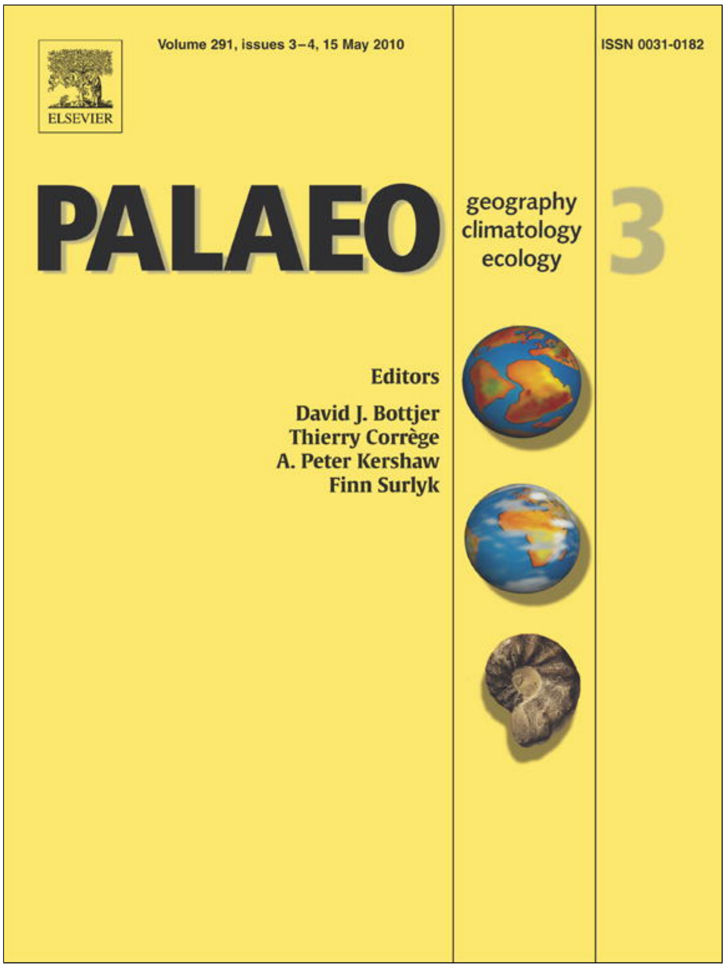
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Late Telychian (early Silurian) graptolitic shales and the maximum Silurian highstand in the NW Anatolian Palaeozoic terranes

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ABSTRACT

The late Llandovery included a period of global sea-level rise with a maximum in the *spiralis* graptolite Biozone, recorded by black graptolitic shales or red beds. Recent work in the less- known Silurian successions in the Zonguldak Terrane, NW Anatolia, has revealed the presence of Llandovery graptolitic black shales in the lower part of the Findikli Formation in the Camdag, Catak and Karadere areas. In the Camdag area, the "black shale member" yielded numerous well preserved graptolite rhabdosomes, including *Oktavites spiralis*, *Barrandeograptus pulchellus* and *Retiolites geinitzianus*. It is suggested that the graptolitic shales in this area were deposited during the *spiralis*–lower *lapworthi* zones. In the Catak and Ovacik areas, black shales intercalated with yellow shales yielded *O. spiralis* and *R. geinitzianus*. The deposition of black shales is related to the time of maximum Silurian sea level.

The graptolitic shales in the Zonguldak Terrane are time-equivalents of the (late Llandovery) violet shales with green layers from a less deep basin in E Istanbul Terrane. In the W Istanbul Terrane, reddish sandstones with Fe-oolitic minerals and brachiopod-bearing carbonates were deposited during the late Llandovery maximum transgression. The early Silurian deposits in the Zonguldak Terrane are more akin to those of E Avalonian successions, whereas those of the Istanbul terrane resemble those of the Gondwanan periphery. Moreover, the studied sections enable the recognition of the regressive trend (or part of it) in this high level stand, as indicated by the deposition of pale and grey-greenish mudstone layers, carbonates and shell beds.

1. Introduction

In contrast to the well-known Silurian successions (e.g. Kaya, 1978) within the classical "Palaeozoic of Istanbul" (Tchihatcheff, 1854) or Istanbul Terrane (Göncüoglu et al., 1997), Silurian rocks were hardly known to the East of Bosporus, so that this part of NW Anatolia, recently identified as a distinct terrane (Zonguldak Terrane; Göncüoglu and Kozur, 1998; Yanev et al., 2006), was considered as an area of non-deposition by some authors (e.g. Derman and Tuna, 2000). Only in recent years have Silurian siliciclastic successions including black shales been recognized (Kozlu et al., 2002; Göncüoglu et al., 2003) and accurately dated by graptolites (Göncüoglu and Sachanski, 2003; Sachanski et al., 2007, 2008) and palynomorphs (Lakova and Göncüoglu, 2005) in the Izmit, Camdag and Eregli–Gülüc areas (Fig. 1) of the Zonguldak Terrane. In the Camdag, Catak and Karadere (Ovacik) areas (Fig. 1), where Silurian rocks cover large areas, the authors have discovered new Telychian (late Llandovery, early Silurian) graptolite localities and collected new samples, which are presented in this study. The studied time interval (late Llandovery) is a period of global sea-level rise with a maximum in the *spiralis* Zone, recorded by black graptolitic shales or, less commonly red beds (Loydell, 1998).

The aims of this study are to report the new Telychian (early Silurian) graptolite discoveries from the Zonguldak terrane and to correlate the rock-units of this time-interval in the Istanbul and Zonguldak terranes, considering particularly the global sea-level rise during the late Telychian. It is the first such study in the eastern part of the European Gondwanan/Perigondwanan terranes and may contribute to a better understanding of the palaeogeographical setting of the NW Anatolian terranes during the early Silurian. The figured specimens are stored in the Geology Museum collection of Middle East Technical University (Ankara, Turkey).

2. Geological framework

Lower Silurian successions were studied in the Camdag, Catak and Karadere (Ovacik) areas of the Zonguldak Terrane in NW Anatolia (Fig. 1a). The Camdag area includes two thrust-sheets with well-developed Palaeozoic successions (Gedik and Önalan, 2002). The

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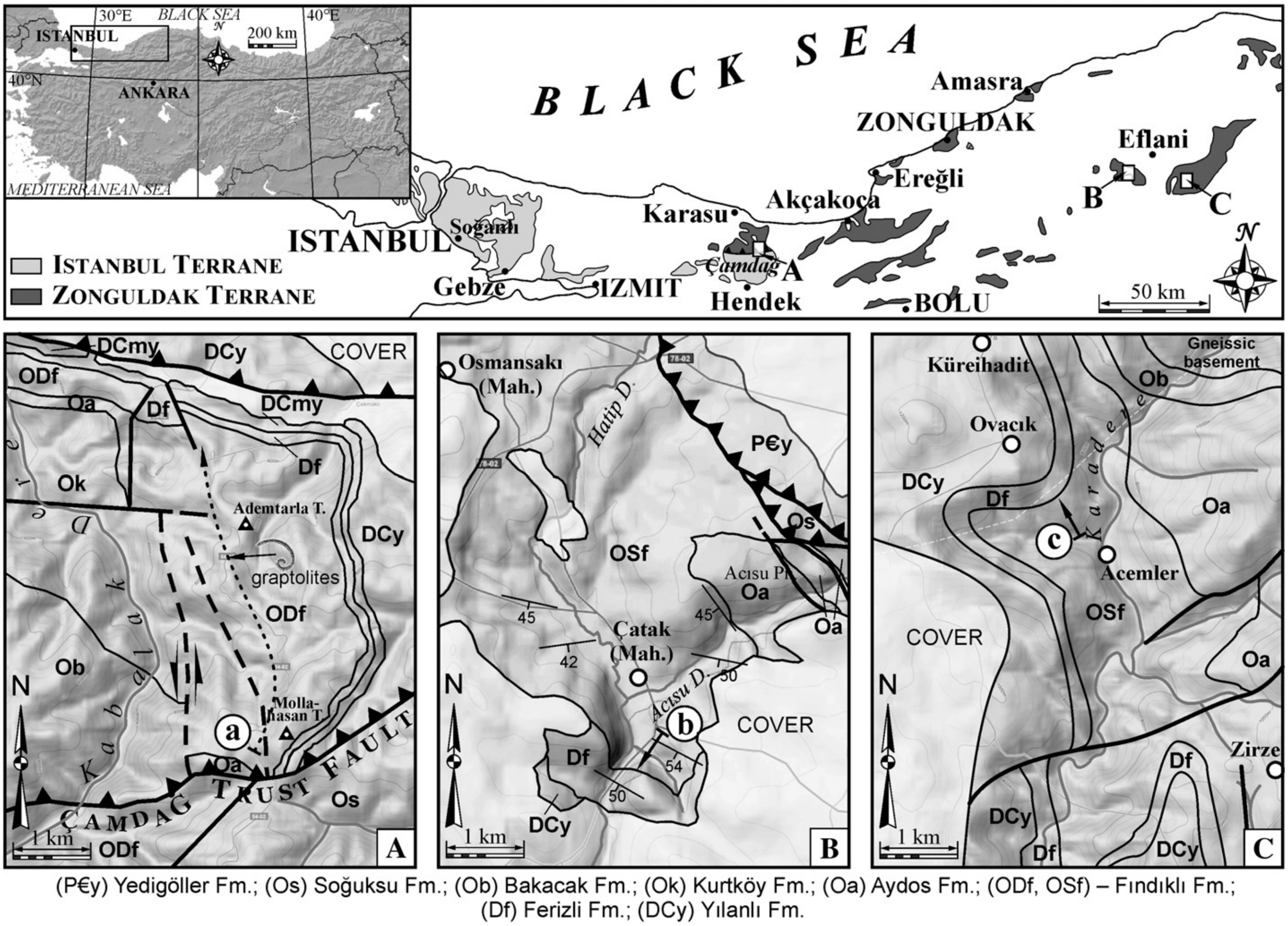


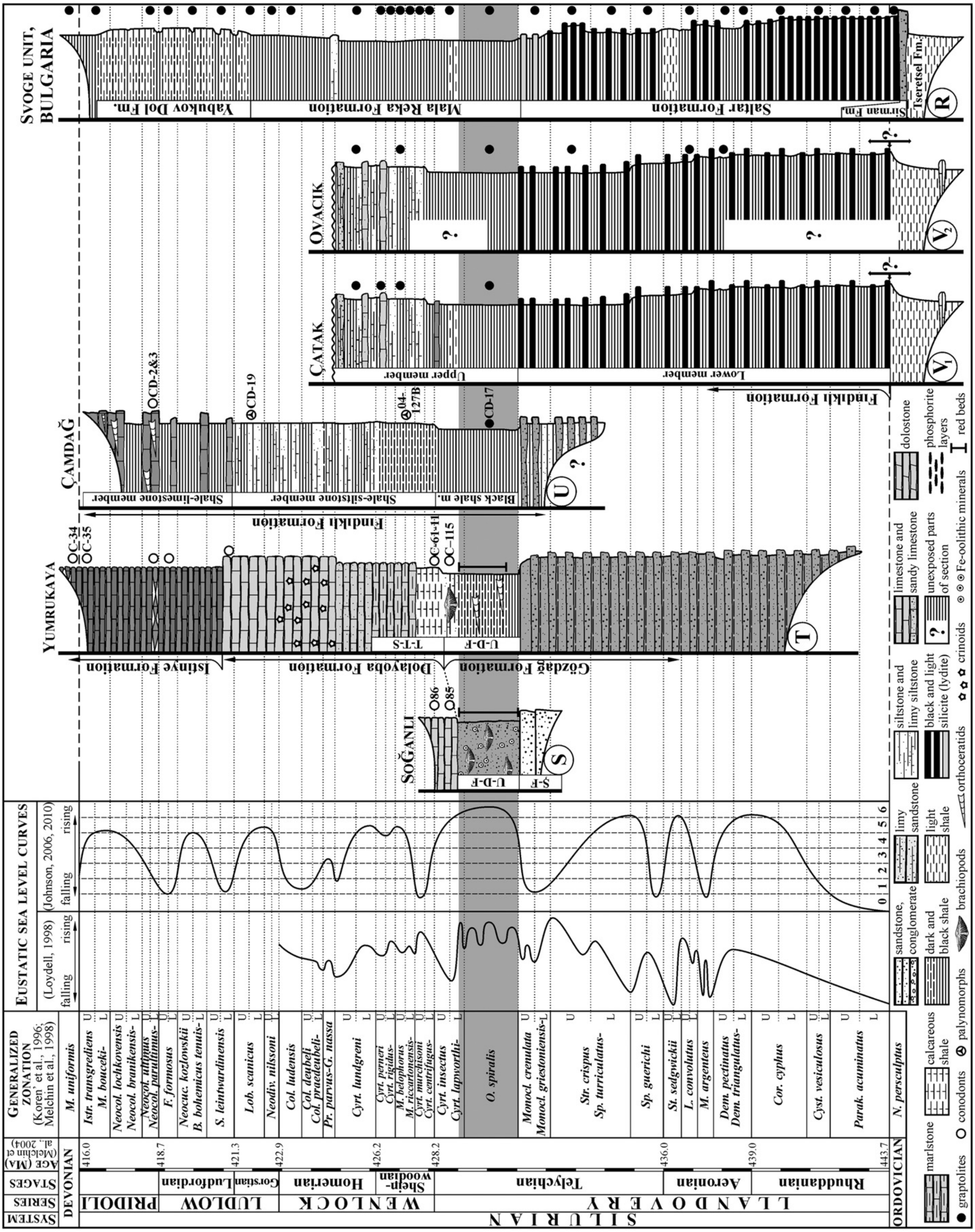
Fig. 1. Distribution of Palaeozoic rocks in NW Anatolia (modified from Göncüoglu et al., 2006) and the location of the studied successions: (A) Camdag (modified from Gedik and Önalan, 2002); (B) Catak (modified from Gedik in Sachanski et al., 2007); (C) Ovacik, Karadere (modified from Boztug, 1992).

northern unit is represented by a very thick but tectonically disrupted Palaeozoic succession with dated Ordovician to mid Carboniferous rocks. The Silurian succession in the northern unit is represented by the Findikli Formation (Aydin et al., 1987), which in Camdag is characterized not by a single and continuous succession but by several partial reference sections, bounded by tectonic contacts (Göncüoglu et al., 2003). Kozlu et al. (2002) informally subdivided the formation into a lower member (black shale member), a middle member (shale-siltstone member) and an upper member (shale-limestone member). The black shale member, which has been re-sampled in this study, has previously yielded upper Llandovery graptolites from the *Oktavites spiralis* biozone, (Göncüoglu and Sachanski, 2003). The newly found graptolites on the Hendek–Karaali Road are restricted to a 2 m thick interval in the lower part of the member (Fig. 1b). The lower part of the overlying shale–siltstone member is dominated by greenish-grey, micaceous shales that have yielded an acritarch association of early Wenlock (Sheinwoodian) age (Boncheva et al., 2009). They are followed by an alternation of dark grey-greenish black siltstones and shales with dark green-black, pyrite-bearing calcareous siltstones and dated as early Ludlow based on palynomorphs (Lakova and Göncüoglu, 2005). The "Orthoceras Limestone" interlayers in the upper part of the shale–limestone member has been dated as Přıdoli (Kozlu et al., 2002).

Along the Catakdere valley (Fig. 1B) to the SE of Eflâni, the newly discovered Findikli Formation is dominated by black siliceous argillites and lydites in the lower part, black argillites and sandy limestones in the middle part and shales with sandy limestone and limey siltstone in the upper part (Fig. 2 V_1). The lowermost series of black graptolitic shales with subordinate limestones and siltstones overlie greenish "spotted shales", very similar to the Ashgilian pre-glacial sediments in Bulgaria (Tseretsel Fm.; Sachanski, 1994) or schists mouchetés in the Ardennes (Verniers and de Vos, 1995). The studied Silurian succession is about 350 m thick with black argillites that alternate with black silicified shales and lydites in its lower part. No fossils could be obtained from this unit. The first graptolite finding from above this succession, however, yielded the graptolites *Retiolites geinitzianus* (Barrande) and *Monograptus priodon* (Bronn). The lithostratigraphy and graptolites of the overlying Silurian series has been recently reported by Sachanski et al. (2007).

In the Ovacik section in Karadere area (Figs. 1C and 2 V_2) the Paleozoic successions have been mapped by Boztug (1992) and the Turkish Petroleum Corporation in detail and the litho- and bio-

Fig. 2. Generalized columnar sections and correlation of the late Llandovery eustatic sea-level maximum-related units in Camdag, Catak and Ovacik (Zonguldak Terrane), Yumrukaya and Soganli (Istanbul Terrane) sections in NW Turkey and Bulgaria.



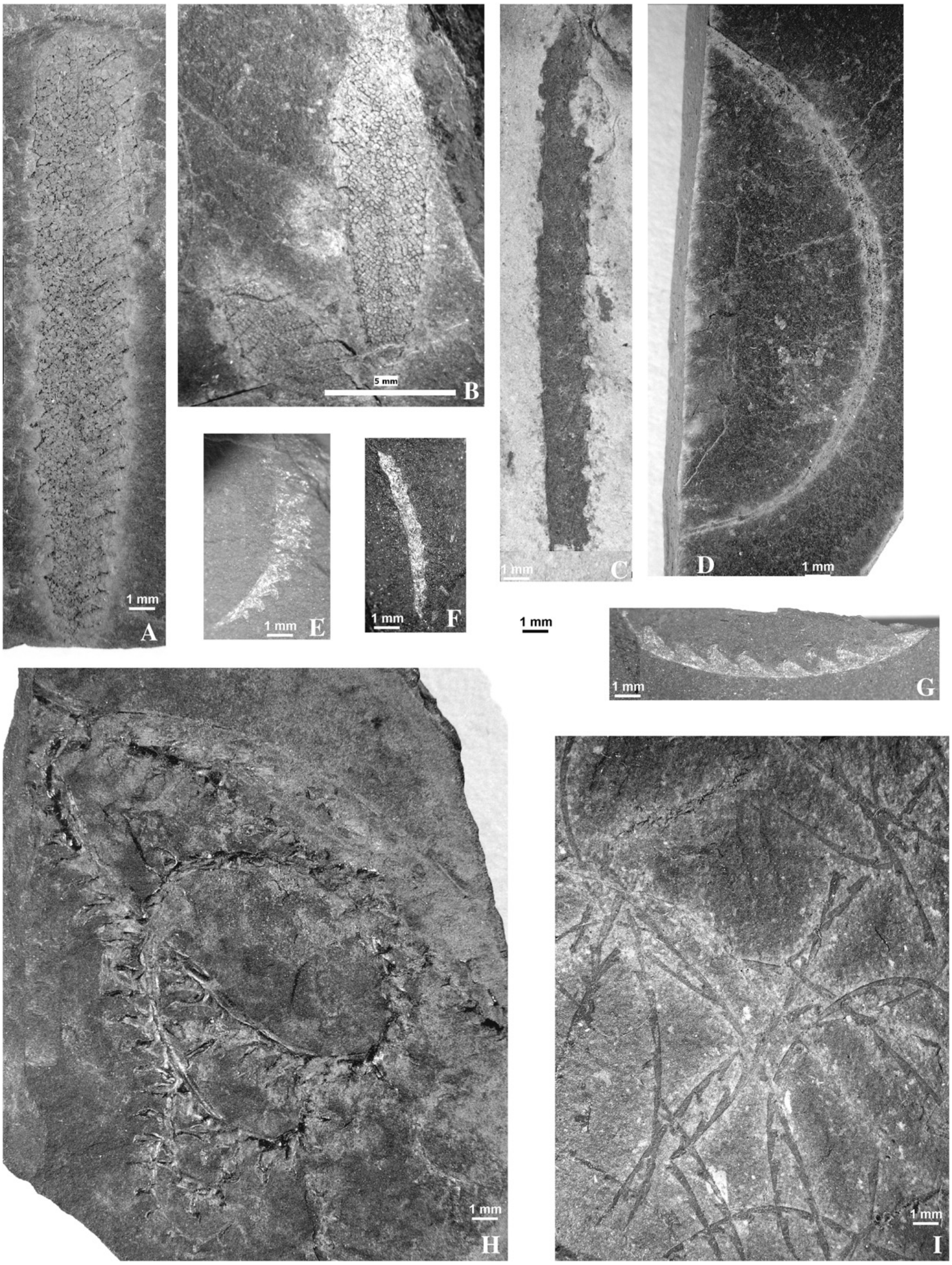


Fig. 3. Graptolites from Camdağ area (NW Turkey). A) *Retiolites genitzianus* (Barrande), CD-17.03.7. B) *Retiolites genitzianus* (Barrande), CD-17.03.6. C) *Monoclimacis vomerina* (Nicholson), CD-17.03.19. D) *Streptograptus nodifer* (Törnquist), CD-17.03.10. E) *Stimulograptus vesiculosus* (Perner), CD-17.03.2'. F) *Pristiograptus* sp., CD-17.03.13. G) *Monograptus curvus* Manck, CD-17.03.22. H) *Oktavites spiralis* (Geinitz), CD-17.03.12. I) *Barrandeograptus pulchellus* (Tullberg), CD-17.03.3'.

stratigraphy is studied by Dean et al. (1997, 2000). In contrast to the western areas Dean et al. (1997) used the name "Findikli Formation" only for the Silurian part of a thick siliciclastic succession, which they subdivided into two informal members: Lower and Upper. The studied section is located to the SW of Ovacik Village, along a forest road along Dorukyol Ridge (Fig. 1C) and corresponds to the Lower

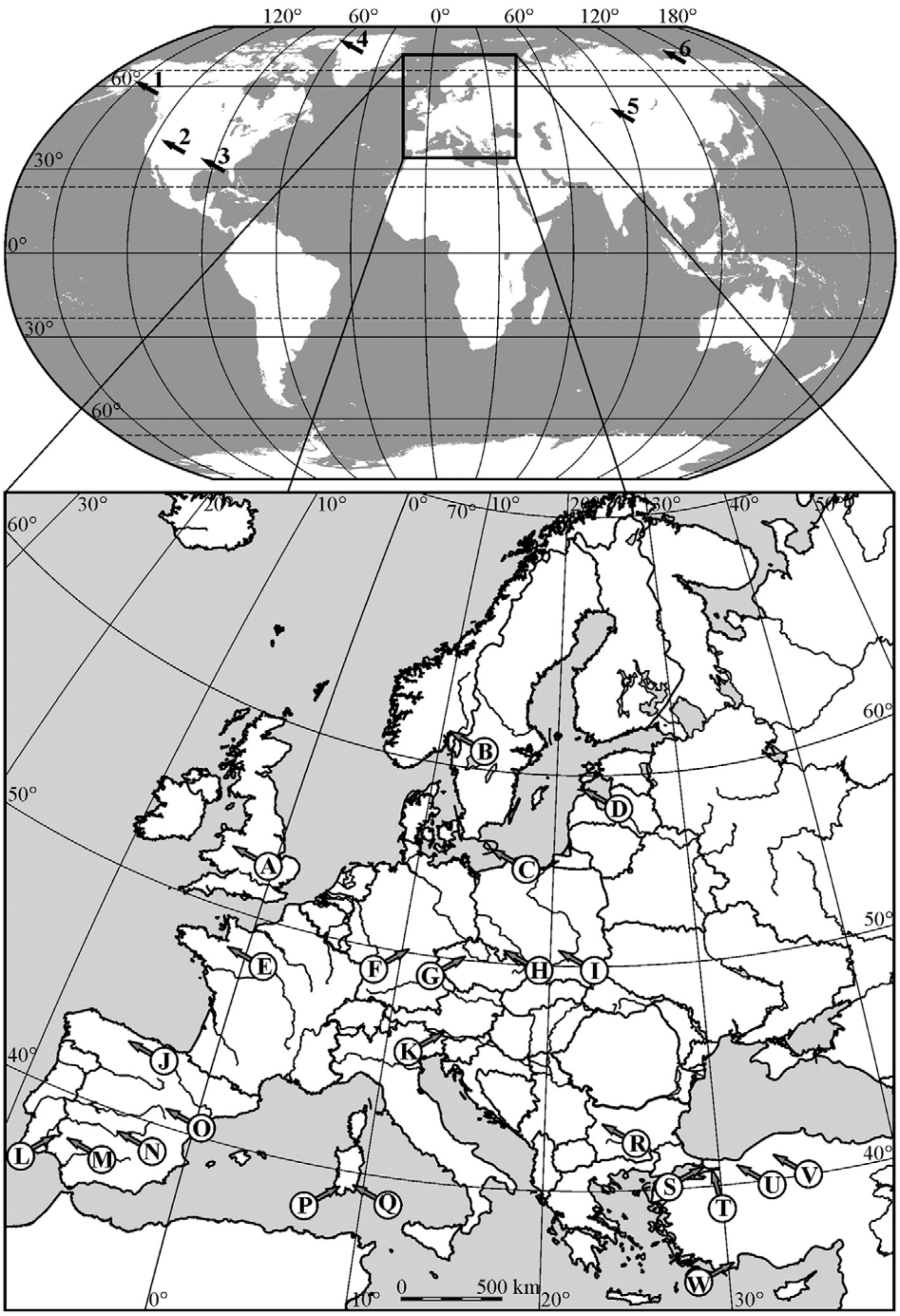


Fig. 4. Location of the sections discussed in the text. (1) Terra Cotta Mountains, Alaska (Churkin and Carter, 1996); (2) central Nevada, U.S.A. (Berry, 1986); (3) Arbuckle Mountains, Oklahoma, U.S.A. (Barrick and Klapper, 1976); (4) western North Greenland (a) section from Kap Lucie Marie (b) section from Kap Independence (c) section from 10 km south of Kap Independence (Bjerreskov, 1981); (5) Gorny Altai, Russia (a) Rossypnaya Mountain section (b) Mayak section (Sennikov et al., 2008); (6) Novosibirsk Islands, Russia (Koren' and Sobolevskaya, 1998); (A) Buttington Brick Pit, Wales (Loydell and Cave, 1993); (B) Ringerike, composite section 8, Norway (Baarli et al., 2003); (C) Bornholm, Denmark (Bjerreskov, 1975); (D) the Ohesaare core, Saaremaa, Estonia (Loydell et al., 1998); (E) the Ménez-Bélairm Syncline, the Armorican Massif, France (Paris et al., 1980); (F) Thuringia, Germany (Maletz and Katzung, 2003); (G) the Barrandian Basin, Czech Republic (Štorch, 1994; Štorch and Kraft, 2009); (H) Bardo Mountains, Sudetes, Poland (Porębska, 1982); (I) Holy Cross Mountains, Poland (Tomczyk, 1962); (J) Cantabrian Zone, Spain (Truyolis et al., 1974; Gutiérrez-Marco et al., 1998); (K) Carnic Alps, Austria (Brett and Schönlaub in Schönlaub, 1998; Loydell, 2003; Brett et al., 2009); (L) the Barrancos region, Portuguese part of Ossa Morena Zone (Robardet et al., 1998; Gutiérrez-Marco et al., 1998; Robardet and Gutiérrez-Marco, 2004); (M) the Valle syncline of the southeastern Ossa Morena Zone, Spain (Jaeger and Robardet, 1979; Gutiérrez-Marco et al., 1998); (N) Corral de Calatrava, Central Iberian Zone, Spain (Štorch, 1998; Loydell et al., 2009); (O) Western Iberian Cordillera, Spain (Gutiérrez-Marco and Štorch, 1998; Štorch, 1998); (P) SW Sardinia, Italy (Gnoli et al., 1990; Štorch and Serpagli 1993; Ferretti et al., 1998; Corradini et al., 2009); (Q) SE Sardinia, Italy (Corradini et al., 1998; Corradini and Ferretti, 2009); (R) Svoge anticline, Bulgaria (modified from Sachanski, 1997, 1998; this paper Fig. 2R); (S) the area of Soganli, north-east of Kartal, NW Turkey (this paper Fig. 2S); (T) the Yumrukaya section, north-east of Gebze, NW Turkey (modified from Haas, 1968; this paper Fig. 2T); (U) the Camdag area, NW Turkey (modified from Boncheva et al., 2009; this paper Fig. 2U); (V) the Catak and Ovacik sections, Pontides, northern Turkey (modified from Sachanski et al., 2007; this paper Fig. 2V_1 and V_2); (W) Taurus Mountains, southwestern Turkey (Dean et al., 1999). Symbols as in Fig. 2.

Member and the lower part of the Upper Member of Dean et al. (2000). In this section, four levels with graptolites were identified (Fig. 2V_2). The zonal-index graptolite species *Oktavites spiralis* (Geinitz) and *M. priodon* are documented at the base of the Upper Member of the Findikli Formation in the area of Ovacik. *M. priodon* associates with *Ret. geinitzianus* in the region of Catak (Fig. 2V_1). *M. priodon* and *Ret. geinitzianus* have a wide stratigraphic range, but the position of these finds (immediately above the lydite–argillite unit — Lower Member of the Findikli Formation) gives us a good reason to consider them as indication for the presence of *spiralis* Biozone.

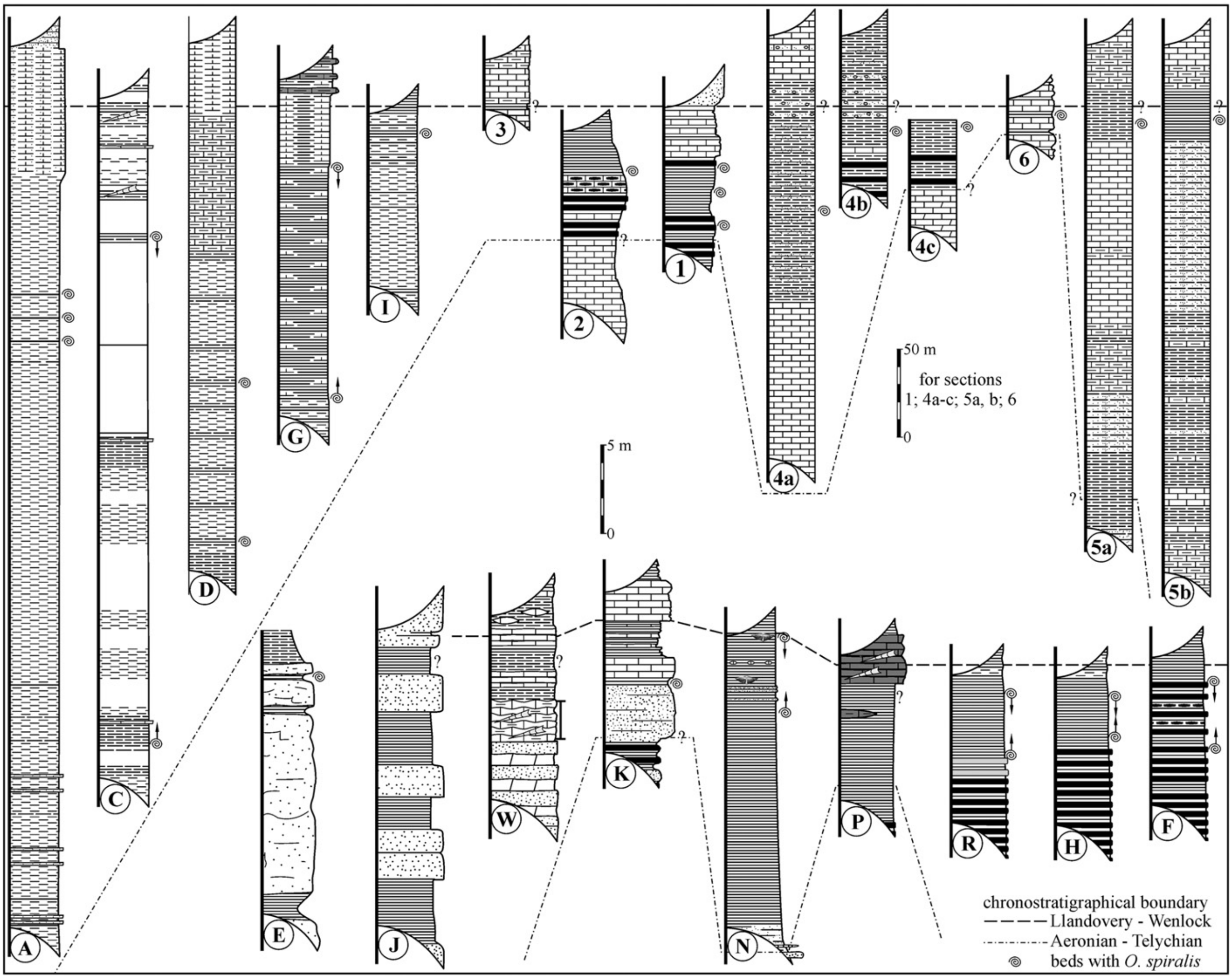


Fig. 5. The sections used in the construction of the Fig. 6.

Moreover, the lithostratigraphic succession in Bulgaria is similar (Sachanski and Tenchov, 1993) — the Saltar Formation (lydite–argillite unit) is followed upwards by Mala reka Formation (black graptolite shales), containing *O. spiralis* in the base (Fig. 2R). The details of the Ovacik Siluran succession are given in Sachanski et al. (2007).

3. The graptolite assemblage and paleontological notes

Göncüoglu and Sachanski (2003) reported the following graptolite species from the lower part of the Findikli Formation in the Camdag area: *Barrandeograptus pulchellus* (Tullberg), *Diversograptus ramosus* (Manck), *Oktavites falx* (Suess), *O. spiralis*, *Monoclimacis vomerina* (Nicholson), *Monograptus curvus* Manck, *M. grobsdorfiensis* Hemmann, *M. mancki* Hemmann, *M. parapriodon* Bouček, *M. priodon*, and *Retiolites angustidens* Elles and Wood. These were moderately well-preserved in low relief.

During the recent study, numerous well preserved (some in relief) specimens have been identified as *O. spiralis* (Fig. 3H) and *B. pulchellus* (Fig. 3I). *Ret. geinitzianus* is also common (Fig. 3A and B). Their dorso-ventral width (DVW) of this gradually increases: 2.5–2.8 mm (5 mm from the proximal end); 3.2–3.4 mm (10 mm from the proximal end); 3.6 mm (15 mm from the proximal end); 4.3 mm (25 mm from the proximal end) to reach a maximum value of 4.5 mm. Such size range is characteristic of the early representatives of the species (Loydell et al., 1997).

A distal fragment at Fig. 3G resembles in its thecal shape and DVW of 1.3 mm both *M. curvus* and *Torquigraptus flagellaris* (Törnquist). According to Přibyl (1945) the density of thecae in *M. curvus* is 8–9 th/10 mm (2TRD = 2.5–2.2 mm), and in *T. flagellaris* — 6 th/5 mm (2TRD = 1.6–1.7 mm). On the basis of this criterion the fragment is identified as *M. curvus* as the 2TRD is 2.2–2.4 mm which corresponds to about 9 th/10 mm. These two species share similar stratigraphical ranges — the uppermost *tullbergi* (*crenulata*) and lower *spiralis* biozones (Štorch, 1998; Loydell et al., 2009).

In the representatives of *Mcl. vomerina* the values of DVW gradually increase from 0.6 to 1.2–1.3 mm at 10 mm from the proximal end to reach 2.0 mm in distal fragments (Fig. 3C), whereas 2TRD ranges from 1.8 to 3.0 mm. *Stimulograptus vesiculosus* (Perner), *Streptograptus nodifer* (Törnquist) and *Pristiograptus* sp. have been recorded for the first time in the Camdag area. Due to tectonic deformation the values of DVW (1.8 mm) in *St. vesiculosus* (Fig. 3E) are greater than those in the Perner's (1899) original diagnosis — 1.4 mm. For the same reason *Pristiograptus* sp. (Fig. 3F) looks dorsally curved. Its DVW is 0.6–0.7 mm, 2TRD — 1.3 mm, and the length — 7.5 mm. It is not identifiable at species level.

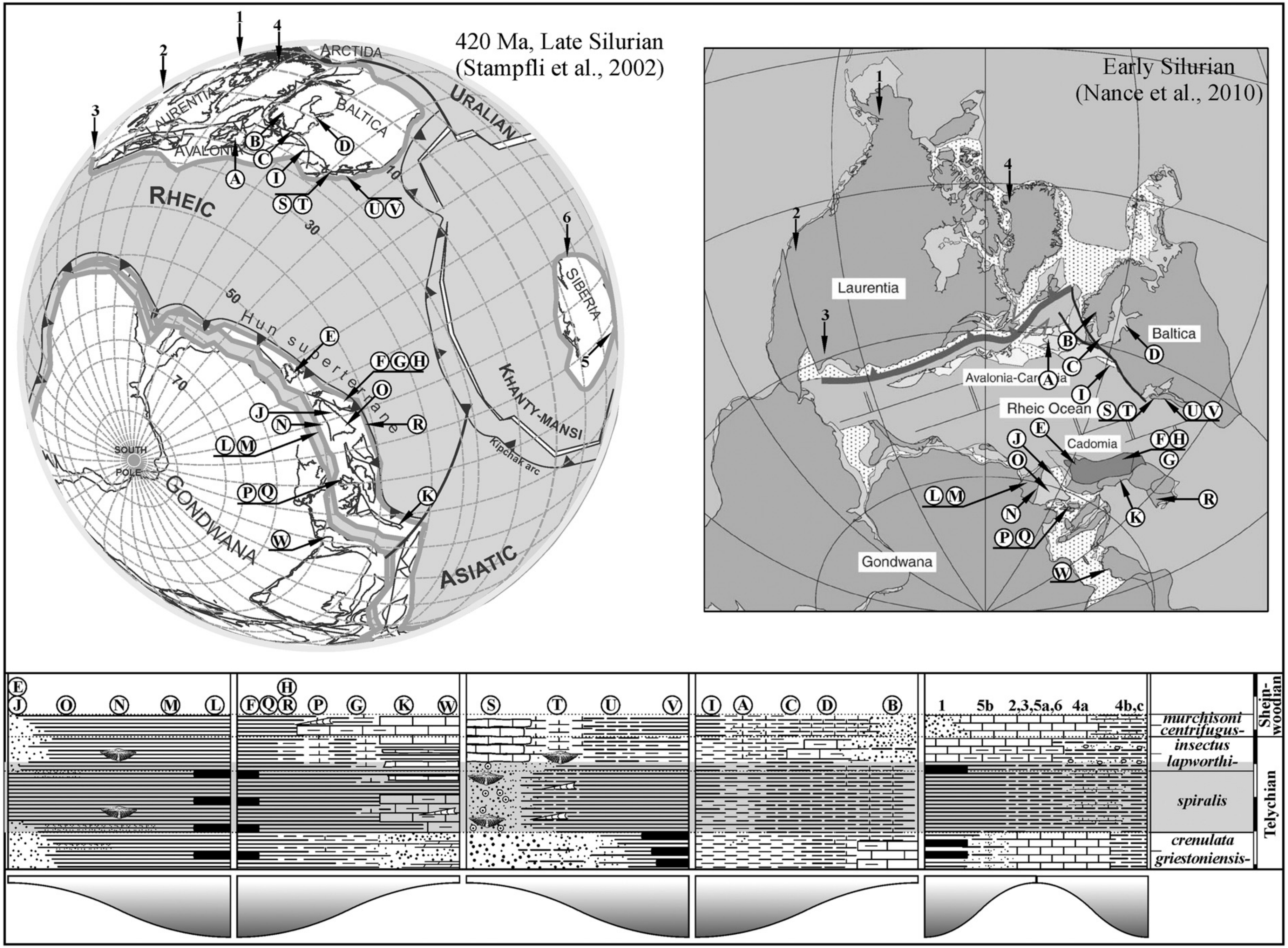


Fig. 6. Silurian world palaeogeography with locations of the sections from Fig. 4. The high sea-levels of the spiralis and early lapworthi biozones (the shaded portion) and the rock record in various palaeoenvironments.

In *Str. nodifer* (Fig. 3D) DVW gradually increases from 0.2 to 0.7–0.8 mm, whereas 2RTD has constant values of 2.1–2.2 mm. Due to the frontal position of the thecae in relation to the rhabdosome, the characteristic thecal form (Zalasiewicz and Howe, 2003; Loydell and Nestor, 2006) is not always visible. In some cases the proximal part shows greater ventral curvature. This is diagnostic for *Str. anguinus* (Rřibyl), although its DVW is no more than 0.5 mm (Loydell et al, 2003). The DVW values in all the fragments are greater — 0.7–0.8 mm.

St. vesiculosus and *Str. nodifer* are typical of the middle and upper part of the *spiralis* Biozone (Loydell et al., 2003, 2009). *O. falx* and *B. pulchellus* (Göncüoglu and Sachanski, 2003) occur in the *spiralis* and lower *lapworthi* biozones (Štorch, 1994); *D. ramosus* — from upper *crenulata* to l*apworthi* biozones (Loydell et al., 2009).

The graptolite material (*Dicellograptus* cf. *complanatus, Monograptus* aff. *priodon, Monograptus* sp.*, Orthograptus* sp. and *Diplograptus* sp.) published by Gedik and Önalan (2002) from Camdag is here re-evaluated. This material was flattened, poorly preserved and tectonically deformed. The revision is as follows: *Dicellograptus* cf. *complanatus* is a deformed monograptid; *Orthograptus* sp. and *Diplograptus* sp. are *Ret. geinitzianus*; *Monograptus* aff. *priodon* is *M. priodon* and *Monograptus* sp. — *Mcl. vomerina*, *Ret. geinitzianus*, *M. priodon* and *Mcl. vomerina* are stratigraphically very long-ranging lower Silurian species (Loydell et al., 1997; Štorch, 1994). This suggests that the deposition of graptolitic shales in the Camdag area occurred during the *spiralis*–lower *lapworthi* zones.

4. Discussion and conclusion

It has been widely accepted that global sea-level fluctuated markedly during the early Silurian probably as a result of the waxing and waning of ice-sheets in NW Gondwana (Brenchley et al., 1994; Loydell, 1998; Page et al., 2007). The highest sea-levels of the Silurian were during the Telychian late *crispus*–early *griestoniensis* and *spiralis*–early *lapworthi* biozones. This interval is represented by black graptolitic shales or less commonly red beds (Loydell, 1998).

A correlation of the Camdag, Catak and Ovacik successions with some other locations and lithologies of the *spiralis*–lower *lapworthi* biozones is given in Fig. 2. In the Camdag area, strata corresponding of *crispus*–early *griestoniensis* Zone age have not been identified yet. However, during the *spiralis*–lower *lapworthi* Zone interval graptolitic black shales were deposited and form the lower part of Findikli Formation (black shale member).

Lower Silurian black graptolitic shales deposited in deeper conditions crop out south-east of Safranbolu (Dean et al. 2000). In the area of Asagi Catakköyü and Ovacik Dorugöl Sirti (Fig. 2 V_1 and V_2) black shales, intercalated with yellow shales yielded *O. spiralis* and *R. geinitzianus*. They are overlain by black siliceous shales with Telychian graptolites. Above, dark grey calcareous shales with Sheinwoodian graptolites occur, intercalated with limestone beds. The deposition of black shales is related to the time of maximum Silurian sea level. Correlation with the coeval deposits in the Istanbul Terrane in the west is crucial for a better understanding of the early Silurian palaeoenvironment and palaeobathymetry.

The graptolitic shales in the Zonguldak are-time-equivalents of the violet shales (with orthoceratids) with green layers (contain brachiopods) from a less deep basin within the upper part of Gözdag Formation ("Umur-Dere-Folge" by Haas, 1968) cropping out at Yumrukaya section to the north-east of Gebze in Istanbul (Figs. 1 and 2T). Beneath these shales the Gözdag Formation consists of dark green fine-grained sandstones and siltstones of Llandovery age ("Kayali-Dere-Folge" and "Seyhli-Folge" by Haas, 1968). The Gözdag Formation is overlain by the limestones of the lowest part of the Dolayoba Formation, the latest Llandovery age being established on conodonts ("Tavşan-Tepe-Schichten" by Haas, 1968). In a shallower environment, reddish sandstones with Fe-oolitic minerals and benthic brachiopods were deposited in the area of Soganli (north-east of Kartal, Figs. 1 and 2S), during the late Llandovery maximum transgression. This succession is underlain by white quartzites and overlain by the intraclastic limestones of the Dolayoba Formation. Recently, obtained biostratigraphical data on conodonts (det: I. Boncheva) and acritarchs (det: I. Lakova) prove the late Telychian age (Göncüoglu et al., 2006).

As a result of the increased sea level during the *spiralis* Zone, black graptolitic shale was deposited in the generally carbonate successions characteristic of the comparatively stable platform environments (Johnson, 2006; in press; Johnson et al., 1998; Koren' et al., 1996; Melchin et al., 1998; Melchin et al., 2004) of Laurentia (sections 1–4, Figs. 4–6) and Siberia (sections 5 and 6, Figs. 4–6). Minor fluctuations (Loydell, 1998) in sea-level are suggested by the intercalation of bioturbated non-graptolitic units in well-dated sequences of Eastern Avalonia (section A, Figs. 4–6) and Baltica (section B, Figs. 4 and 6 and sections C, D and I, Figs. 4–6). In sandstone dominated sections (sections E and J, Figs. 4–6) or carbonate sequences (sections K and W, Figs. 4–6) from the Gondwanan periphery, black shales were deposited during the late Telychian sea-level maximum. Sections from the Istanbul Terrane (Yumrukaya and to some extend Soganli) are here associated with this sedimentation type. The gradual increase of sea level does not always have a distinct lithological expression, especially in pelagic anoxic conditions with the deposition of black graptolite shales, siliceous shales and siliciclastics (section F, Figs. 4–6, sections M, O, Q and L, Figs. 4 and 6). These sections enable the recognition of the regressive trend (or part of it) in this high level stand. It is indicated by the deposition of pale and grey-greenish mudstone layers, carbonates and shell beds (sections H, N, P and R, Figs. 4–6). Similar sequences are exposed in the Catak and Ovacik sections of the Zonguldak Terrane (Figs. $2V_{1,\ 2}$, 4 V and 6 V). The structure of the Findikli Formation in the region of Camdag is not so well elucidated due to the tectonic breaks and the insufficient palaeontological evidence. A rich and varied graptoloid fauna is documented only from within the *spiralis* and perhaps lower *lapworthi* biozones. The increased graptoloid diversity is a clear signal (Loydell, 1998) for the establishment of more deep marine environments during this period.

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