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Silurian Graptolite, Conodont and Cryptospore Biostratigraphy of the Gülüç Section in Ereğli, Zonguldak Terrane, NW Anatolia, Turkey

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Abstract: The studied Gülüç section of the Silurian Fındıklı Formation is situated on the western bank of Gülüç Creek in Ereğli, NW Anatolia, Turkey, in the eastern part of the Zonguldak Terrane. The Gülüç section consists of 3 sedimentary packages: greenish grey limy siltstones, 5–7 m thick (1), overlain by an irregular alternation of black shales and clayey limestones, about 15 m thick (2), and a 6–7 m thick succession of mainly siltstones and sandy limestones (3). A combined biostratigraphy based upon graptolites, cryptospores and conodonts indicates that Package 1 is of Llandovery (Rhuddanian, Aeronian and/or early Telychian) age, Package 2 and Package 3 are of late Wenlock–early Ludlow (Homerian and Ludfordian) age. Graptolites in packages 2 and 3 indicate the presence of the *Cyrtograptus lundgreni, Neodiversograptus nilssoni* and *Lobograptus scanicus* graptolite biozones. The *Ozarkodina crassa* Biozone occurs in the lower Gorstian (Ludlow). The specific features of the Gülüç section (lithological changes, condensation, stratigraphic gap, change in graptolite diversity) are related to the global model of Silurian T–R cycles. The Silurian Fındıklı Formation in the Gülüç section, about 20 m thick, represents a condensed lithological succession which differs significantly from the coeval thick, stratigraphically widespread black shales and siltstones of the same formation in the Zonguldak and İstanbul terranes. Sixteen cryptospore species are described and their stratigraphic and geographic distributions are summarised.

Key Words: Ereğli, Zonguldak Terrane, Graptolites, Conodonts, Cryptospores, biostratigraphy

Siluriyen Graptolit, Konodont ve Kriptospor Biyostratigrafisi, Gülüç Kesiti-Ereğli, Zonguldak Tektonik Birliği, KB Anadolu

Özet: İncelenen Siluriyen yaşlı Fındıklı Formasyonu'na ait Gülüç kesiti Zonguldak tektonik birliğinin doğu kesiminde yer almakta olup Ereğli yakınındaki Gülüç Çayı'nın batı yamacında bulunur. Kesitte alttan üste; 5–7 m kalınlıkta yeşilimsi gri karbonatlı şeyller (1), 15 m kadar kalınlıkta düzensiz ardalanmalı siyah şeyl ve killi kireçtaşları (2) ve 6–7 m kalınlıkta silttaşı ve kumlu kireçtaşından (3) oluşma üç çökel paket gözlenir. Graptolit, kriptospor ve konodontların birlikte kullanılarak kurulan biyostratigrafiye göre Paket 1 Landoveryen (Ruddaniyen, Aeroniyen ve/veya erken Telişiyen) Paket 2 ve 3 ise geç Venlokiyen–erken Ludloviyen (Homeriyen ve Ludfordian) yaşındadır. İkinci ve Üçüncü paketlerde yer alan graptolitler *Cyrtograptus lundgreni, Neodiversograptus nilssoni* ve *Lobograptus scanicus* graptolit biyozonlarına işaret eder. *Ozarkodina crassa* Biyozonu alt Gorstiyen'de (Ludloviyen) yer alır. Gülüç kesitinin özellikleri (litolojik değişimler, kondenzasyon, stratigrafik boşluk, graptolit çeşitliliğinde değişiklikler) Siluriyen T-R döngelerinin global modeli ile uyum içindedir. Gülüç kesitinde yaklaşık 20 m kalınlık sunan Fındıklı Formasyonu kondanse bir istifi temsil etmekte olup aynı formasyonun İstanbul ve Zonguldak tektonik birliklerinde yaygın olarak yüzeylenen siyah şeyl ve silttaşı istiflerinden belirgin olarak farklıdır. Çalışmada onaltı kriptospor türü tanımlanmış, bunların stratigrafik ve coğrafi dağılımları özetlenmiştir.

Anahtar Sözcükler: Ereğli, Zonguldak Tektonik Birliği, Graptolit, Konodont, Kriptospor, biyostratigrafi

Introduction

The Silurian in NW Anatolia is part of the Alpine İstanbul–Zonguldak Terrane, separated by the Intra-Pontide Suture from the Alpine Sakarya Composite Terrane to the South (Göncüoğlu *et al.* 1997). To the North, it is bounded by the Black Sea Basin, the remnant of the Para-Tethys ocean (e.g., Stampfli 2000). It is considered to be a Gondwana-derived fragment that amalgamated with southern Europe or Laurussia during the Variscan Orogeny (Göncüoğlu 1997, 2001; Yanev *et al.* 2006). Some authors (e.g., Görür *et al.* 1997; Stampfli 2000; Raumer *et al.* 2002), however, suggested a southern Baltican origin. In previous studies it was considered as a single entity, with Palaeozoic successions overlying a Cadomian basement (Şengör *et al.* 1984). A recent review of the Palaeozoic stratigraphy (e.g., Göncüoğlu 1997) has shown that the succession of events and the lithostratigraphic successions in the east and west areas differ in a way that can not be explained simply by changes in the depositional environment. Therefore, Göncüoğlu & Kozur (1998, 1999) and Kozur & Göncüoğlu (2000) have suggested that the Palaeozoic successions in the west and east should represent two distinct terranes, the İstanbul and Zonguldak terranes, respectively (Figure 1).

In the İstanbul Terrane around İstanbul (Figure 1), the Silurian stratigraphy is well studied (e.g., Haas 1968; Önalan 1981). The lower Silurian (Llandovery) in this area is repesented mainly by a thick package of siliciclastics, overlain by shallow-marine limestones that continue up to the upper Ludlow. The succession is about 800 m thick and consists of shallow ramp deposits (Önalan 1981). In the easternmost outcrops of the Zonguldak terrane in the East, in the Karadere area (Figure 1), the early Silurian rocks were studied in detail by Dean *et al.* (2000).

In contrast to these recent studies in the west and east, in the Gülüç area located south of Ereğli (Figure 1), the Silurian succession, known since the late 1940s (Egemen 1947), has not been studied.

In this study the authors describe for the first time the litho- and bio-stratigraphy of a condensed sequence of strata of Llandovery to Ludlow age and correlate the succession with coeval ones in the İstanbul and Zonguldak terranes in NW Anatolia. It is the first biostratigraphic study of the Silurian of Turkey that combines data obtained from graptolites, conodonts and cryptospores contributing to our understanding of chronostratigraphy and basin development.

Geological Framework and Previous Findings

The studied Silurian rocks in the Gülüç section occur in a tectonic inlier south of Ereğli, NW Anatolia. In

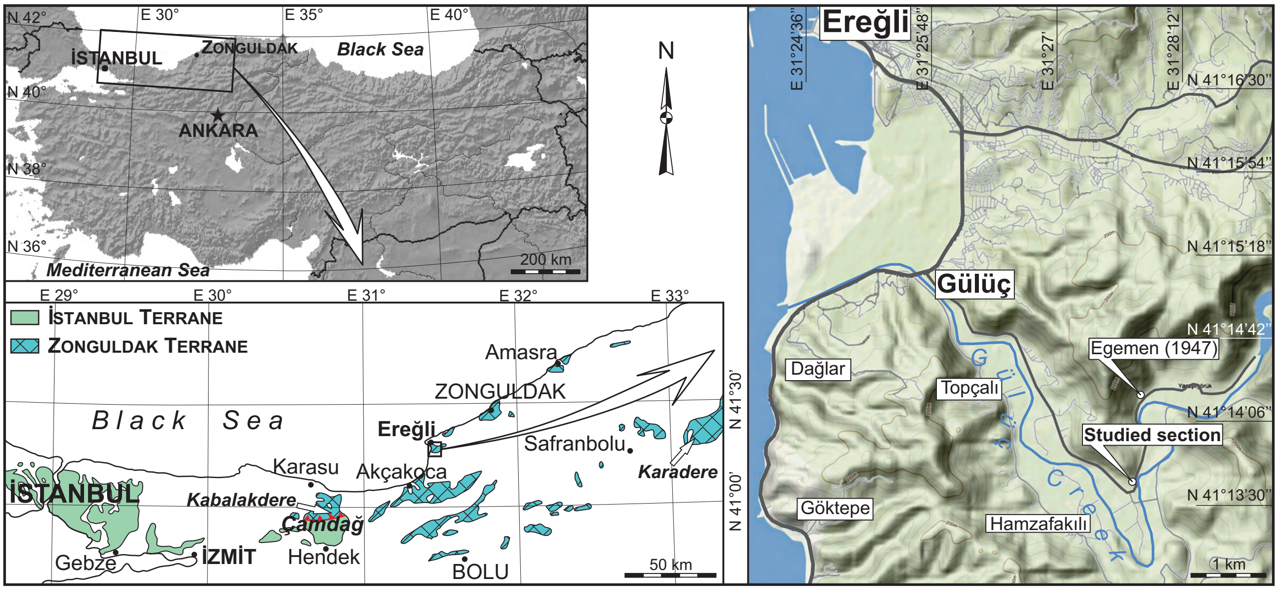

Figure 1. Geographic position of the Gülüç section and Palaeozoic outcrops in the İstanbul and Zonguldak terranes and Çamdağ area.

the recently published 1/100,000 scale geological maps (Altun & Aksay 2002) the Silurian outcrops are not shown, although they had already been dated by Egemen (1947). Later, Dean in Dean *et al.* (2000) reported on Wenlock graptolites from grey mudstones of the Fındıklı Formation near Ereğli.

The section is located on the road to the Gülüç Dam (Figure 1) and includes a NE-dipping homoclinal succession. The lowest part observed comprises brownish weathering mudstones and shales of unknown age. The measured section (Figure 2) starts above them and is characterized by three concordant packages. The succession is 28 m thick and is unconformably overlain by the Upper Cretaceous Yemişliçay Formation, comprising conglomerates, volcaniclastic sandstones and andesites (Altun & Aksay 2002).

From the Gülüç section, Egemen (1947) first figured and described *Monograptus* cf. *armoricanus* Philippot, *Monograptus* cf. *miloni* Philippot and *Monograptus* cf. *dubius* Suess. We have no information whether this collection is stored. The

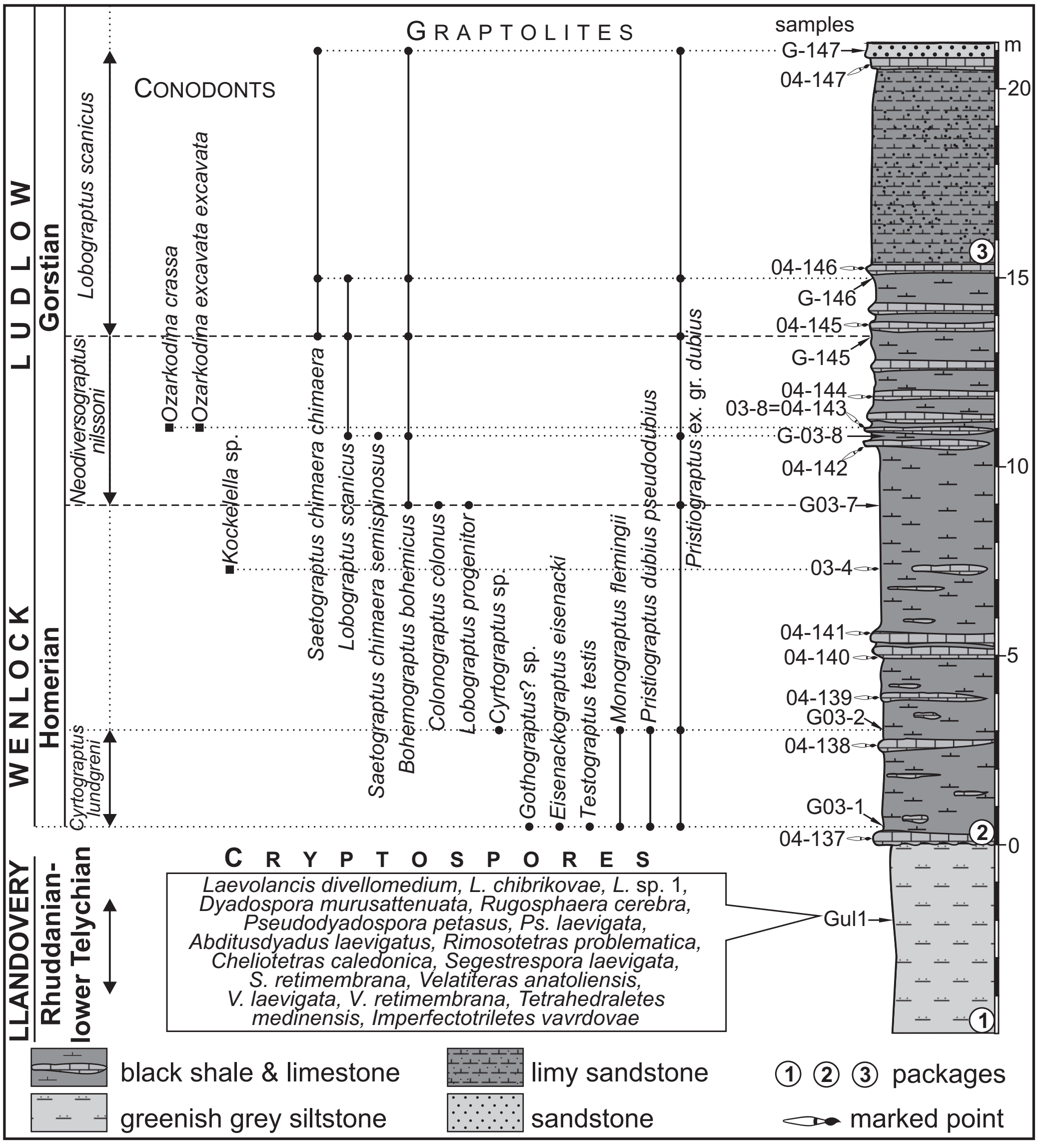

Figure 2. Geological column of the Gülüç section with the ranges of graptolites and conodonts, graptolite biozonation and position of the productive cryptospore sample.

material described and figured by Egemen (1947) is too poorly documented for positive identification. *Monograptus armoricanus* Philippot was recorded previously only in the *Cyrtograptus lundgreni* Biozone (lower Homerian, Wenlock) of the Armorican Massif. To identify his new species, Philippot (1944) indicated three main features: the rhabdosome is dorsally curved in the proximal part; dorsoventral width gradually increases, reaching 5 mm in the distal part; the thecae are simple, tubular-shaped and the thecal inclination is 45°. Egemen's specimens possess only the latter character of *M. armoricanus*. It is possible that the specimen belongs to *Pristiograptus dubius* (Suess) – a long-ranging species known from the Wenlock to the Přídolí (Rickards & Wright 2003). The specimen described by Egemen (1947) as '*Monograptus* cf. *miloni* Philippot' is without doubt a representative of *Saetograptus*, which ranges from the Gorstian (but not from the lowest part) to lower Ludfordian (Zalasiewicz *et al.* 2009).

Material and Method

The section was measured and sampled for conodonts and palynomorphs. Graptolites were collected from selected levels. Conodont samples were taken from each limestone bed and palynological samples at every 50 cm. Standard palynological (HCl-HF-HCl) and the standard conodont (CH_3COOH – 8–15 %) processing methods were used. All figured graptolite specimens are housed in the General Directorate of Mineral Research & Exploration (MTA), Ankara, Turkey. The micropalaeontological and palynological material is housed in the collections of MTA and Geological Institute, Sofia.

Description of the Gülüç Section

The studied section of the Silurian Fındıklı Formation is situated near Gülüç village on the western (left) bank of Gülüç Creek to the south of Ereğli, NW Anatolia, Turkey (Figure 1). The Gülüç section consists of 3 packages: 5–7-m-thick greenish grey limy siltstones (Package 1), overlain by an irregular alternation of black shales and clayey limestones, about 15 m thick (Package 2) and on top a 6–7-m-thick package of mainly siltstones and sandy limestones with single sandstone and limestone beds (Package 3).

At the base of the section (Package 1), within the greenish grey siltstones, acritarchs and cryptospores occur, the former being scarce and poorly preserved. No chitinozoans were found. Among the collected samples, only one sample – Gul 1, was productive. The cryptospore assemblage consists of 17 species of naked and enveloped monads, dyads and tetrads of the genera *Laevolancis, Dyadospora, Pseudodyadospora, Tetrahedraletes, Rimosotetras, Cheliotetras, Abditusdyadus, Segestrespora, Velatitetras* and *Imperfectotriletes*. The cryptospore taxa recorded are: *L. chibrikovae* Steemans, Higgs & Wellman, *L. divellomedium* (Chibrikova) Burgess & Richardson, *L.* sp. 1, morphon *D. murusattenuata* (*sensu* Steemans *et al.* 1996), *Ps. Laevigata* Johnson, *Ps. Petasus* Wellman & Richardson, *T. medinensis* Strother & Traverse, *R. problematica* Burgess, *Ch. Caledonica* Wellman & Richardson, *A. laevigatus* Wellman & Richardson, *R. cerebra* Miller & Eames, *S. laevigata* Burgess, *S. membranifera* (Johnson) Burgess, *V. anatoliensis* Steemans, Le Hérissé & Bozdogan, *V. laevigata* Burgess, *V. retimembrana* (Miller & Eames) Wellman & Richardson and *I. vavrdovae* Steemans, Higgs & Wellman (Figure 2).

Above, within the shale-limestone alternation in Package 2, black shales are predominant and yielded fairly diverse graptolites, illustrated in Plates I and II. The lowermost 3 m yielded *Pristiograptus* ex. gr. *dubius, Testograptus testis* (Barrande), *Monograptus flemingii* (Salter), *Eisenackograptus eisenacki* (Obut & Sobolevskaya) and *Cyrtograptus* sp., indicating that this interval belongs to the *Cyrtograptus lundgreni* Biozone (Homerian, Wenlock) (Figure 2). *Kockelella* sp. occurs in the middle part of this package in sample 03-4 in a 6-m-thick interval barren of graptolites. Nine metres above the base of Package 2, *Lobograptus progenitor* Urbanek, *Colonograptus colonus* (Barrande), *Pristiograptus* ex. gr. *dubius* and *Bohemograptus bohemicus* (Barrande) indicate the upper *Neodiversograptus nilssoni* Biozone (lower Gorstian, Ludlow). The limestone bed about 11 m above the base of Package 2 (sample 03-8) yielded the conodonts *Ozarkodina crassa* Walliser and *Oz. excavata excavata* (Branson & Mehl) (with Pa elements and M elements).

The uppermost 9–10 m of Package 2 and Package 3, within the limy sandstones, correspond to the

Lobograptus scanicus Biozone (Gorstian) and contain *Lobograptus scanicus* (Tullberg), *Saetograptus chimaera chimaera* (Barrande) and *Pristiograptus* ex. gr. *dubius*.

Biostratigraphy

A combined biostratigraphy based on graptolites, conodonts and cryptospores indicates that greenish-grey siltstones in the Package 1 are of Llandovery (Rhuddanian–early Telychian) age, the shale-limestone alternation of Package 2 and Package 3 of siltstones, limestones and sandstones is of late Wenlock–early Ludlow age (Homerian and Gorstian).

Cryptospores

The cryptospore assemblage from Package 1 in the Gülüç section (sample Gul 1) is characterized by many naked cryptospore tetrads and dyads. Envelope-enclosed cryptospores are also diverse and represented by four genera. The naked cryptospores (*Dyadospora, Tetrahedraletes, Cheliotetras, Rimosotetras*) dominate numerically over the enveloped monads, dyads and tetrads of the genera *Rugosphaera, Abditusdyadus, Segestrespora* and *Velatitetras*. Laevigate alete monads of the genus *Laevolancis* and cryptospores with imperfect trilete mark of *Imperfectotriletes* occur, too. True trilete spores are absent.

The cryptospore assemblage from the base of the Gülüç sections is comparable with assemblages known from elsewhere in the interval between two bioevents in the Late Ordovician–early Silurian cryptospore evolution: (1) the incoming of *Laevolancis divellomedium* in the Rhuddanian (Steemans *et al.* 2000) and (2) the first occurrence of true trilete spores of *Ambitisporites avitus* and the coeval disappearance of enveloped enclosed cryptospores in the late Llandovery, Telychian (Burgess 1991; Wellman & Gray 2000; Steemans 2001). These events were diachronous on different palaeocontinents.

In Avalonia, in the type sections of the Llandovery and Wenlock in the UK, *L. divellomedium* first occurs in the Sheinwoodian (Burgess 1991; Burgess & Richardson 1991). In Northern Gondwana, in Saudi Arabia, the incoming of *L. divellomedium* was documented in the Rhuddanian and defines the base of *Laevolancis divellomedium* Interval Biozone (Steemans *et al.* 2000). Similarly, in Western Gondwana, in Paraguay, *L. divellomedium* Biozone (*Divellomedium* I subzone) was assigned to the Rhuddanian–lower Aeronian on the basis of chitinozoan data (Le Herisse *et al.* 2001; Steemans & Pereira 2002).

The second cryptospore bioevent, the abundant occurrence of true trilete spores and the disappearance of enveloped cryptospores, occurred at the Aeronian–Telychian boundary in the UK (Burgess 1991). In Saudi Arabia these events were documented at the base of the *L. divellomedium* β Subzone in the middle Aeronian (Steemans *et al.* 2000). In Paraguay, these two almost coeval events define the base of the *Divellomedia* II Subzone within the upper Aeronian (Steemans & Pereira 2002).

Thus, the cryptospore assemblage from the Gülüç section is obviously older than late Telychian. Similar assemblages consisting of predominantly naked cryptospores, some enveloped cryptospores, representatives of *L. divellomedia* and single or no true trilete spores normally occur in the Llandovery (upper Rhuddanian to lower Telychian) in Saudi Arabia and Paraguay (Steemans & Pereira 2002). Biozonal correlation is possible with the cryptospore *divellomedium* α Subzone from Saudi Arabia, the *divellomedium* I Subzone from Paraguay (Steemans *et al.* 2000; Steemans & Pereira 2002) and with the *Velatitetras-Ambitisporites* Biozone in southern Turkey, Katian–Rhuddanian (Steemans *et al.* 1996).

Due to the diachronism of some cryptospore first appearances on different palaeocontinents, regional biozonal schemes should be applied and the age is not precisely determinable based on cryptospores and trilete spores alone. Anyhow, the age of sample Gul 1 could not be younger than early Telychian, based on the absence of true trilete spores, and not older than Rhuddanian–Aeronian because enveloped cryptospores are still present but uncommon. The co-existence of enveloped cryptospores and *Laevolancis divellomedium* (Figure 4) suggests a Rhuddanian–early Telychian age (Steemans & Pereira 2002).

A recent palynological study of the Upper Ordovician in Saudi Arabia documented an earlier occurrence of hilate spores (e.g., *Laevolancis*) and trilete spores on Gondwana (Steemans *et al.* 2009). These spores are of Katian age, determined on the basis of chitinozoan and actitarch biostratigraphy. The earliest valcular land plants probably emerged and diversified in Gondwana during the Late Ordovician (Steemans *et al.* 2009).

The palaeogeographic distribution of the cryptospores documented from the Gülüç sections is shown in Figure 5. It is evident that cryptospore-producing primitive land plants occupied all of the palaeocontinents in the Llandovery. The only exceptions are *Abditusdyadus laevigatus,* which is restricted to Avalonia, North and West Gondwana, and *Cheliotetras caledonica* known from Laurentia, Baltica and Avalonia. As a whole, the Llandovery cryptospore assemblage of the Gülüç section is quite similar to those from England and Scotland, the Taurides in southern Turkey, Saudi Arabia, Libya and South America.

Graptolites

The Silurian graptolite biozonal scheme used in this paper (Figures 2 & 3) is that of Koren' *et al.* (1996) completed by Melchin (1998). The graptolite-bearing levels are indicated in Figure 3 and the graptolite ranges in Figure 2. The graptolites occur more often in the dark grey shales (Package 2) and are poorly preserved as flattened, black peridermal films. Most of the graptolites do not seem to show much tectonic distortion. The most common are representatives of *Pr*. ex. gr. *dubius* (Plate II, g). The species from the lowermost graptolite-bearing level (G03-1), *T. testis* and *E. eisenacki* (Plate II, f), are characteristic of the *Cyrt*. *lundgreni* graptolite Biozone. The specimens figured in Plate I (d and f) show the characteristic *Testograptus* hook-shaped rabdosome but not the strong and backwards directed paired apertural spines of *T. testis testis* (Urbanek & Teller 1974; Lenz 1990). The former feature makes the studied specimens very close to *T. testis incomptus* (Lenz & Melchin 1991). Lenz & Melchin (2008), however, stated that the subspecies *T. testis testis*, *T. testis incomptus*, and *T. testis inornatus* (Elles) may be part of a single, variable population, rather than being separate subspecies. For this reason the specimens studied here are identified as *T. testis*. On the surface of the same rock sample (field number G03-1.1) occur a couple of retiolitid graptolites with an Appendix. Only representatives of *Gothograptus* and *Eisenackograptus* have such an appendix and they coexist with *T. testis* (Kozłowska-Dawidziuk 2004). One complete specimen with a dense reticulum (Plate II, f), although flattened, is similar to *E. eisenacki* and *G. storchi* Lenz & Kozłowska, both species being known from the *lundgreni* Biozone. The shape of the distal end is closer to that of *E. eisenacki*, and the large lateral proximal orifice characteristic of *G. storchi* was not observed. Thus, the specimen is identified as *E. eisenacki*. Lenz & Kozłowska-Dawidziuk (2001) mentioned that this species shows large ranges in variation of important features. The specimen from level G03-1 is similar to *E. eisenacki* figured by Obut & Sobolevskaya (1965, plate 3, figure 5), Lenz & Melchin (1987, plate 2, figure 5), Lenz (1993, plate 8, figures 5, 8, plate 9, figures 1, 5, 9) and Loydell *et al.* (2010, figure 4e). The same level also yielded fragments (Plate II, l) in which the prominent vertical list (probably the nema) is part of the skeletal structure of the distal part of the rhabdosome, which is a diagnostic feature of the genus *Gothograptus* (Kozłowska-Dawidziuk 1990, 1995, Figure 9). Within the *Cyrt. lundgreni* graptolite Biozone, species of *Gothograptus* occur commonly (Kozłowska-Dawidziuk 1990; Lenz & Kozłowska 2006). Future detailed study of this interval could complete the graptolite association. It should be noted that the *Cyrt. lundgreni* graptolite Biozone is characterized by a considerable diversity of retiolitid genera (Lenz & Kozłowska 2007).

Pristiograptus pseudodubius Bouček (Plate II, e) occurs in the levels G03-1 and G03-2. This is a species of *dubius* group with a dorsoventral width rarely exceeding 1.0 mm (1, 2 mm), a thecal spacing of 10–11 in 10 mm, and thecal inclination of 30° (Přibyl 1943). The same levels also yield *Monograptus flemingii*. Two rhabdosomes preserved in lateral (Plate II, a) and ventral (Plate II, d) view from sample G03-2.3 show short lateral spines on the thecal apertures and thick hooks. *Cyrtograptus* sp. (Plate I, a) from the same sample G03-2 is a poorly preserved fragment of a curved procladium with missing proximal end and cladia. The cyrtograptids, *Pr. dubius pseudodubius* and *M. flemingii,* disappeared in the upper part of *Cyrt*. *lundgreni* graptolite Biozone. Hence, the upper boundary of this biozone is placed at their last occurrence in the section (level G03-2). Above,

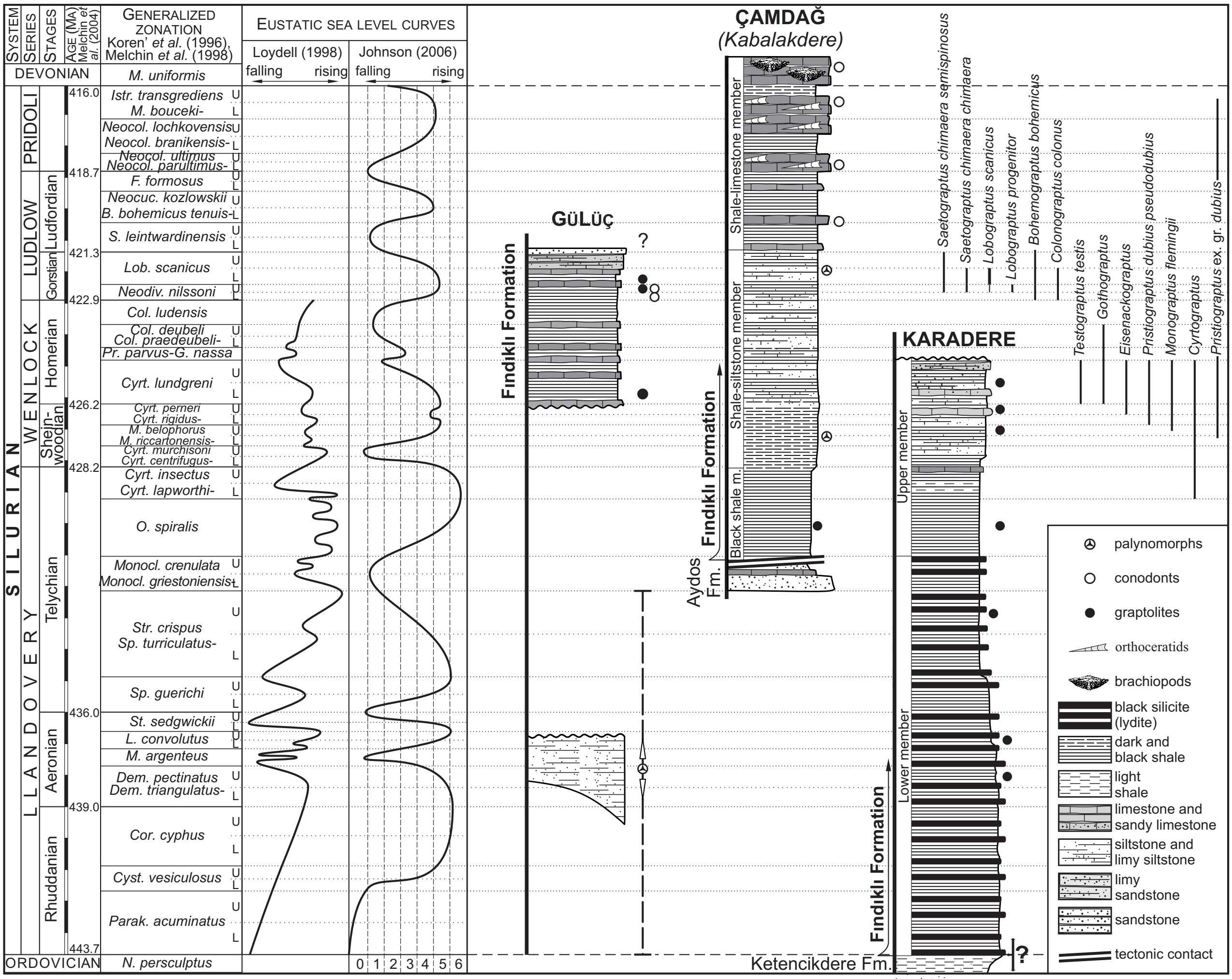

Figure 3. Sections of the the Fındıklı Formation in the Zonguldak Terrane and stratigraphic ranges of the graptolite taxa (*Pristiograptus* ex. gr. *dubius* after Rickards & Wright 2003, *Monograptus flemingii* and *Pristiograptus dubius pseudodubius* after Štorch 1994, *Eisenackograptus* and *Gothograptus* after Lenz & Kozłowska 2007, all the rest after Zalasiewicz *et al.* 2009). The Silurian graptolite biozonal scheme is that of Koren' *et al.* (1996) completed by Melchin *et al.* (1998), the Silurian time scale is that of Melchin *et al.* (2004) and the eustatic sea level curves are those of Loydell (1998) and Johnson (2006). Abbreviations: L– lower, U– upper, *N. – Normalograptus, Parak.– Parakidograptus, Cyst.– Cystograptus, Dem.– Demirastrites, L.– Lituigraptus, M.– Monograptus, St.– Stimulograptus, Sp.– Spirograptus, Str.– Streptograptus, Monocl.– Monoclimacis, O.– Oktavites, Cyrt.– Cyrtograptus, Pr.– Pristiograptus, G.– Gothograptus, Col.– Colonograptus, Neodiv.– Neodiversograptus, Lob.– Lobograptus, S.– Saetograptus, B.– Bohemograptus, Neocuc.– Neocucullograptus, Neocol.– Neocolonograptus, Istr – Istrograptus.*

a 6-m-thick interval devoid of graptolites follows. It is overlain by a 6-m-thick interval (between levels G03-7 to G-146) rich in graptolites. In the uppermost 6 m of the section, in Package 3, only fragments occur, mostly from representatives of the genera *Bohemograptus, Saetograptus and Pristiograptus.*

Level G03-7 yielded *Lob. progenitor* (Pl. II, c), *Col. colonus* (Plate I, c) and *B. bohemicus* (Plate I, e and g), the latter occurring up to the top of the section. The Wenlock-Ludlow boundary is traced here at the first occurrence of these three species. This boundary is probably at somewhat lower level, as *Lob. progenitor* is characteristic for the upper *Neodiv. nilssoni* graptolite Biozone. The specimens from level G03-8 show lateral spines only on the first few 3–5 proximal thecae (Plate I, b, h; Plate II, h, i).

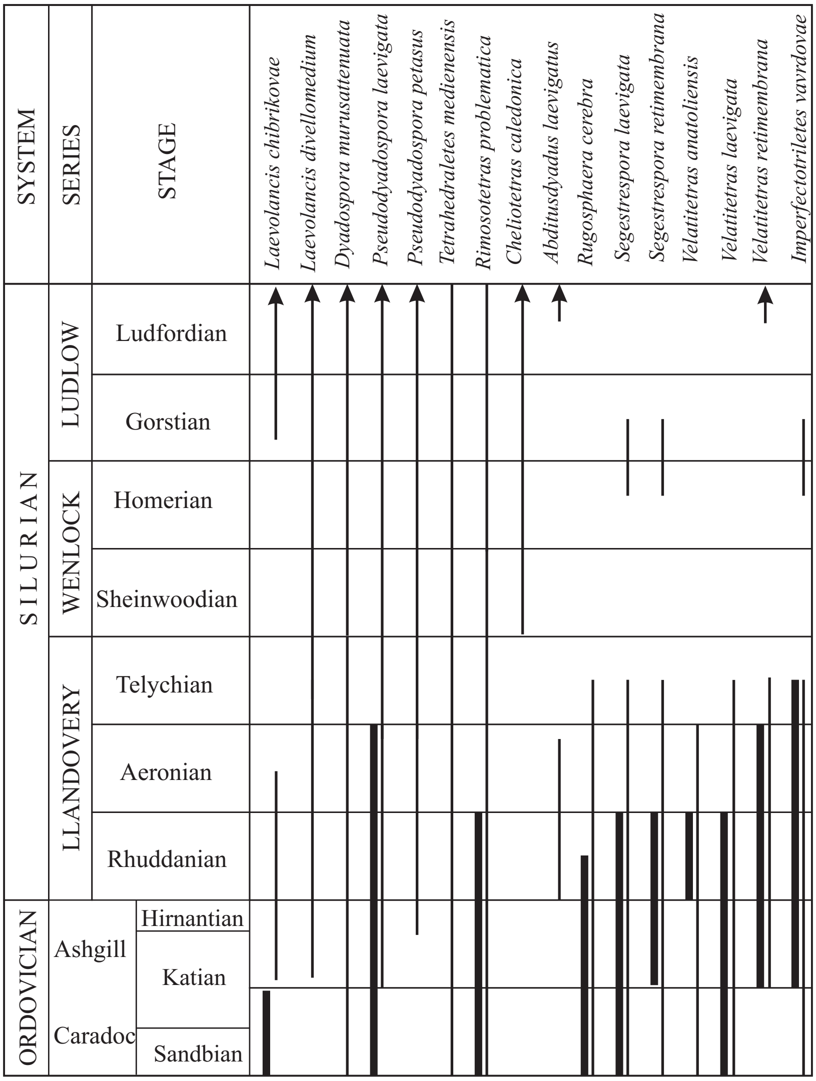

Figure 4. Stratigraphic ranges of cryptospores from the Gülüç section as known in the Upper Ordovician, Llandovery and Wenlock; type areas in UK (thick lines) and worldwide (thin lines).

The proximal lappets are longer and more spine-like, like those on *Saetograptus* (Urbanek 1958). The dorsoventral width is relatively great (2.3–2.5 mm). The specimens are identified as *Saetograptus chimaera semispinosus* (Elles & Wood) and not as *Col. colonus*. They are similar to *Monograptus chimaera* var. *semispinosus* figured by Elles & Wood (1911, plate 39, figure 4a – refigured by Zalasiewicz *et al.* 2009, figure 18, image 397) and to *Saetograptus semispinosus* figured by Koren' & Suyarkova (2007, text-figure 3, image 16, plate 1, figure d). At the same level occurs one fragment of *Lob. scanicus*. This species is also common in two overlying graptolite-bearing levels (Plate II, b, g). The lower boundary of the *Lob. scanicus* graptolite Biozone is traced at level G-145, where *S. chimaera chimaera* occurs, a species characteristic of this biozone. *S. chimaera chimaera* is represented by straight proximal fragments 5–6 mm long, containing 6–7 thecae widening rapidly from 0.8–0.9 mm to 1.5–1.6 mm, and slighty ventrally curved sicula with apertural width to 0.3 mm (Plate II, k). Some flattened distal fragments from level G-147,

Cryptospores	Laurentia			Baltica		Avalonia			N. Gondwana				Western Gondwana	China
	USA	Canada	Canada	Norway	Sweden	Wales & England	Scotland	Belgium	Czech Republic	Libya	Saudi Arabia	Turkey		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Laevolancis divellomedium - plicata		×			×		×			×	×	×	×	×
Laevolancis chibrikovae		×				×					×		×	×
Dyadospora murusattenuata-murusdensa	×	×			×		×	×	×	×	×	×	×	×
Pseudodyadospora laevigata	×				×	×		×	×	×	×	×	×	×
Pseudodyadospora petasus					×		×			×	×	×	×	
Tetrahedraletes medinensis	×	×	×	×	×	×		×		×	×	×	×	
Rimosotetras problematica	×			×		×	×			×	×	×	×	
Cheliotetras caledonica		×			×		×							
Abditusdyadus laevigatus							×				×		×	
Rugosphaera cerebra	×					×		×	×	×		×	×	
Segestrespora laevigata	×					×					×	×	×	
Segestrespora retimembrana	×					×		×	×	×	×	×	×	
Velatitetras anatoliensis						×		×		×	×	×	×	
Velatitetras laevigata	×					×		×		×	×	×	×	×
Velatitetras retimembrana	×		×			×	×	×	×	×	×	×	×	
Imperfectotriletes vavrdovae	×					×		×		×	×	×	×	

Figure 5. Palaeogeographic distribution of the cryptospores from the Gülüç section on the Ordovician and Silurian palaeocontinents. Sources: Laurentia: 1– Llandovery, USA (Johnson 1985; Strother & Traverse 1979; Miller & Eames 1982); 2– Silurian, Nova Scotia, Canada (Beck & Strother 2001); 3– Llandovery, Quebec, Canada (Duffield 1985); Baltica: 4– Llandovery and Wenlock, Norway (Smelror 1987); 5– Wenlock and Ludlow, Gotland, Sweden (Hagström 1997); Avalonia: 6– Upper Ordovician, Llandovery and Wenlock, England and Wales, UK (Burgess 1991; Burgess & Richardson 1991; Wellman 1996); 7– Wenlock in Scotland (Wellman 1993a, b; Wellman & Richardson 1996; Richardson 1996); 8– Upper Ordovician, Belgium (Steemans 2001); North Gondwana: 9– Middle and Upper Ordovician in the Czech Republic (Vavrdová 1984, 1988, 1989, 1990); 10– Upper Ordovician–Pridoli, Libya (Gray *et al.* 1982; Richardson 1988; Rubinstein & Steemans 2002); 11– Katian (Steemans *et al.* 2009), Llandovery (Rhuddanian) (Steemans *et al.* 2000) and Homerian–Gorstian (Wellman *et al.* 2000) in Saudi Arabia; 12– Upper Ordovician (Hirnantian) in SW Turkey (Steemans *et al.* 1996); West Gondwana: 13– Upper Ordovician, Llandovery in Paraguay, Brazil and Argentina (Gray *et al.* 1992; Le Hérissé *et al.* 2001; Steemans & Pereira 2002; Mizusaki *et al.* 2002; Rubinstein & Vaccari 2004); 14– uppermost Ordovician to Ludlow–Pridoli in China (Wang *et al.* 1997, 2005).

poorly preserved in dorso-lateral view, show at first glance (Plate II, j) thecal spines originating from the dorsal aperture margin. According to Elles & Wood (1911), this is characteristic of *S. leintwardinensis* (Hopkinson) but after re-investigation of the type marerial of *S. leintwardinensis* this statement was rejected and sicula morphology was emphasized as a diagnostic feature (Maletz 1997). All collected specimens are similar in their sicula morphology to *S. chimaera*, but not to the Ludfordian species of *Saetograptus* (Maletz 1996, 1997; Lenz 1988; Zhang & Lenz 1997; Lenz & Kozłowska-Dawidziuk 2004).

Přibyl (1948) regarded *Monograptus miloni* Philippot, 1944 as a synonym of *Saetograptus leintwardinensis primus* (Bouček 1936) and Jaeger (1959) considered the latter as a synonym of *Saetograptus fritschi linearis* (Bouček 1936). The specimen described by Egemen (1947) as '*Monograptus* cf. *miloni* Philippot' – a dorsally curved in proximal part streptograptid, is possibly *S. fritschi linearis*, a species characteristic of the *S. leintwardinensis* graptolite Biozone (lowermost Ludfordian). The position of this find in the Gülüç section is not known. The presence of post-Gorstian sediments is still doubtful.

Conodonts

Scarce conodont material from two samples has been extracted which is insufficient to determine conodont zonation in the Gülüç section. The conodont collection from sample 03-8 includes, for example, *Ozarkodina crassa* and *Oz. excavata excavata*. The latter is a well known and abundant Silurian taxon. In the studied section all elements of this subspecies range in the Ludlow come from one single sample and therefore are of no stratigraphical significance.

The indicative presence of *Oz. crassa* and *Oz. excavata excavata* (with Pa elements and M element) (Plate III) in one sample should be explained with the concurrent ranges of these taxa in the lower part of the Ludlow in *Oz. crassa* conodont Biozone. Within this biozone, *Oz. crassa* makes its first occurrence but we have no data from samples below 03-8.

The conodont fauna in sample 03-4 differs from that in sample 03-8 in some respects, e.g., *Kockelella* sp has been found. The occurrence of *Kockelella* sp. in sample 03-4 may indicate Ludlow which corresponds to a stratigraphical interval in the lowermost *Neodiv. nilssoni* graptolite Biozone. The position of conodont sample 03-4 is within a graptolite-barren interval. No other graptolite and conodont coexistence has been recorded in the Gülüç section, except in an interval of 3 m between the samples 03-8 and 03-4. There are only a few conodont elements per kilogram in this interval.

The *Oz. crassa* Biozone is early Ludlow in age in the Cellon section, Austria (Walliser 1964). It is known also from Sardinia (Corradini & Serpagli 1999). The Wenlock-Ludlow boundary stratotype in the UK yielded graptolites (Aldridge & Schönlaub 1989), the first occurrence of the *Neodiversograptus nilssoni* defining the base of the Ludlow. This graptolite zone corresponds partly to the *Ozarkodina bohemica* conodont biozone in the lower Gorstian, which is coeval with the *Oz. crassa* biozone.

Reconstruction of the Silurian Basin in the Ereğli Area

During the Silurian both the İstanbul and Zonguldak terranes have been assumed to be located at the northern margin of the Armorican/Avalonian terrane assemblage, facing the Rheic Ocean (Göncüoğlu 2001; Yanev *et al.* 2006). This setting was recently supported by the findings of Lakova & Göncüoğlu (2005) and Sachanski *et al.* (2010). Considering the overall depositional features of the Gülüç succession, the Ereğli area was, very probably, during the Silurian a shallow marginal basin at the southern Rheic Ocean margin.

In this basin, the lowest fossilferous Silurian succession is represented by Package 1 of the Gülüç section, and has been assigned to the Rhuddanian, Aeronian and/or lower Telychian. The upper Telychian and Sheinwoodian are missing. The overlying Package 2 and Package 3 correspond to the Homerian and Gorstian.

The Gülüç section is condensed in its Homerian and Gorstian part, as about 4.9 Ma are represented by a sedimentary rock thickness of 21 m, indicative of a low sedimentation rate of c. 4 mm/10^3 years. The uniform greenish-grey siltstones of Llandovery age are replaced by black graptolitic shales with limestone beds in the Homerian and Gorstian. No graptolites have been found between the lower Homerian *lundgreni* and lower Gorstian *Neodiv. nilssoni* biozones.

The characteristic features of the Gülüç section could be interpreted in the light of a global model of

Silurian sea-level changes and T–R cycles proposed by Loydell (1998) and Johnson (2006) (Figure 3). The Llandovery (Rhuddanian, Aeronian, early Telychian) greenish grey limy siltstones with land plant microfossils were deposited in a near-shore marine environment. The absence of the upper Telychian and the Sheinwoodian could be explained by the effect of transgressive-regressive cycles and mainly by local tectonic extension which elevated parts of the basin. During the Homerian and Gorstian, the sedimentation of black shales and limestones was governed by the mid-Wenlock *Cyrt. lundgreni* Zone transgressive event. The absence of graptolites between the *Cyrt. lundgreni* and *Neodiv. nilssoni* biozones could be related to a basinward migration of the graptolite habitat due to the late Homerian regression or simply reflects that graptolites were destroyed by taphonomic processes. The deposition of the *Neodiv. nilssoni* and *Lob. scanicus* Biozone interval, which has yielded diverse graptolites, corresponds to the early Gorstian transgressive event. Loydell (1998) showed a rise in sea-level within the *Cyrt. lundgreni* Zone which is more consistent with the Turkish data. There is general agreement that the late Homerian was a time of lower sea-levels than normal ones and that the early Ludlow represents a time of very high sea-level within the Silurian. The Turkish data is certainly consistent with this. The regressive phase between the early Gorstian and Ludfordian transgressive events resulted in the deposition of coarser siliciclastics.

Correlation of the Silurian Formations in the Zonguldak and İstanbul Terranes

The studied section of the Fındıklı Formation in Gülüç Creek differs significantly from the Silurian successions in the Zonguldak Terrane to the east and to the west, as well as from those of the Çamdağ area and the İstanbul Terrane. The Gülüç section is characterized by a considerable pre-Homerian hiatus and the occurrence of graptolites and conodonts at isolated levels within the Homerian and Gorstian. The Llandovery is represented by uniform greenish-grey siltstones unknown elsewhere in the Zonguldak terrane. The Wenlock–Ludlow (Homerian–Gorstian) are represented by specific deposits: an irregular shale-limestone alternation dominated by black shales and a regressive facies (siltstones, calcareous sandstones and limestones) in the uppermost Gorstian.

To the east in the Zonguldak Terrane, in the Safranbolu area, the best studied Silurian section is in Karadere (Dean *et al.* 2000). The Fındıklı Formation is represented by its 'Lower member' and 'Upper member'. The Lower member, of Llandovery age, is 135 m thick and consists of lydites and black argillites rich in graptolites. The Upper member, of Wenlock age, consists of 90-m-of thick grey mudstones. Between these two members, there is an unexposed interval of about 80 m. Thus, the total thickness of the lower Silurian is not less than 300 m.

To the west, in the Çamdağ area, in a complex zone with İstanbul and Zonguldak-type successions in juxtaposed tectonic slices (Göncüoğlu *et al.* 2006), a composite section of the Fındıklı Formation was described by Göncüoğlu *et al.* (2003). The formation is informally divided into: black shale member – black graptolitic shales, Llandovery; shale-siltstone member – black shales and light grey siltstones, Wenlock and Ludlow; and shale-limestone member – black shales and limestones with *Orthoceras*, Pridoli. The age of these members is based on graptolites, acritarchs and conodonts. Due to numerous thrust sheets within the Fındıklı Formation its exact thickness could not be calculated. Recently, combined conodont and acritarch biostratigraphy of the Kabalakdere section showed an almost complete Silurian succession of the Fındıklı Formation (Boncheva *et al.* 2009).

In the İstanbul Terrane, within different sections studied by the present authors the oldest dated Silurian rocks (Aeronian–Telychian) were found within shales with iron ooids and chamositic shales overlying a quartzite interval. They are comformably overlain by shallow-marine carbonates with late Telychian (Llandovery) to early Ludlow fossils (Haas 1968). The chamositic/iron-oolitic part is correlated with the highstand at the end of Llandovery (Göncüoğlu *et al.* 2006; Sachanski *et al.* 2010). Around İzmit, a series of alternating dark limestones and yellowish calcareous shales yielded graptolites of the *Cyrt. lundgreni* Biozone of the lower Homerian, Wenlock (Sachanski *et al.* 2008).

Conclusions

The combined biostratigraphic data comprising graptolite and cryptospore fossil records in Gülüç Creek indicate that the green-grey siltstones of Package 1 are of Llandovery (Rhuddanian–early Telychian) age, the shale-limestone alternation of Package 2 and Package 3 of siltstones, limestones and sandstones are of late Wenlock–early Ludlow age (Homerian and Gorstian). In Package 1, the coexistence of enveloped cryptospores and *Laevolancis divellomedium* (Figure 2) suggests a Rhuddanian–early Telychian age. Graptolites in packages 2 and 3 indicate the *Cyrt. lundgreni, Neodiv. nilssoni* and *Lob. scanicus* graptolite biozones.

The conodonts from Package 2 of the Gülüç section confirm a Gorstian (Ludlow) age. The coexistence of *Oz. crassa*, *Oz. excavata excavata* (with Pa elements and M element) corresponds to the lower part of the Ludlow (*Oz. crassa* conodont Biozone).

The described specific features at the Gülüç section (lithological changes, condensation, stratigraphic gap, change in the graptolite diversity) are related to the global model of Silurian T–R cycles suggested by Loydell (1998) and Johnson *et al.* (1998). In general, the Llandovery is characterized by a near-shore marine environment. As a result of the transgressive-regressive cycles and mainly by formation of local uplifts in the basin, the upper Telychian and the Sheinwoodian are not represented. During the Homerian and Gorstian, black shales and limestones were deposited during the mid-Wenlock *Cyrt. lundgreni* Zone transgressive event. The regressive phase between the early Gorstian and Ludfordian transgressive events corresponds to the deposition of sandstones in the upper package of the section.

The Silurian Fındıklı Formation at Gülüç section, about 20 m thick, represents a condensed lithological succession with a stratigraphic gap. These features differ significantly from the coeval thick and stratigraphically extensive black shales and siltstones of the same formation in the eastern part of the Zonguldak Terrane. This probably suggests a tectonically more active marginal position for the Ereğli area at the southern margin of the Rheic Ocean.

Systematic Palaeontology (Iskra Lakova)

Anteturma Cryptosporites (Richardson *et al.* 1984) Richardson 1988

Naked fused cryptospore tetrads

Genus *Cheliotetras* Wellman & Richardson 1993

Type. Cheliotetras caledonica Wellman & Richardson 1993.

Cheliotetras caledonica Wellman & Richardson 1993

Plate V (d, h, g)

1993 *Cheliotetras caledonica* gen. et sp. nov.; Wellman & Richardson, p. 162, plate 1, figures 1–7.

1993a *Cheliotetras caledonica* Wellman & Richardson; Wellman, p. 50, plate 3, figures 7–8.

1993b *Tetrahedraletes medinensis* (Strother & Traverse) Wellman & Richardson; Wellman, figure 9a.

1996 *Cheliotetras caledonica*; Richardson, plate 1, figure 3.

1996 *Cheliotetras caledonica* Wellman & Richardson; Wellman & Richardson, p. 64, plate 13, figure 1.

1997 *Cheliotetras caledonica* Wellman & Richardson; Hagström, p. 305, figure 6A.

2001 *Cheliotetras caledonica* Wellman & Richardson; Beck & Strother, plate 11, figure 3.

Material. 8 specimens.

Description. Laevigate permanent fused tetrads with flang-like extension of each spore beyond the junction.

Diameter. 30–32 mm.

Occurrence. Sheinwoodian, Homerian and Lochkovian in Scotland (Wellman 1993a, b; Richardson 1996; Wellman & Richardson 1993, 1996); Gorstian–Ludfordian in Canada (Beck & Strother 2001), Ludfordian in Gotland, Sweden (Hagström 1997).

Naked unfused cryptospore tetrads

Genus *Rimosotetras* Burgess 1991

Type. *Rimosotetras problematica* Burgess 1991.

Rimosotetras problematica Burgess 1991

Plate V (e, f)

(see the list of earlier synonyms in Wellman & Richardson 1993 and Steemans *et al.* 1996)

1988 *Nodospora burnhamensis* 'loose tetrad'; Richardson, plate 19, figures 11, 12.

1988 'Loose tetrad', spore crassitate thin-walled variety; Richardson, plate 19, figures 7, 8.

1991 *Rimosotetras problematica* sp. nov.; Burgess, p. 586, plate 1, figures 12, 14–15.

1993 *Rimosotetras problematica* Burgess; Wellman & Richardson, p. 163, plate 1, figures 8–10.

1993a *Rimosotetras problematica* Burgess; Wellman, p. 115, plate 1, figures 4, 5.

1996 *Rimosotetras problematica* Burgess; Richardson, plate 1, figure 1

1996 *Rimosotetras problematica* Burgess; Steemans *et al.*, p. 55, plate 4, figures 5, 6.

2000 *Rimosotetras problematica* Burgess; Steemans *et al.*, p. 100, plate 3, figures j, k.

2000 *Rimosotetras problematica* Burgess; Wellman *et al.*, p. 117, plate 1, figure d.

2001 *Rimosotetras problematica* Burgess; Le Hérissé *et al.*, plate 4, figure 7; non plate 4, figure 8.

2002 *Rimosotetras problematica*; Mizusaki *et al.*, figure 3k.

2004 *Rimosotetras problematica* Burgess; Rubinstein & Vaccari, p. 1045, plate 1, figure 8.

Material. 6 specimens.

Description. Partially separating tetrahedral tetrads of subtriangular spore-like units.

Diameter. 28–32 mm.

Occurrence. Caradoc–upper Silurian in Laurentia, Baltica, Avalonia, N and W Gondwana. Lower Silurian in New York State, USA (Gray & Boucot 1971); Wenlock in Norway (Smelror 1987); Caradoc in the Caradoc type area in Wales, UK (Wellman 1996), uppermost Ordovician to upper Rhuddanian in the Llandovery type area, England, UK (Burgess 1991); Sheinwoodian in Scotland (Richardson 1996); upper Ashgill to Aeronian/Telychian in Libya (Richardson 1988); Upper Ordovician–upper Silurian in SE Turkey (Steemans *et al.* 1996); Rhuddanian to Homerian–?upper Gorstian in Saudi Arabia (Steemans *et al.* 2000; Wellman *et al.* 2000); Rhuddanian–Telychian in Paraguay (Steemans & Pereira 2002), Aeronian to lower Telychian in Brazil (Le Hérissé *et al.* 2001; Mizusaki *et al.* 2002); upper Hirnantian to lower Llandovery in Argentina (Rubinstein & Vaccari 2004).

Genus *Tetrahedraletes* (Strother & Traverse) Wellman & Richardson 1993

Type. Tetrahedraletes medinensis (Strother and Traverse) Wellman and Richardson 1993

Tetrahedraletes medinensis (Strother & Traverse) emend. Wellman & Richardson 1993

Plate IV (p, q, r, t); Plate IV (a, b, c)

(see the list of earlier synonyms in Wellman & Richardson 1993 and Steemans *et al.* 1996).

1987 *Tetrahedraletes medinensis* Strother & Traverse; Smelror, figure 4j.

1987 Tetrad type A; Smelror, figure 4h.

1993a *Tetrahedraletes medinensis* Strother & Traverse; Wellman, p. 52, plate 4, figures 1–3.

1993b *Tetrahedraletes medinensis* Strother and Traverse; Wellman, figure 9d, non figure 9a.

1996 *Tetrahedraletes medinensis*; Richardson, plate 1, figures 2, 7, 10.

1996 *Tetrahedraletes medinensis* Strother & Traverse; Wellman & Richardson, p. 64, plate 5, figures 3–4, 7.

1996 *Tetrahedraletes medinensis* Strother & Traverse; Steemans *et al.*, p. 57, plate 5, figures 1–2.

1997 *Tetrahedraletes medinensis* Strother & Traverse; Hagström, p. 305, figure 6B, C.

2000 *Tetrahedraletes medinensis* Strother & Traverse; Steemans *et al.,* p. 104, plate 4, figures c, d.

2000 *Tetrahedraletes medinensis* Strother & Traverse; Wellman *et al.,* p. 118, plate 1, figures a–c.

2001 *Tetrahedraletes medinensis* Strother & Traverse; Beck & Strother, plate 3, figure 13; plate 11, figures 4, 5.

2001 *Tetrahedraletes medinensis* Strother & Traverse; Steemans, p. 9, figures 6.3–5.

2001 *Tetrahedraletes medinensis* Strother & Traverse emend; Le Hérissé *et al.,* plate 5, figure 15.

2002 *Tetrahedraletes medinensis* Strother & Traverse emend; Lavender & Wellman; plate 2, figure 4.

2002 *Tetrahedraletes medinensis*; Mizusaki *et al.,* figure 4b.

2004 *Tetrahedraletes medinensis* Strother & Traverse; Rubinstein & Vaccari, p. 1045, text-figure 4b.

Material. 35 specimens.

Description. Levigate tetrahedral tetrads of subcircular to circular shape.

Diameter. 29–36 mm.

Occurrence. Upper Caradoc to Lower Devonian in Laurentia, Baltica, Avalonia, N and W Gondwana. Upper Llandovery in Quebec, Canada (Duffield 1985); Silurian in Nova Scotia, Canada (Beck & Strother 2001); Llandovery, Pennsylvania and New York, USA (Strother & Traverse 1979; Miller & Eames 1982); Telychian and Sheinwoodian in Norway (Smelror 1987); Ludlow in Gotland, Sweden (Hagström 1997); Homerian and Sheinwoodian in Scotland; lower Lochkovian in England, UK (Wellman 1993a; Richardson 1996; Wellman & Richardson 1993, 1996); Hirnantian in Belgium (Steemans 2001); upper Caradoc to upper Aeronian in Libya (Richardson 1988); Upper Ordovician and upper Silurian in SE Turkey (Steemans *et al.* 1996); Rhuddanian to Homerian–?lower Gorstian in Saudi Arabia (Steemans *et al.* 2000); Rhuddanian–Telychian in Paraguay (Steemans & Pereira 2002); Aeronian to lower Telychian in Brazil (Le Hérissé *et al.* 2001; Mizusaki *et al.* 2002); upper Ashgill to lower Llandovery in Argentina (Rubinstein & Vaccari 2004).

Naked fused cryptospore dyads

Genus *Pseudodyadospora* Johnson 1985

Type. Pseudodyadospora laevigata Johnson 1985

Pseudodyadospora laevigata Johnson 1985

Plate IV (g–k)

(see the list of synonyms in Steemans *et al.* 1996).

1985 *Pseudodyadospora laevigata* Johnson; Johnson, p. 33, plate 7, figure 11.

1988 *Pseudodyadospora* cf. *laevigata* Johnson; Richardson, p. 95.

1989 *Pseudodyadospora laevigata* Johnson; Vavrdová, figure 2.11.

1991 *Pseudodyadospora laevigata* Johnson; Burgess, p. 587, plate 1, figures 13, 16–17.

1996 *Pseudodyadospora laevigata* Johnson; Wellman, p. 115, plate 1, figures 11–15; plate 2, figures 1–10.

1996 *Pseudodyadospora laevigata* Johnson; Steemans *et al.,* p. 51, plate 3, figures 11, 12.

1997 *Pseudodyadospora laevigata* Johnson; Hagstrom, p. 307, figure 7H.

2000 *Pseudodyadospora laevigata* Johnson; Steemans *et al.,* p. 100, plate 3g.

2000 *Pseudodyadospora laevigata* Johnson; Wellman *et al.,* p. 118, plate 1, figure l.

2001 *Pseudodyadospora laevigata* Johnson; Steemans, p. 7, figure 4.14.

2002 *Pseudodyadospora laevigata*; Mizusaki *et al.,* figure 3i.

2005 *Pseudodyadospora laevigata* Johnson; Wang *et al.,* p. 156, plate 1, figure 13.

Material. 12 specimens.

Description. Pseudodyads of elliptical to subcircular outline without separation between the spore-like units.

Diameter. 32–34 mm.

Occurrence. Caradoc to upper Silurian in Laurentia, Baltica, Avalonia, N Gondwana and China. Llandovery (Rhuddanian) in Pennsylvania, USA (Strother & Traverse 1979; Johnson 1985); Ludfordian in Gotland, Sweden (Hagström 1997); Caradoc type area in England (Wellman 1996); Hirnantian in Belgium (Steemans 2001), Hirnantian to upper Aeronian in the Llandovery type area, Wales, UK (Burgess 1991); Ashgill in the Czech Republic (Vavrdová 1988, 1989); Caradoc in Libya (Richardson 1988); Upper Ordovician to upper Silurian in SE Turkey (Steemans *et al.* 1996); Rhuddanian and Aeronian in Saudi Arabia (Steemans *et al.* 2000; Wellman *et al.* 2000); Rhuddanian–lower Aeronian in Brazil (Mizusaki *et al.* 2002); Ludlow–Pridoli in China (Wang *et al.* 2005).

Pseudodyadospora petasus Wellman & Richardson 1993

Plate IV (l, o)

1993 *Pseudodyadospora petasus* sp. nov.; Wellman & Richardson, p. 168, plate 2, figures 1–7.

1993a *Pseudodyadospora petasus* Wellman & Richardson; Wellman, p. 56, plate 2, figures 11–13.

1996 *Pseudodyadospora petasa*; Richardson, plate 1, figure 4.

1996 *Pseudodyadospora petasus* Wellman & Richardson; Wellman & Richardson, p. 64, plate 5, figure 9; plate 13, figure 2.

1996 *Pseudodyadospora petasus* Wellman & Richardson; Steemans *et al.*, p. 53, plate 3, figures 13, 14; plate 4, figure 1.

1997 *Pseudodyadospora petasus* Wellman & Richardson; Hagström, p. 307, figure 7I.

2000 *Pseudodyadospora petasus* Wellman & Richardson; Steemans *et al.*, p. 100, plate 3, figures h, i.

2000 *Pseudodyadospora petasus* Wellman & Richardson; Wellman *et al.*, p. 120, plate 2, figures a–c.

2002 *Pseudodyadospora petasus* Wellman & Richardson; Rubinstein & Steemans, plate 4, figure 20.

2002 *Pseudodyadospora petasus* Wellman & Richardson; Lavender & Wellman, plate 2, figure 3.

2002 *Pseudodyadospora petasus*; Mizusaki *et al.*, figure 3j.

2004 *Pseudodyadospora petasus* Wellman & Richardson; Rubinstein & Vaccari, p. 1045, plate 1, figure 7.

Material. 4 specimens.

Description. Pseudodyads of ellipsoidal outline of two entirely fused spore-like units.

Diameter. 30–32 mm.

Occurrence. Upper Hirnantian to lower Lochkovian in Avalonia, Baltica, N and W Gondwana. Sheinwoodian, Homerian and Gorstian in Scotland (Wellman 1993a; Wellman & Richardson 1993; Richardson 1996); mid-Lochkovian in Scotland (Wellman & Richardson 1996); Ludfordian in Gotland, Sweden (Hagström 1997); Ludlow and Lochkovian in Libya (Rubinstein & Steemans 2002); Ludlow and Pridoli in SE Turkey (Steemans *et al.* 1996); Rhuddanian to Homerian–?lower Gorstian in Saudi Arabia (Steemans *et al.* 2000; Wellman *et al.* 2000); upper Aeronian in Paraguay (Steemans & Pereira 2002); Rhuddanian–lower Aeronian in Brazil (Mizusaki *et al.* 2002); upper Hirnantian–lower Llandovery in Argentina (Rubinstein & Vaccari 2004).

Naked unfused cryptospore dyads

Genus *Dyadospora* Strother & Traverse 1979

Type. *Dyadospora murusattenuata* Strother & Traverse 1979.

Morphon *Dyadospora murusattenuata* Strother & Traverse sensu Steemans, Le Hérissè & Bozdoğan 1996

Plate IV (e, f)

(see the list of synonyms of *D. murusdensa* and *D. murusattenuata* in Wellman & Richardson 1993; Steemans *et al.* 1996).

1993 *Dyadospora murusattenuata* Strother & Traverse; Wellman & Richardson, p. 169, plate 3, figures 9, 12.

1993 *Dyadospora murusdensa* (Strother & Traverse) Burgess & Richardson; Wellman & Richardson, p. 170, plate 3, figures 10, 13.

1996 *Dyadospora murusdensa*; Richardson, plate 1, figure 5.

1996 Morphon *Dyadospora murusattenuata* Strother & Traverse; Steemans *et al.,* p. 63, plate 6, figures 1–2.

1997 *Dyadospora murusattenuata* (Strother & Traverse) Burgess & Richardson; Hagström, p. 307, figure 6H–I.

1997 *Dyadospora murusdensa* (Strother & Traverse) Burgess & Richardson; Hagström, p. 307, figure 7A, B.

2000 Morphon *Dyadospora murusattenuata* Strother & Traverse; Steemans *et al.,* p. 98, plate 1, figure l; plate 2, figures a, b.

2000 Morphon *Dyadospora murusattenuata* Strother & Traverse sensu Steemans *et al.* 1996; Wellman *et al.,* p. 118, plate 1, figures h, i.

2001 *Dyadospora murusdensa* (Strother & Traverse) Burgess & Richardson; Beck & Strother, plate 4, figure 5.

2001 Morphon *Dyadospora murusattenuata* Strother & Traverse sensu Steemans *et al.* 1996; Steemans, p. 7, figure 4.1.

2002 *Dyadospora murusattenuata* Strother & Traverse; Lavender & Wellman, plate 2, figure 1.

2002 *Dyadospora murusdensa* Strother & Traverse; Lavender & Wellman, plate 2, figure 2.

2002 *Dyadospora murusattenuata*; Mizusaki *et al.,* figure 3b.

2002 *Dyadospora murusdensa*; Mizusaki *et al.,* figure 3c.

2004 Morphon *Dyadospora murusattenuata* Strother & Traverse sensu Steemans *et al.* 1996; Rubinstein & Vaccari, p. 1042, plate 1, figure 10.

2005 *Dyadospora murusattenuata* Strother & Traverse; Wang *et al.,* p. 156, plate 1, figures 4–6.

2005 *Dyadospora murusdensa* Strother & Traverse; Wang *et al.,* p. 156, plate 1, figure 12.

Material. 27 specimens.

Description. Naked laevigate unfused dyads with clear line of junction.

Diameter. 29–32 mm.

Occurrence. Hirnantian to Lochkovian in Laurentia, Baltica, Avalonia, N and W Gondwana and China. Rhuddanian to Aeronian in New York State and Pennsylvania, USA (Miller & Eames 1982; Strother & Traverse 1979; Johnson 1985); Silurian in Nova Scotia, Canada (Beck & Strother 2001); Ludfordian in Gotland, Sweden (Hagström 1997); Sheinwoodian, Homerian and Lochkovian in Scotland (Burgess & Richardson 1991; Wellman 1993a, b; Wellman & Richardson 1993; Richardson 1996); Hirnantian in Belgium (Steemans 2001); Upper Ordovician in the Czech Republic (Vavrdová 1989); Rhuddanian and Aeronian in Libya (Richardson 1988); Upper Ordovician and upper Silurian in SE Turkey (Steemans *et al.* 1996); Rhuddanian to Aeronian–?lower Gorstian in Saudi Arabia (Steemans *et al.* 2000; Wellman *et al.* 2000); Rhuddanian–Telychian in Paraguay (Steemans & Pereira 2002); Aeronian to lower Telychian in Brazil (Le Hérissè *et al.* 2001; Mizusaki *et al.* 2002); upper Hirnantian to lower Llandovery in Argentina (Rubinstein & Vaccari 2004); uppermost Ordovician and Ludlow–Pridoli in China (Wang *et al.* 1997, 2005).

Dissociated true dyad (Hilate cryptospores)

Genus *Laevolancis* Burgess & Richardson 1991

Type. *Laevolancis divellomedium* (Chibrikova) Burgess & Richardson 1991.

Laevolancis chibrikovae Steemans, Higgs & Wellman 2000

Plate IV (b)

(see the list of synonyms in Steemans *et al.* 2000).

2000 *Laevolancis chibrikovae* sp. nov.; Steemans *et al.,* p. 99, plate 2, figures n, o; plate 3, figure a.

2001 *Laevolancis divellomedium* (Chibrikova) Burgess & Richardson; Beck & Strother, plate 4, figure 4.

2004 *Laevolancis chibikovae* Steemans *et al.;* Rubinstein & Vaccari, p. 1044, plate 1, figure 11.

Material. 2 specimens.

Description. Hilate cryptospores with hilum torn or missing, formed by a physical dissociation of permanent dyads.

Diameter. 30–32 mm.

Occurrence. Caradoc to Pridoli in Laurentia, Avalonia, N and W Gondwana and China. Caradoc in the type area in the UK (Wellman 1996); Silurian in Nova Scotia, Canada (Beck & Strother 2001); Rhuddanian in Saudi Arabia (Steemans *et al.* 2000); upper Hirnantian to lower Llandovery in Argentina (Rubinstein & Vaccari 2004); uppermost Ordovician in China (Wang *et al.* 1997).

Morphon *Laevolancis divellomedium* (Chibrikova) Burgess & Richardson 1991

Plate III (a)

(see the list of synonyms of *L. divellomedium* and L. *plicata* included in the morphon *L. divellimedium* in Wellman & Richardson 1993; Steemans *et al.* 1996).

1993 *Laevolancis divellomedium* (Chibrikova) Burgess & Richardson; Wellman & Richardson, p. 172, plate 3, figures 8, 11.

1993 *Laevolancis plicata* Burgess & Richardson; Wellman & Richardson, p. 173, plate 3, figure 7.

1996 *Laevolancis divellomedia*; Richardson, plate 1, figures 8, 9.

Non 1996 *Laevolancis divellomedia* (Chibrikova) Burgess & Richardson 1991; Wellman, p. 112, plate 1, figures 21–24; plate 2, figures 17–19.

1996 *Laevolancis divellomedium* (Chibrikova) Burgess & Richardson 1991; Steemans *et al.* plate 6, figures 3, 4.

1997 *Laevolancis divellomedia* (Chibrikova) Burgess & Richardson; Hagström, p. 307, figures 7S.

1997 *Laevolancis plicata* Burgess and Richardson; Hagström, p. 308, figure 7T.

2000 *Laevolancis divellomedium* (Chibrikova) Burgess & Richardson; Steemans *et al.,* p. 99, plate 3, figures b–e.

2000 Morphon *Laevolancis divellomedia-plicata* sensu Steemans *et al.* 1996; Wellman *et al.,* p. 122, plate 2, figures k, l.

2001 *?Laevolancis divellomedia* (Chibrikova) Burgess & Richardson; Beck & Strother, plate 4, figure 3, non figure 4.

2001 *Laevolancis divellomedia* (Chibrikova) Burgess & Richardson; Le Hérissé*et al.,* plate 4, figures 4, 5.

2002 *Laevolancis divellomedium* Burgess & Richardson; Rubinstein & Steemans, plate 4, figure 19.

2002 *Laevolancis divellomedia* (Chibrikova) Burgess & Richardson; Lavender & Wellman, plate 1, figure 1.

2002 *Laevolancis plicata* Burgess & Richardson; Lavender & Wellman, plate 1, figure 2.

2002 *Laevolancis divellomedium*; Mizusaki *et al.,* figure 3f, g.

2005 *Laevolancis plicata*; Turnau *et al.,* figure 3E.

2005 *Laevolancis divellomedia* (Chibrikova) Burgess and Richardson; Turnau *et al.,* figure 3F.

2005 *Laevolancis divellomedia* (Chibrikova) Burgess & Richardson; Wang *et al.,* p. 156, plate 1, figures 1, 7, 8; plate 2, figure 6.

Material. 5 specimens.

Description. Subcircular hilate cryptospores with flattened to concave hilum.

Diameter. 28–30 mm.

Occurrence. Llandovery–Frasnian in all palaeocontinents. Homerian to Ludfordian in Gotland, Sweden (Hagström 1997); Sheinwoodian, Homerian and Lochkovian in Scotland (Wellman 1993a, b; Wellman & Richardson 1993; Richardson 1996); upper Ludfordian in Libya (Richardson 1996); Ludlow and Pridoli in Libya (Rubinstein & Steemans 2002); upper Silurian in SE Turkey (Steemans *et al.* 1996); Rhuddanian to Homerian–?lower Gorstian in Saudi Arabia (Steemans *et al.* 2000); Rhuddanian–Telychian in Paraguay (Steemans & Pereira 2002); Aeronian to lower Telychian in Brazil (Le Hérissé *et al.* 2001), Ludlow–Pridoli in China (Wang *et al.* 2005). The morphon also occurs in Canada, USA, Belgium, Poland, Russia, Spain, Algeria, Bolivia and Australia (see Steemans *et al.* 1996). The only pre-Wenlockian record is from the Rhuddanian to the Telychian in Saudi Arabia, Brazil and Paraguay.

Envelope enclosed cryptospores

Genus *Abditusdyadus* Wellman & Richardson 1996

Type. Abditusdyadus histosus Wellman & Richardson 1996

Abditusdyadus laevigatus Wellman & Richardson 1996

Plate V (o, t)

1996 *Abditusdyadus laevigatus* gen. et sp. nov.; Wellman & Richardson, p. 68, plate 4, figures 7, 8.

2000 *Abditusdyadus laevigatus* Wellman & Richardson; Steemans *et al.,* p. 94, plate 1, figures a–d.

2002 *Abditusdyadus laevigatus* Wellman & Richardson; Lavender & Wellman, plate 2, figure 6.

2002 *Abditusdyadus laevigatus*; Mizusaki *et al.,* figure 3a.

Material. 6 specimens.

Description. Dyads of two lavigate hilate cryptospores enveloped with thick walls.

Diameter. 34–38 mm.

Occurrence. Lower Lochkovian in Scotland (Lavender & Wellman 2002; Wellman & Richardson 1996); Rhuddanian in Saudi Arabia (Steemans *et al.* 2000); Rhuddanian–lower Aeronian in Brazil (Mizusaki *et al.* 2002).

Genus *Rugosphaera* Strother & Traverse 1979

Type. Rugosphaera tuscarorensis Strother &Traverse 1979

Rugosphaera cerebra Miller & Eames 1982

Plate V (l)

1982 *Rugosphaera*? *cerebra* Miller & Eames; Miller & Eames, p. 249, plate 5, figure 4; plate 6, figures 10–12.

1988 *Rugosphaera*? *cerebra* Miller & Eames; Richardson, p. 95.

1989 *Rugosphaera cerebra* Miller & Eames; Vavrdová, figure 2.14.

1991 *Rugosphaera* cf. *R. cerebra* Miller & Eames; Burgess, p. 593, plate 2, figures 11, 12.

1996 *Rugosphaera cerebra* Miller & Eames; Wellman, p. 116, plate 4, figures 16–20; plate 5, figures 8, 9, 11, 12.

1996 *Rugosphaera cerebra* Miller & Eames; Steemans *et al.,* p. 55, plate 4, figures 7, 8.

2001 *Rugosphaera cerebra* Miller & Eames; Steemans, p. 9, figure 5.4–5.

2001 *Rugoshaera cerebra* Miller & Eames; Le Hérissé *et al.,* plate 4, figure 9; non plate 4, figure 6.

Material. 3 specimens.

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

Diameter. 33–36 mm.

Occurrence. Caradoc to lower Telychian in Laurentia, Avalonia, N and W Gondwana.

Rhuddanian to lower Aeronian in New York, USA (Miller & Eames 1982); Caradoc in the Caradoc type area in England (Wellman 1996); lower Rhuddanian in the Llandovery type area in Wales, UK (Burgess 1991); Hirnantian in Belgium (Steemans 2001); Upper Ordovician in the Czech Republic (Vavrdová 1989); Caradoc-Ashgill in Libya (Richardson 1988); Upper Ordovician in SE Turkey (Steemans *et al.* 1996); Aeronian to lower Telychian in Brazil (Le Hérissé *et al.* 2001).

Genus *Segestrespora* Burgess 1991 emend. Steemans *et al.* 1996

Type. Segestrespora membranifera (Johnson) Burgess 1991

Segestrespora laevigata Burgess 1991

Plate V (i)

(see the list of previous synonyms in Burgess 1991; Steemans *et al.* 1996.)

1991 *Segestrespora laevigata* sp. nov.; Burgess, p. 589, plate 2, figure 1.

1996 *Segestrespora laevigata* Burgess; Steemans *et al.*, p. 56, plate 4, figure 12.

1996 *Segestrespora laevigata* Burgess; Wellman, p. 120, plate 3, figures 10, 14–17.

2000 *Segestrespora laevigata* Burgess; Steemans *et al.*, p. 102, plate 3, figure n.

2000 *Segestrespora laevigata* Burgess; Wellman *et al.*, p. 120, plate 2, figure d.

2001 *Segestrespora laevigata* Burgess; Le Hérissé *et al.*, plate 4, figure 10.

2004 *Segestrespora laevigata* Burgess; Rubinstein & Vaccari, p. 1045, plate 1, figure 2.

Material. 4 specimens.

Description. Laevigate subcircular to oval dyads or pseudodyads enclosed in laevigate envelope.

Diameter. 28–35 mm.

Occurrence. Caradoc to Homerian–Gorstian in Laurentia, Avalonia, N and W Gondwana. Rhuddanian to Aeronian in New York State, USA (Miller & Eames 1982); Rhuddanian in Pennsylvania, USA (Johnson 1985); Caradoc in the Caradoc type area in UK (Wellman 1996); Ashgill to Rhuddanian in the Llandovery type area, UK (Burgess 1991); Upper Ordovician in SW Turkey (Steemans *et al.* 1996); Rhuddanian to ?Homerian–Gorstian in Saudi Arabia (Steemans *et al.* 2000; Wellman *et al.* 2000); Llandovery–Aeronian to lower Telychian in Brazil (Le Hérissé *et al.* 2001); upper Hirnantian to lower Llandovery in Argentina (Rubinstein & Vaccari 2004).

Segestrespora membranifera (Johnson) Burgess 1991

Plate V (p)

(see the list of previous synonyms in Burgess 1991; Steemans *et al.* 1996).

1991 *Segestrespora (Dyadospora) membranifera* (Johnson) comb. nov.; Burgess, p. 588, plate 2, figures 2–5.

1996 *Segestrespora membranifera* (Johnson) Burgess; Steemans *et al.*, p. 56, plate 4, figure 13.

2000 *Segestrespora membranifera* (Johnson) Burgess; Steemans *et al.*, p. 102, plate 3, figures o, p.

2000 *Segestrespora membranifera* (Johnson) Burgess; Wellman *et al.*, p. 120, plate 2, figures e, f.

2001 *Segestrespora (Dyadospora) membranifera* (Johnson) Burgess; Steemans, p. 9, plate 5, figure 7.

2002 *Segestrespora membranifera*; Mizusaki *et al.*, figure 3l.

2004 *Segestrespora membranifera* (Johnson) Burgess; Rubinstein & Vaccari, p. 1045, text-figure 4a.

Material. 3 specimens.

Description. Laevigate subcircular to elliptic dyads or pseudodyads enclosed in an envelope with reticulate sculpture.

Diameter. 30–31 mm.

Occurrence. Upper Ordovician to Homerian–Gorstian in Laurentia, Avalonia, N and W Gondwana. Rhuddanian in Pennsylvania, USA (Johnson 1985); Ashgill to Rhuddanian in the Llandovery type area, UK (Burgess 1991); Hirnantian in Belgium (Steemans 2001); Rhuddanian to lower Aeronian in Libya (Richardson 1988); Ashgill in the Czech Republic (Vavrdová 1989), Upper Ordovician in SW Turkey (Steemans *et al.* 1996); Rhuddanian to ?Homerian–Gorstian in Saudi Arabia (Steemans *et al.* 2000; Wellman *et al.* 2000); Rhuddanian–lower Aeronian in Paraguay (Steemans & Pereira 2002); Llandovery–Aeronian to lower Telychian in Brazil (Le Hérissè *et al.* 2001; Mizusaki *et al.* 2002); upper Hirnantian to lower Llandovery in Argentina (Rubinstein & Vaccari 2004).

Genus *Velatitetras* Burgess 1991

Type. Velatitetras laevigata Burgess 1991.

Velatitetras anatoliensis Steemans, Le Hérissè & Bozdoğan 1996

Plate V (m)

1988 *Nodospora* sp. E; Richardson, p. 94.

1991 *Velatitetras* sp. A; Burgess, p. 586, plate 1, figure 11.

1996 *Velatitetras anatoliensis* sp. nov.; Steemans *et al.;* p. 59, plate 5, figures 3, 4.

2000 *Velatitetras anatoliensis* Steemans *et al.;* Wellman *et al.*, p. 118, plate 1, figure k.

2001 *Velatitetras anatoliensis* Steemans *et al.;* Steemans, p. 9, figure 6.6–7.

2001 *Velatitetras anatoliensis* Steemans *et al.;* Le Hérissé *et al.*, plate 5, figure 22.

2002 *Velatiteras anatoliensis*; Mizusaki *et al.*, figure 4c.

Material. 2 specimens.

Description. Laevigate enveloped tetrads; the envelope sculptured with small grana.

Diameter. 30–32 mm.

Occurrence. Upper Ordovician to Aeronian–Telychian in Avalonia, N and W Gondwana. Rhuddanian in the Llandovery type area, Wales, UK (Burgess 1991); Ashgill to lower Aeronian in Libya (Richardson 1988); Upper Ordovician in SE Turkey (Steemans *et al.* 1996); Hirnantian in Belgium (Steemans 2001); Rhuddanian to Aeronian in Saudi Arabia (Steemans *et al.* 2000); Rhuddanian in Paraguay (Steemans & Pereira 2002); Rhuddanian to lower Telychian in Brazil (Le Hérissé *et al.* 2001; Mizusaki *et al.* 2002).

Velatitetras laevigata Burgess 1991

Plate V (j, k, n)

(see the list of synonyms in Steemans *et al.* 1996)

1991 *Velatitetras laevigata* sp. nov.; Burgess, p. 583, plate 1, figures 5, 6.

1996 *Velatitetras laevigata* Burgess; Wellman, p. 121, plate 3, figures 5–7.

1996 *Velatitetras laevigata* Burgess; Steemans *et al.*,; p. 60, plate 5, figures 5–7.

2000 *Velatitetras laevigata* Burgess; Steemans *et al.*, p. 104, plate 4, figure e, f.

2000 *Velatitetras laevigata* Burgess; Wellman *et al.*, p. 118, plate 1, figure j.

2001 *Velatitetras laevigata* Burgess; Steemans, p. 9, figure 6.8–9.

2001 *Velatitetras laevigata* Burgess; Le Hérissé *et al.*, plate 5, figures 15–18.

2002 *Velatitetras laevigata*; Mizusaki *et al.*, figure 4d, e.

2004 *Velatitetras laevigata* Burgess; Rubinstein & Vaccari, p. 1047, text-figure 4E.

Non 2005 *Velatitetras laevigata* Burgess; Wang *et al.*, p. 156, plate 1, figures 1–3.

Material. 19 specimens.

Description. Enveloped tetrads with laevigate, diaphanous folded envelope.

Diameter. 32–38 mm.

Occurrence. Caradoc to Aeronian in Laurentia, Avalonia, N and W Gondwana and China. Lower Ordovician to Llandovery in Kentucky and Ohio, USA (Gray 1985, 1988); Caradoc in the Caradoc type area in England, UK (Wellman 1996); Ashgill to Rhuddanian in the Llandovery type area in Wales, UK (Burgess 1991); Hirnantian in Belgium (Steemans 2001); Rhuddanian to lower Aeronian in Libya (Richardson 1988); Upper Ordovician in SE Turkey (Steemans *et al.* 1996); Rhuddanian to Aeronian in Saudi Arabia (Steemans *et al.* 2000); Rhuddanian–lower Aeronian in Paraguay (Steemans & Pereira 2002); Rhuddanian to lower Telychian in Brazil (Le Hérissé *et al.* 2001; Mizusaki *et al.* 2002); upper Hirnantian to lower Llandovery in Argentina (Rubinstein & Vaccari 2004); uppermost Ordovician in China (Wang *et al.* 1997).

Velatitetras retimembrana (Miller & Eames) Steemans, Le Hérissè & Bozdoğan 1996

(see the list of synonyms in Steemans *et al.* 1996)

1996 *Velatitetras (Nodospora) retimembrana* (Miller & Eames) ? comb. nov.; Wellman & Richardson, p. 70, plate 6, figures 1, 2.

1996 *Velatitetras retimembrana* (Miller & Eames) Steemans *et al.*, comb. nov., p. 60, plate 5, figures 8–10.

2000 *Velatitetras (Nodospora) retimembrana* (Miller & Eames) Steemans *et al.;* Steemans *et al.*, p. 104, plate 4, figures g–h.

2001 *Velatitetras retimembrana* (Miller & Eames) Wellman & Richardson; Steemans, p. 9, figure 6.10.

2001 *Velatitetras retimembrana* (Miller & Eames) Wellman & Richardson; Le Hérissé *et al.*, plate 5, figure 19.

2004 *Velatitetras retimembrana* (Miller & Eames) Wellman & Richardson; Rubinstein & Vaccari, p. 1047, text-figure 4D.

Material. 3 specimens.

Description. Enveloped laevigate tetrads; envelope ornamented with muri forming a reticulum.

Diameter. 28–30 mm.

Occurrence. Upper Ordovician to lower Lochkovian in Laurentia, Avalonia, N and W Gondwana. Upper Llandovery in Quebec, Canada (Duffield 1985); Rhuddanian to Aeronian in New York State, USA (Miller & Eames 1982); Rhuddanian in Pennsylvania, USA (Johnson 1985); Lower Ordovician to mid-upper Llandovery in Kentucky, USA (Gray 1985); Ashgill in Ohio, USA (Gray 1988); Ashgill to Aeronian in the Llandovery type area, Wales, UK (Burgess 1991); lower Lochkovian in Scotland (Wellman & Richardson 1996); Hirnantian in Belgium (Steemans 2001); Upper Ordovician in the Czech Republic (Vavrdová 1988, 1989); Rhuddanian to lower Aeronian in Libya (Richardson 1988); Upper Ordovician in SE Turkey (Steemans *et al.* 1996); Rhuddanian in Saudi Arabia (Steemans *et al.* 2000); Rhuddanian–lower Aeronian in Paraguay (Steemans & Pereira 2002); Rhuddanian to lower Telychian in Brazil (Le Hérissé *et al.* 2001; Mizusaki *et al.* 2002); upper Hirnantian to lower Llandovery in Argentina (Rubinstein & Vaccari 2004).

Incertae sedis

Genus *Imperfectotriletes* Steemans, Higgs & Wellman 2000

Type. *Imperfectotriletes (?Ambitisporites) patinatus* Steemans, Higgs & Wellman 2000.

Imperfectotriletes vavrdovae (Richardson) Steemans, Higgs & Wellman 2000

Plate V (q, r, s)

(see the list of synonyms in Steemans *et al.* 2000)

1988 *Ambitisporites? vavrdovii (=imperfectus*) sp. nov.; Richardson, p. 93,97, plate 20, figures 4–6, non figures 1–3.

1996 *Ambitisporites? vavrdovii* Richardson; Steemans *et al.*, p. 66, plate 6, figures 5, 6.

2000 *Imperfectotriletes vardovae* (Richardson) gen. and comb. nov.; Steemans *et al.*, p. 99, plate 2, figures i–m.

2001 *Ambitisorites avitus* Hoffmeister; Beck & Strother, plate 1, figures 5, 7, 14, 17–18.

2001 *Ambitisporites capitaneus* sp. nov.; Beck & Strother, plate 4, figures 12–14.

2001 *Imperfectotriletes (? Ambitisporites) vavrdovae* Steemans *et al.;* Steemans, p. 7, figure 4.6.

2001 *Imperfectotriletes vavrdovae* (Richardson) Steemans *et al.;* Le Hérissé *et al.*, plate 4, figure 2.

2002 *Imperfectotriletes vavrdovae*; Mizusaki *et al.*, figure 3e.

2004 *Imperfectotriletes vavrdovae* (Richardson) Steemans *et al.;* Rubinstein & Vaccari, plate 1, figures 1, 6.

Material. 14 specimens.

Description. Laevigate monads of subcircular to subtriangular outline derived from 'loose' tetrads.

Diameter. 28–38 mm.

Occurrence. Ashgill to Homerian–Gorstian in Laurentia, Avalonia, N and W Gondwana. Llandovery in Pennsylvania, USA (Johnson 1985); Silurian in Nova Scotia, Canada (Beck & Strother 2001); Ashgill to lower Telychian in UK (Burgess 1991); Hirnantian in Belgium (Steemans 2001); Caradoc to lower Telychian in Libya (Gray *et al.* 1982; Richardson 1988); Upper Ordovician in SE Turkey (Steemans *et al.* 1996); Rhuddanian to ?Homerian–Gorstian in Saudi Arabia (Steemans *et al.* 2000; Wellman *et al.* 2000); Rhuddanian–Aeronian in Paraguay (Steemans & Pereira 2002); Rhuddanian to lower Telychian in Brazil (Le Hérissé *et al.* 2001; Mizusaki *et al.* 2002); upper Hirnantian–lower Llandovery in the Czech Republic (Vavrdová 1988) and Argentina (Rubinstein & Vaccari 2004).

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Appendix – List of Identified Daxa

Graptolites (V. Sachanski)

Bohemograptus bohemicus (Barrande 1850)

Colonograptus colonus (Barrande 1850)

Eisenackograptus Kozłowska-Dawidziuk 1990

Eisenackograptus eisenacki (Obut & Sobolevskaya 1965)

Gothograptus Frech 1897

Lobograptus scanicus (Tullberg 1883)

Lobograptus progenitor Urbanek 1966

Monograptus flemingii (Salter 1852)

Pristiograptus dubius (Suess 1851)

Pristiograptus pseudodubius (Bouček 1932)

Saetograptus chimaera chimaera (Barrande 1850)

Saetograptus chimaera semispinosus (Elles & Wood 1911)

Testograptus testis (Barrande 1850)

Conodonts (I. Boncheva, G. Saydam)

Ozarkodina excavata excavata (Branson & Mehl 1933) – Pa elements and M elements

Ozarkodina crassa Walliser 1964

Kockelella sp.

Cryptospores (I. Lakova)

Cheliotetras caledonica Wellman & Richardson 1993

Rimosotetras problematica Burgess 1991

Tetrahedraletes medinensis Strother & Traverse 1979

Pseudodyadospora laevigata Johnson 1985

Pseudodyadospora petasus Wellman & Richardson 1993

Morphon *Dyadospora murusattenuata* sensu Steemans, Le Hèrissè & Bozdoğan 1996

Laevolancis chibrikovae Steemans, Higgs & Wellman 2000

Laevolancis divellomedium (Chibrikova 1959) Burgess & Richardson 1991

Laevolancis sp.

Abditusdyadus laevigatus Wellman & Richardson 1996

Rugosphaera cerebra Miller & Eames 1982

Segestrespora laevigata Burgess 1991

Segestrespora membranifera (Johnson) Burgess 1991

Velatitetras anatoliensis Steemans, Le Hèrissè & Bozdoğan 1996

Velatitetras laevigata Burgess 1991

Velatitetras retimembrana (Miller & Eames 1982) Wellman & Richardson 1996

Imperfectotriletes vavrdovae Steemans, Higgs & Wellman 2000

Plate 1

Graptolites from the Gülüç section, NW Anatolia. **(a)** *Cyrtograptus* sp.; samples G03-2; field number G03-2.1. **(b)** *Saetograptus chimaera semispinosus* (Elles & Wood, 1911); G03-8; G03-8.1. **(c)** *Colonograptus colonus* (Barrande, 1850); G03-7; G03-7.3. **(d, f)** *Testograptus testis* (Barrande, 1850); G03-1 ; G03-1.1. **(e)** *Bohemograptus bohemicus* (Barrande, 1850); G03-8; G03-8.2. **(g)** *Pristiograptus* ex. gr. *dubius* and *Bohemograptus bohemicus* (Barrande, 1850); G-145; G-145.4. **(h)** *Saetograptus chimaera semispinosus* (Elles & Wood, 1911); G03-8; G-143.1. (a, d, f) *lundgreni* Biozone; (b, c, e, h) upper *nilssoni* Biozone (*progenitor* Biozone); (g) *scanicus* Biozone. Scale bar equals 1 mm except for f (0.5 mm).

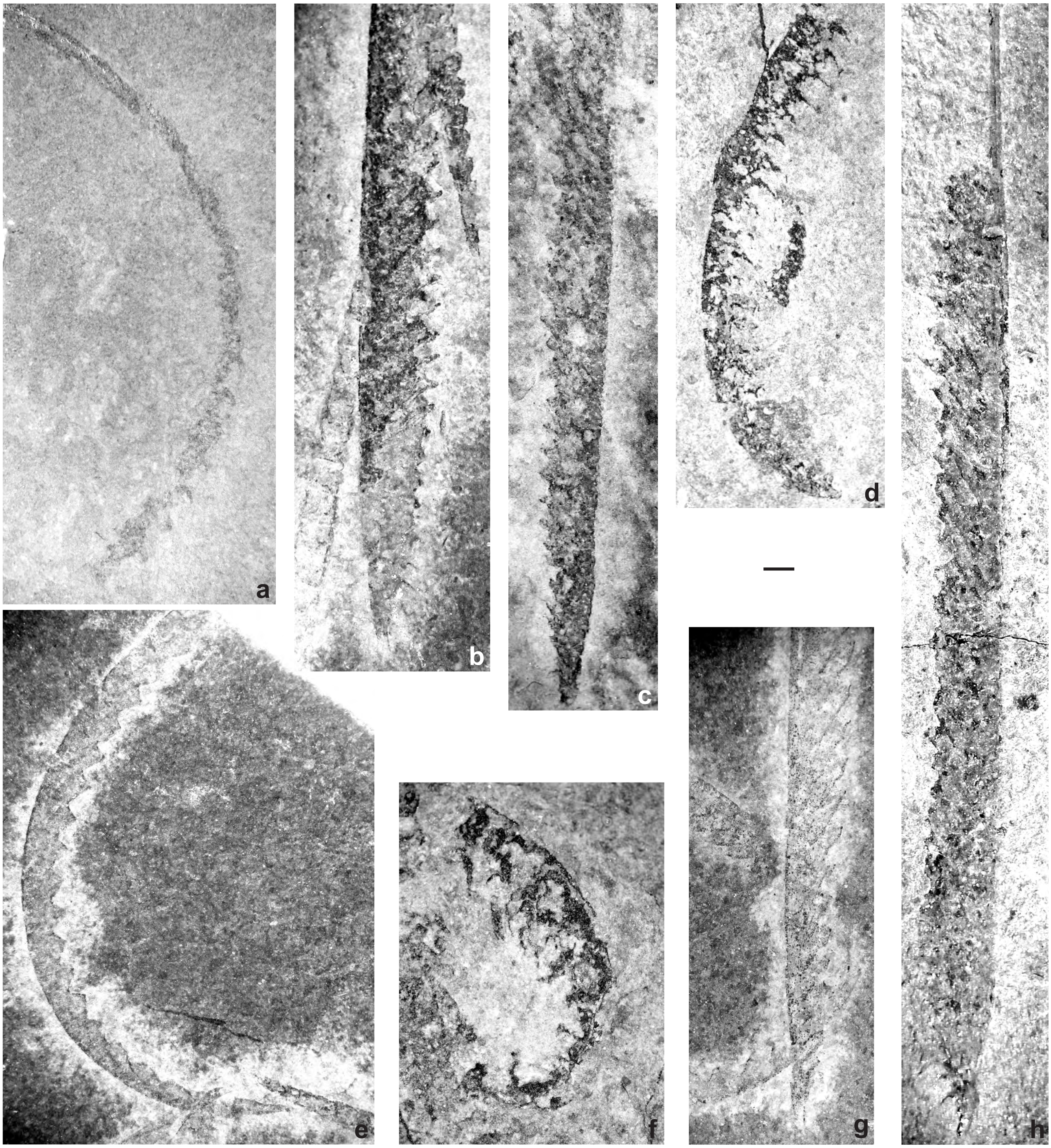
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Plate 2

Graptolites from the Gülüç section, NW Anatolia. **(a, d)** *Monograptus flemingii* (Salter, 1852); samples G03-2; field number G03-2.3. **(b)** *Lobograptus scanicus* (Tullberg, 1883); G-146; G-146.3. **(c)** *Lobograptus progenitor* Urbanek, 1966; G03-7; G03-7.6. **(e)** *Pristiograptus dubius pseudodubius* (Bouček, 1932); G03-1; G03-1.1. **(f)** *Eisenackograptus eisenacki* (Obut & Sobolevskaya, 1965); G03-1; G03-1.1. **(g)** *Lobograptus scanicus* (Tullberg, 1883); G-145; G-145.5. **(h, i)** *Saetograptus chimaera semispinosus* (Elles & Wood, 1911); G03-8; (h) G-143.2, G03-8.1. **(j, k)** *Saetograptus chimaera chimaera* (Barrande, 1850); G-147; (j) G-147.2, (k) G-147.3. **(l)** *Gothograptus*? sp.; G03-1; G03-1.2. (a, d, e, f, l) *lundgreni* Biozone; (c, h, i) upper *nilssoni* Biozone (*progenitor* Biozone); (b, g, j, k) *scanicus* Biozone. Scale bar equals 1 mm except for f (0,5 mm).


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Plate 3

Conodonts from the Gülüç section, NW Anatolia. All figures are from sample 04-143. **(a, c)** *Ozarkodina excavata excavata* (Branson & Mehl 1933), M elements. **(b, d, e, f, g)** *Ozarkodina excavata excavata* (Branson & Mehl 1933), Pa elements.

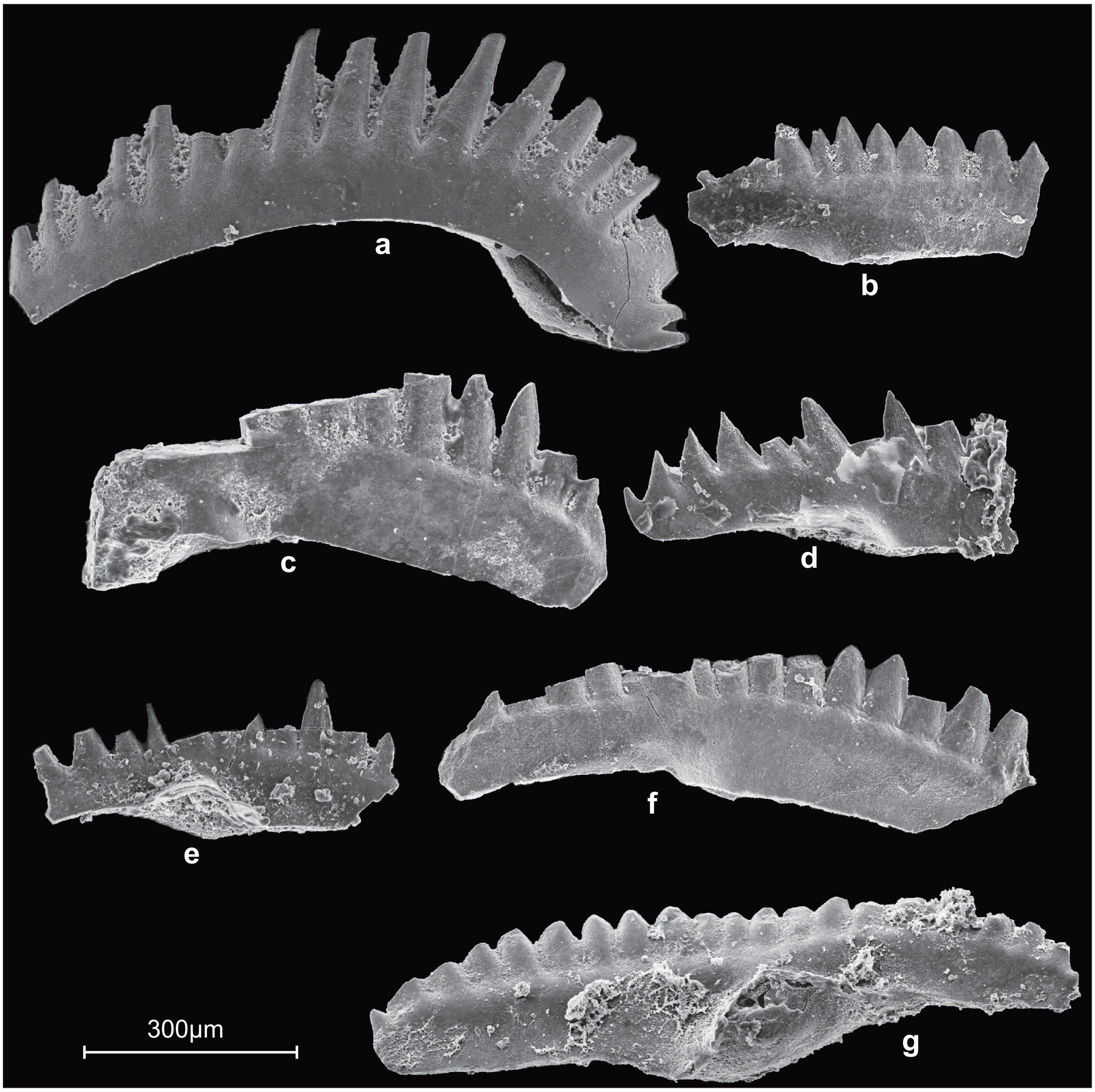
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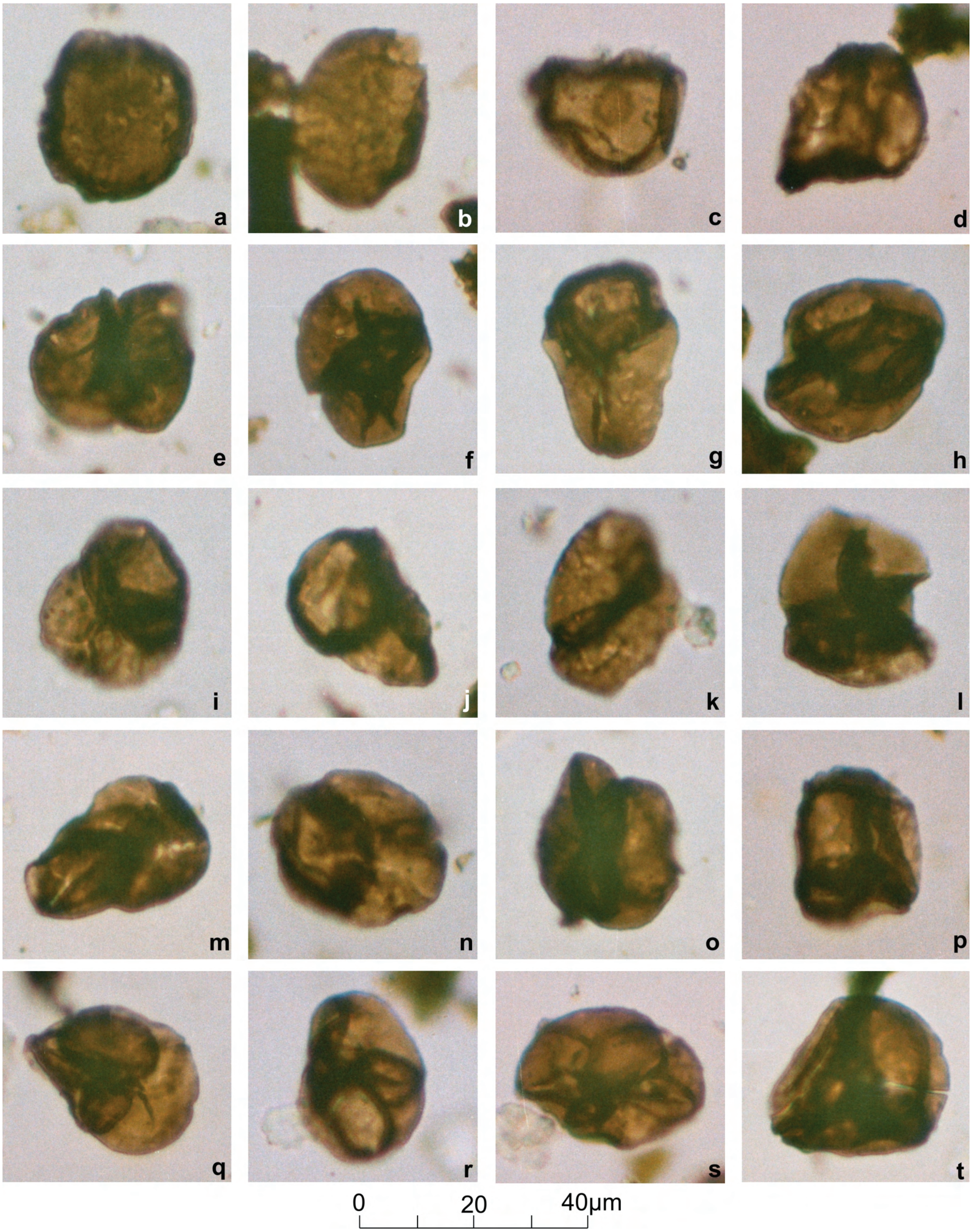
Plate 4

Cryptospores from the Gülüç Section, NW Anatolia, Turkey. All from sample Gul 1, Llandovery, magnification x1000. **(a)** *Laevolancis divellomedium* (Chibrikova) Burgess & Richardson, 1991. **(b)** *Laevolancis chibrikovae* Steemans *et al.* 2000. **(c)** *Laevolancis* sp. nov. **(d)** *Laevolancis* sp. 1. **(e, f)** Morphon *Dyadospora murusattenuata* sensu Steemans *et al.* 1996. **(g, h, i, j, k)** *Pseudodyadospora laevigata* Wellman & Richardson 1996. **(l, o)** *Pseudodyadospora petasus* Wellman & Richardson 1996. **(m)** Loosed dyad of cryptospores with imperfect trilete mark. **(n)** Laevigate fused tetrad. **(p, q, r, t)** *Tetrahedraletes medinensis* Strother & Traverse 1979 emend. Wellman & Richardson 1993. **(s)** ?Spore tetrad of unequal cryptospores.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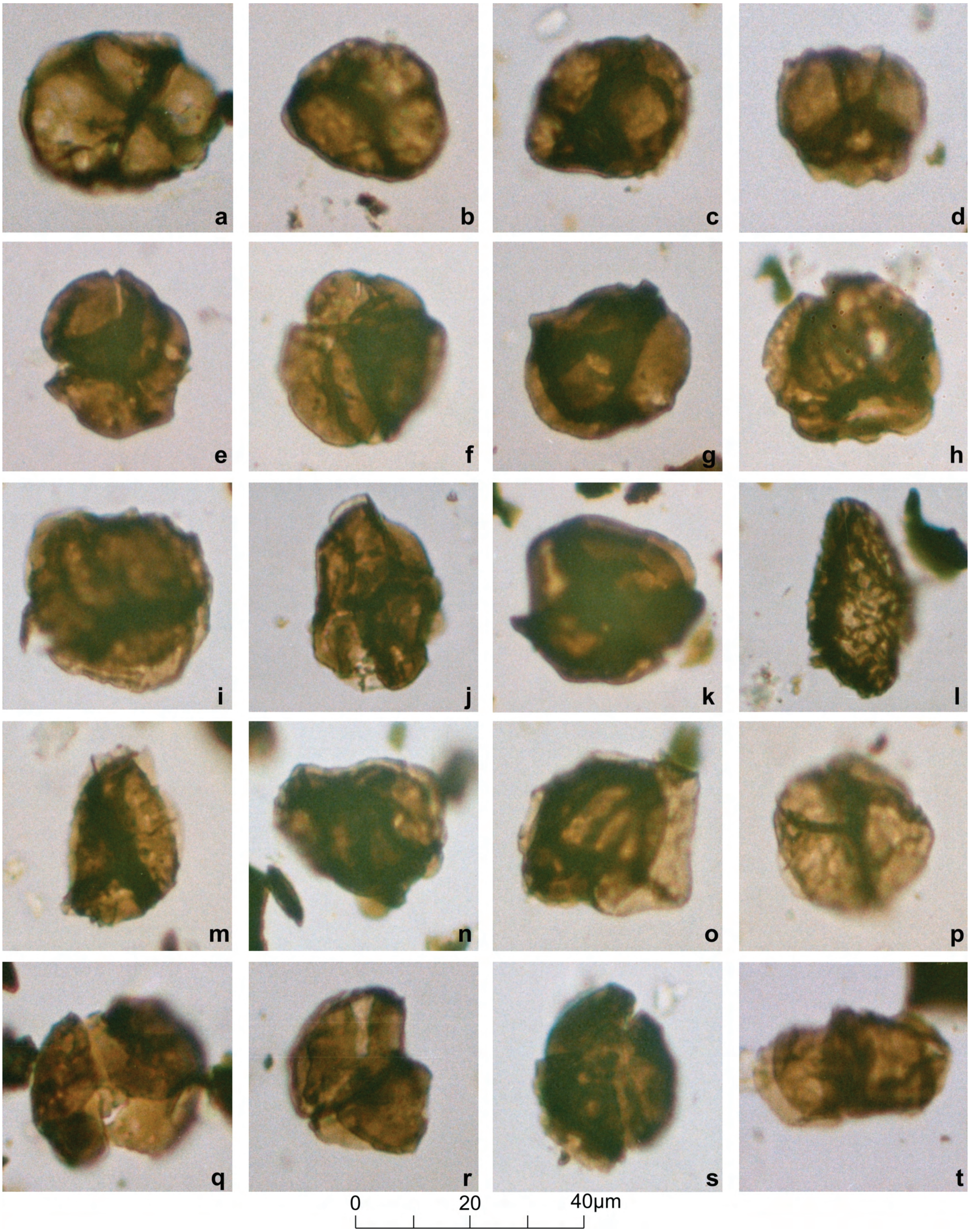
40μm

Plate 5

Cryptospores from the Gülüç Section, NW Anatolia, Turkey. All from sample Gul 1, Llandovery, magnification x1000. **(a, b, c)** *Tetrahedraletes medinensis* Strother & Traverse 1979. **(d, g, h)** *Cheliotetras caledonica* Wellman & Richardson 1993. **(e, f)** *Rimosotetras problematica* Burgess 1991. **(i)** *Segestrespora laevigata* Burgess 1991. **(j, k, n)** *Velatitetras laevigata* Burgess 1991. **(l)** *Rugosphaera cerebra* Miller & Eames 1982. **(m)** *Velatitetras anatoliensis* Steemans *et al.* 1996. **(o, t)** *Abditusdyadus laevigatus* Wellman & Richardson 1996. **(p)** *Segestrespora membranifera* (Johnson) Burgess 1991. **(q, r, s)** *Imperfectotriletes vavrdovae* Steemans *et al.* 2000.


a
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