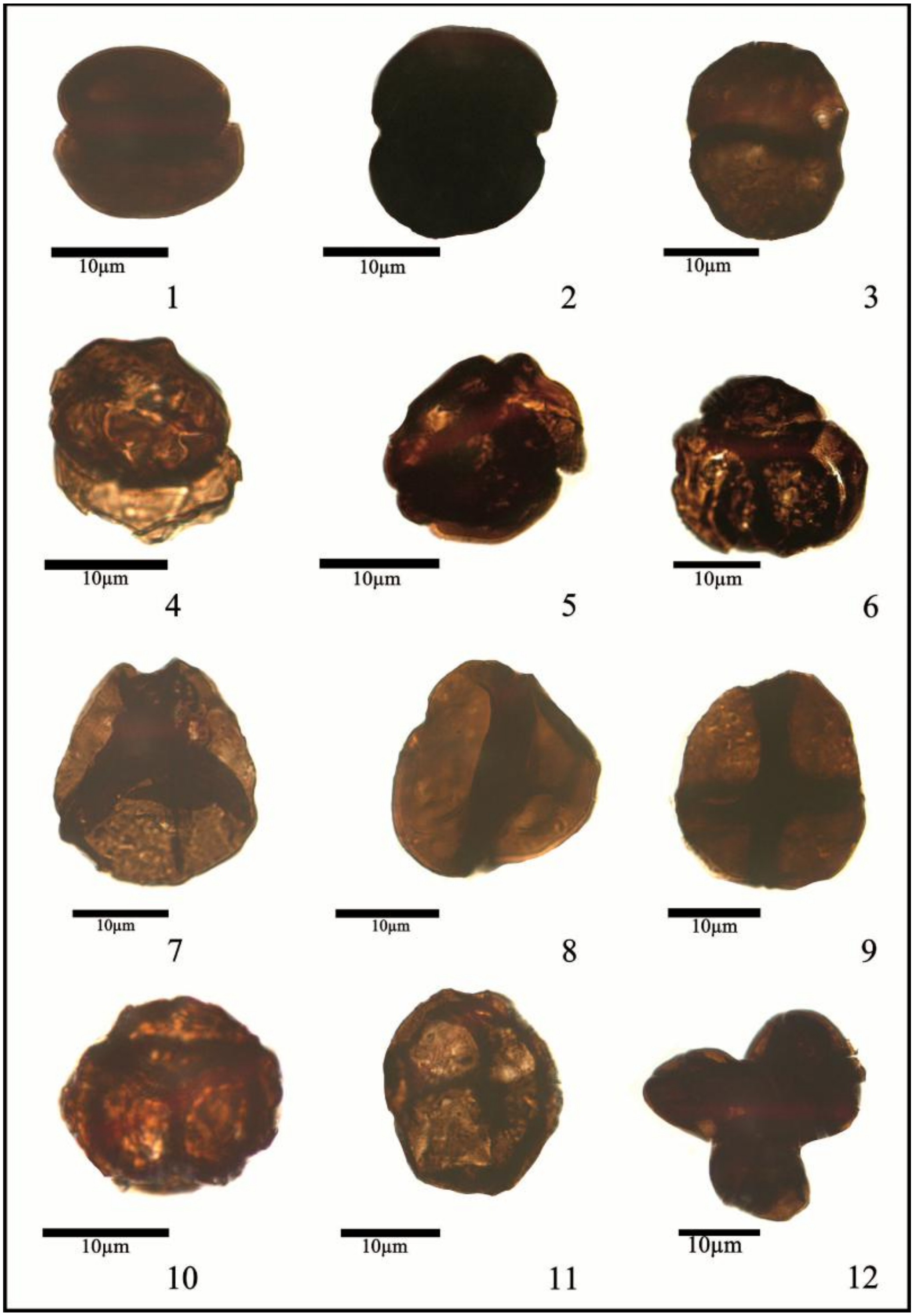
Genus *Gneudnaspora* Balme emend. Breuer, Al-Ghazi, Al-Ruwaili, Higgs, Steemans & Wellman 2007
Gneudnaspora divellomedia (Chibrikova) Balme 1988 var. minor Breuer, Al-Ghazi, Al-Ruwaili,

Plate 1



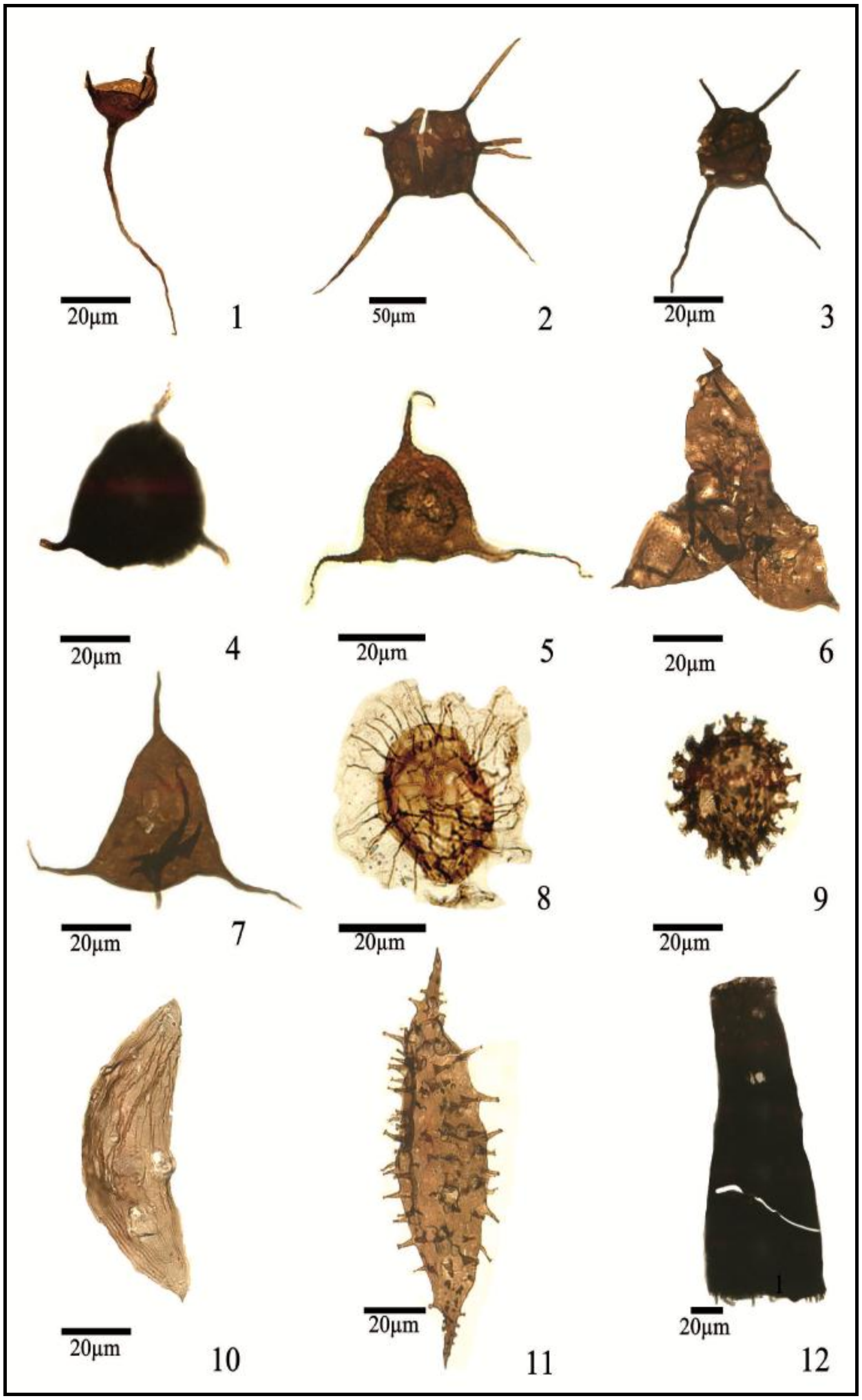
1&2. *Gneudnaspora divellomedia* (Chibrikova) Balme 1988 var. Breuer, Al-Ghazi, Al-Ruwaili, Higgs, Steemans & Wellman 2007. 3) *Hispanaediscus* sp.. 4. *Rugosphaera cerebra* Miller & Eames 1979. 5. *Dyadospora murusdensa* Strother & Traverse 1979 emend. Burgess & Richardson 1991. 6. *Segestrespora rugosa* (Johnson) Burgess 1991. 7) *Segestrespora* sp. cf. *S. rugosa* (Johnson) Burgess 1991. (Surfacial Granular sculptures are probably due to pyritization). 8. *Cheilotetras caledonica* Wellman & Richardson 1993. 9. *Rimosotetras problematica* Burgess 1991. 10. *Tetrahedraletes* sp. cf. *T. medinensis* Strother & Traverse 1979 emend. Wellman & Richardson 1993. 11&12. *Tetrahedraletes medinensis* Strother & Traverse 1979 emend. Wellman & Richardson 1993

Plate 2



1&4. *Dyadospora murusdensa* Strother & Traverse 1979 emend. Burgess & Richardson 1991. 2. *Dyadospora murusattenuata* Strother & Traverse 1979 emend. Steemans, Le Herisse & Bozdogan 1996. 3. *Abditusdydus laevigatus* Wellman & Richardson 1996. 5. *Cheilotetras caledonica* Wellman & Richardson 1993. 6&7. *Rimosotetras problematica* Burgess 1991. 8. *Tetrahedraletes grayae* Strother 1991. 9&11. *Tetrahedraletes medinensis* Strother & Traverse 1979 emend. Wellman & Richardson 1993. 10. *Tetrahedraletes* sp. cf. *T. medinensis* Strother & Traverse 1979 emend. Wellman & Richardson 1993. 12. Cryptospores cluster

Plate 3



1. *Orthosphaeridium bispinosum* Turner 1984. 2. *Orthosphaeridium octospinosum* Eisenack 1968. 3. *Orthosphaeridium rectangulare* (Eisenack, 1963) Eisenack 1968. 4. *Veryhachium subglobosum* Jardin, Combaz, Magloire & Peniguel 1974. 5. *Villosacapsula* sp. cf. *setosapellicula* (Loeblich, 1970) Loeblich & Tappan 1976. 6. *Veryhachium triangulatum* Konzolava-Mazancova 1969. 7. *Sylvanidium paucibrachium* Loeblich 1970. 8. *Tunisphaeridium eisenackii* Loeblich & Tappan 1978. 9. *Tylotopalla* sp.. 10. *Dactylofusa striatifera* (Cramer & Diez 1972) Fensome, Williams, Barss, Freeman & Hill 1990. 11. *Safirotheca* sp. cf. *S. safira* Vavrdová 1989. 12. *Spinachitina oulebsiri* Paris *et al.* 2000

Higgs, Steemans & Wellman 2007
Pl. 1, Figs. 1–2

Dimensions. 30 (45) 55 µm.

Description. Monad spores, hemispherical in longitudinal view, with a hilum and an equatorial thickening.

Occurrence. Middle Ordovician (Dapingian–Darwilian): Argentina (Rubinstein *et al*., 2010; 2011); Late Ordovician (Katian–Hirnantian): Southern British (Wellman, 1996); Late Ordovician (Katian–Hirnantian): Southeast Turkey (Steemans *et al*. 1996); Late Ordovician (Katian– Hirnantian): Southern Xinjiang, China (Wang *et al*., 1997); Late Ordovician (Katian- Hirnantian): Belgium (Steemans, 2001); Late Ordovician: Saudi Arabia (Miller *et al*., 2007); Late Ordovician (Katian–Hirnantian): Southern Saudi Arabia (Steemans *et al*., 2009); Late Ordovician (Katian– Hirnantian): Anticosti Island, Québec, Canada, and Estonia (Vecoli *et al*., 2011); Middle Silurian (Wenlock): Shropshire, England (Burgess & Richardson, 1991); Late Silurian (Ludlow): Southern Tunisia (Vecoli *et al*., 2009); Early– Late Devonian: Northern Saudi Arabia (Bureuer *et al*., 2007).

Genus *Hispanaediscus* Cramer 1966 emend.
Burgess & Richardson 1991
***Hispanaediscus* sp.**
Pl. 1, Fig. 3

Dimensions. 17 (23) 30 µm.

Description. Amb subrounded, distal exine ornamented, with closely spaced verrucae, in part coalescing to form muri 1–2 µm wide and about 1 µm high; Hilum very thin and transparent.

Occurrence. This genus is very similar to the reported genus of Katian–Hirnantian Anticosti Island, Québec, Canada, and Estonia (Vecoli *et al*., 2011). For precise determination of this species, there should be a hilum on the proximal face, and also, the ornamentations should be real not pyrite damaged (personal communication of Prof. Wellman). We found a taxa similar to this form and to a genus reported by Vecoli *et al*., (2011) from the Upper Ordovician strata of the Zagros basin, South of Iran (unpublished data, National Oil Company of Iran).

Genus *Rugosphaera* Strother & Traverse 1979
Rugosphaera cerebra Miller & Eames 1979
Pl. 1, Fig. 4

Dimensions. 35 (40) 45 µm.

Description. Laevigate subcircular monads enclosed in rugulate envelopes. The ornamentation of the envelope consists of closely spaced sinuous muri**.**

Occurrence. Late Ordovician (late Caradoc; early Katian): Shropshire, England (Richardson, 1988); Late Ordovician (late Caradoc; early Katian): Wales (Richardson, 1988); Late Ordovician: Southeast Turkey (Steemans *et al*., 1996).

List of cryptospores taxa

Abditusdydus laevigatus Wellman & Richardson 1996.
Cheilotetras caledonica Wellman & Richardson 1993.
Dyadospora murusdensa Strother & Traverse 1979 emend. Burgess & Richardson 1991.
Dyadospora murusattenuata Strother & Traverse 1979 emend. Steemans, Le Herisse & Bozdogan 1996.
Gneudnaspora divellomedia (Chibrikova) Balme 1988 var. Breuer, Al-Ghazi, Al-Ruwaili, Higgs, Steemans & Wellman 2007.
Hispanaediscus sp.
Rimosotetras problematica Burgess 1991.
Rugosphaera cerebra Miller & Eames 1979.
Segestrespora rugosa (Johnson) Burgess 1991.
Segestrespora sp. cf. *S. rugosa* (Johnson) Burgess 1991.
Tetrahedraletes grayae Strother 1991.
Tetrahedraletes medinensis Strother & Traverse 1979 emend. Wellman & Richardson 1993.
Tetrahedraletes sp. cf. *T. medinensis* Strother & Traverse 1979 emend. Wellman & Richardson 1993.

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