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GRAPTOLITE RESEARCH IN TÜRKIYE: AN OVERVIEW OF STUDIES UNDERTAKEN IN THE FIRST QUARTER OF THE 21ST CENTURY

Valeri Sachanski*,** ✉ Juan Carlos Gutiérrez-Marco***, Ibrahim Gedik°, Hüseyin Kozlu°°, Cengiz Okuyucu°°°, Necdet Özgül•, Iskra Lakova**, D. Gülnur Saydam-Demiray°, Hilal Akın°, Iliana Boncheva**, Dimitar Sachkov*[1], Mehmet Cemal Göncüoğlu••

* University of Mining and Geology "St. Ivan Rilski", Sofia, Bulgaria.
** Geological Institute, Bulgarian Academy of Sciences, Sofia, Bulgaria.
***Instituto de Geociencias (CSIC, UCM) and Facultad de Ciencias Geológicas Universidad Complutense, Madrid, Spain.
° General Directorate of Mineral Research and Exploration, Ankara, Türkiye.
°° Turkish Petroleum Corporation, Ankara, Türkiye.
°°°Ankara Hacı Bayram Veli University, School of Land Registry and Cadastre, Ankara, Türkiye.
•GEOMAR, İstanbul, Türkiye
••Middle East Technical University, Ankara, Türkiye.

✉ Corresponding author, e-mail: valeri.sachanski@mgu.bg

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ABSTRACT

This paper presents a comprehensive synthesis and critical re-evaluation of graptolite research undertaken in Türkiye since the beginning of the twenty-first century, with particular emphasis on Ordovician and Silurian successions of the İstanbul–Zonguldak Composite Terrane, the Tauride–Anatolide Terrane, and the Southeastern Anatolian Autochthon. Drawing upon published studies, unpublished reports, and new taxonomic and chronostratigraphic revisions, this review summarizes graptolite occurrences, biostratigraphic frameworks and depositional settings across these tectonostratigraphic units. Ordovician data document the timing and nature of early Palaeozoic marine transgressions, refine correlations of Tremadocian–Darriwilian successions, and reveal peri-Gondwanan palaeobiogeographical affinities, including links with Avalonia–Armorica. Silurian successions are shown to preserve a detailed record of the post-Hirnantian transgression, maximum flooding events and subsequent regression, expressed in widespread graptolitic black shale records, condensed sections and regionally significant stratigraphic gaps. Comparison with coeval successions from Europe, North Africa and Arabia indicates that the Turkish terranes occupied key positions along the northern Gondwanan margin and followed distinct palaeogeographic trajectories during closure of the Rheic Ocean. This synthesis highlights the central role of graptolites in correlating Lower Palaeozoic successions across Anatolia and emphasizes their importance for reconstructing terrane evolution, palaeoceanography and basin development in the eastern Mediterranean region.

INTRODUCTION

The first graptolite discoveries since the beginning of the new millennium were made by Ibrahim Gedik and M. Cemal Göncüoğlu in the İstanbul–Zonguldak Composite Terrane, and by Hüseyin

Kozlu and Yılmaz Günay in the Taurides and the SE Anatolian Autochthon. The results of these initial findings were reported in Gedik and Önalan (2001), Kozlu et al. (2002, unpublished report), Göncüoğlu and Sachanski (2003), and Monod et al. (2003).

Subsequent field studies, which significantly expanded knowledge of graptolite localities in the İstanbul–Zonguldak Composite Terrane, were carried out in 2003 and 2004 within the framework of the bilateral project "Correlation of the Palaeozoic Terranes in Bulgaria and NW Anatolia: Implications for the Tectonic–Palaeogeographic Evolution of NW Gondwana." This project was conducted jointly by the Scientific and Technological Research Council of Türkiye (Türkiye Bilimsel ve Teknolojik Araştırma Kurumu, TÜBİTAK) and the Bulgarian Academy of Sciences (Project 102Y157; leaders: Prof. Dr. M. Cemal Göncüoğlu, METU, Ankara, Türkiye, and Prof. Dr. Slavcho Yanev, Geological Institute, Sofia, Bulgaria).

In spring 2012, M. Cemal Göncüoğlu, Hüseyin Kozlu and Valeri Sachanski conducted more detailed investigations of graptolites in the Değirmentaş–Halevikdere section of the Eastern Taurides. These studies were undertaken in connection with the field excursion of the conference "Palaeozoic of Northern Gondwana and Its Petroleum Potential: A Field Workshop," organized by the Turkish Association of Petroleum Geologists and held from 9–14 September 2012 in Kayseri, Türkiye.

The results of these investigations were presented at numerous conferences and published in various journals between 2003 and 2015 (Boncheva et al., 2005, 2009; Göncüoğlu and Sachanski, 2009; Göncüoğlu et al., 2003, 2005, 2014a, b, 2015; Kozlu et al., 2012a, b; Lakova et al., 2006a, b, c; Sachanski and Göncüoğlu, 2009; Sachanski et al., 2006, 2007, 2008, 2010, 2012, 2015; Yanev et al., 2004, 2006).

The most recent research on Turkish graptolites is the master's thesis of Hilal Akın, "Graptolite biostratigraphy of the Silurian of the Diyarbakır Basin, Southeastern Turkey," completed in 2021 under the supervision of David Loydell (University of Portsmouth, UK), and the publication of Tanrıkulu and Loydell (2025).

The aim of this paper is to summarize and revise the data obtained since 2000 on graptolites from localities in Türkiye. In addition, some of the results of Dean et al. (2000) from the central Pontides (Karadere–Zirze area) are re-evaluated here from both taxonomic and chronostratigraphic perspectives.

GEOLOGICAL FRAMEWORK

Türkiye is located within one of the most tectonically complex regions of the world. This complexity largely reflects its palaeogeographic position between two major mega-continents—Laurasia to the north and Gondwana to the south—throughout much of its geological history. During at least four major orogenic cycles (Cadomian, Variscan, Palaeotethyan and Alpine), continental fragments derived from both mega-continents were rifted apart, new oceanic domains developed between them, and these fragments subsequently collided to form a highly intricate tectonic mosaic. The present-day configuration largely represents the product of the most recent Alpine orogenic event.

Conventional tectonic classifications (e.g. Şengör and Yılmaz, 1981; Şengör et al., 1982) which were mainly based on the distribution of geological bodies during the Alpine period, proved increasingly insufficient as new data—particularly those supported by radiometric age determinations—became available from different parts of these units. These data demonstrated that many Alpine tectonic bodies contain evidence of pre-Alpine geological events that can be correlated across different regions. Consequently, an alternative tectonic framework based on "terrane tectonics", in the sense of Hamilton (1990) and Howell (1994), began to be applied.

Göncüoğlu et al. (1994, 1997) proposed the first terrane-based tectonic map of the region, which was subsequently refined (e.g. Göncüoğlu, 2010, 2019). This proposal was adopted by several authors (e.g. Okay and Tüysüz, 1999; Yanev et al., 2006; Okay, 2008; Moix et al., 2008; Papanikolaou, 2021), although it has also been questioned by others (e.g. Şengör et al., 2019; 2025)

Within this framework, the Alpine terranes (Fig. 1a)—the İstanbul–Zonguldak Composite Terrane (IZCT), together with the Taurides of the Tauride–Anatolide Terrane (TAT) and the SE Anatolian Autochthonous Unit (SEAA) represent the principal areas where non-metamorphic Palaeozoic rock units occur and from which the graptolite material reviewed in this study have been collected.

The IZCT extends along the Black Sea coast of NW Anatolia. In its western part (the İstanbul Terrane), the basement is represented by a Cadomian intra-oceanic arc, whereas in the eastern part (the Zonguldak Terrane) the basement rocks are interpreted as products of a Cadomian continental arc. The palaeogeographic affinity of these basement complexes—whether peri-Gondwanan or related to Baltica—remains a matter of debate (see Ustaömer et al., 2011 for a recent discussion).

The earliest overstep sequence in both units is of Early Ordovician age (e.g. Arpat et al., 1978; Göncüoğlu, 1997; Özgül, 2012; Göncüoğlu et al., 2014a). However, the Variscan evolution of the IZCT differs between its eastern and western sectors. In the east, a distinct unconformity of Caledonian age associated with a well-defined thermal event (Bozkaya et al., 2012a, b) has been documented, whereas in the west the succession is continuous from the Ordovician to the early Carboniferous. It is also noteworthy that Carboniferous successions differ markedly between these sectors, suggesting contrasting palaeogeographic and tectonic settings during the Variscan orogeny. Consequently, it remains debated whether the IZCT should be assigned to the peri-Gondwanan, Armorican or Avalonian terrane assemblages (see Murphy et al., 2023 for a recent discussion).

The subsequent overstep sequence of the IZCT, both in the east and west, consists of late Permian to Early Triassic continental clastic deposits, indicating their earliest tectonic amalgamation. The Ordovician–Silurian graptolite-bearing sections discussed in this review are separated into different parts of the IZCT below in order to be able to assess possible variations in their palaeobiogeographic position. Their correlation is more complex than that of sections in the Taurides and the SE Anatolian Autochthonous Unit.

The Lower Palaeozoic successions investigated using graptolites are located within the Central (Kaledibi) and Eastern (Değirmentaş–Halevikdere) non-metamorphic Tauride Units (Özgül, 1976; Göncüoğlu and Şahin, 2012) of the TAT. The TAT aquired its terrane character at the end of the Permian to the beginning of the Triassic, when it rifted away from the remainder of the SEAA—that is, the northern edge of the Gondwanan Arabian microcontinent—during the opening of the southern branch of Neotethys. It shares the same Cadomian basement and Palaeozoic cover with the SEAA.

Özgül (1976) proposed a fundamental model for the structural framework of the TAT that has been widely adopted in subsequent studies. According to this model, Palaeozoic successions within numerous allochthonous tectono-stratigraphic units represent parts of a vast platform, and their relatively minor lithostratigraphic differences reflect variations in depositional environments across that platform. During the closure of the northern and southern branches of the Neotethys, these tectono-stratigraphic units were thrust over one another. Units derived mainly from the northern part of the platform underwent metamorphism, forming the Anatolides, whereas those that escaped both imbrication and metamorphism are referred to as the Taurides (e.g. Ketin, 1959, 1966). Graptolite-bearing Ordovician (e.g. Ghienne et al., 2010; Kozlu and Ghienne, 2012; Elicki et al., 2022; Tanrıkulu and Loydell, 2025) and Silurian (Varol et al., 2006; Kozlu et al., 2012a; Tanrıkulu and Loydell, 2025) formations occur mainly in the Aladağ, Geyikdağ and Alanya Units (*sensu* Özgül, 1976) of the TAT.

Ordovician and Silurian graptolite-bearing rocks in the SEAA have been mainly reported from Çermik–Korudağ outcrops and from drill-cores in the Diyarbakır Basin. At the former location, the lower visible part of a 32 m-thick black shale-lydite unit contains graptolites of Rhuddanian age, while the uppermost part of the black shale succession extends up to the late Wenlock. Subsurface data discussed in this review are derived from the Gökiçi-1 well, located in the immediate vicinity of the Korudağ section, which revealed both lower Silurian strata and the underlying Hirnantian glaciomarine sediments. The master's thesis of Hilal Akın (2021) reports 38 graptolite species spanning nine biozones (Rhuddanian, Telychian, Sheinwoodian, and early Homerian), from a total of 31 samples.

The early Palaeozoic graptolite-bearing successions of the SEAA correlate well with those of the Arabian Peninsula (e.g. Şenalp and Tetiker, 2024)

MATERIAL AND METHODS

Documented graptolites occur most frequently in black shales and variably siliceous black shales. Highly siliceous lithologies, traditionally referred to as lydites or bedded cherts, also contain graptolites; however, specimens are rarely recovered as complete rhabdosomes. Upon mechanical impact, they tend to disintegrate into fragments or break along irregular fracture surfaces that do not coincide with bedding planes.

In black shales, graptolites are typically preserved as flattened, black peridermal films, whereas in siliceous black shales they may occasionally be preserved pyritized in low relief. With the exception of a few fragments described by Sachanski et al. (2010, 2015), most graptolites do not show evidence of tectonic distortion.

The limestones near Derince-İznit (Sachanski et al., 2008) yielded three-dimensionally preserved graptolite rhabdosomes together with cephalopods. Graptolites have also been reported from fine-grained sandstones (Sachanski et al., 2012). Although most of the succession is barren of macrofossils, graptolites may locally occur in abundance and are sometimes preserved in relief on isolated bedding planes (Göncüoğlu et al., 2014a).

Irrespective of the originally stated repository, all figured graptolite specimens figured in Sachanski et al. (2007, 2008, 2010, 2012 and 2015, Fig. 10:1-11 and Fig. 11) are currently housed in the Natural History Museum of the General Directorate of Mineral Research and Exploration (MTA), Ankara, Türkiye. The specimen TS-85-1 (Sachanski et al., 2006) is housed in the Laboratory of Geocollections, Geological Institute, Bulgarian Academy of Sciences (Inv. No. F.5.2.7), where it forms part of the institute's museum exhibition.

RESULTS

The locations of the sections from which graptolites have been recorded are shown in Figures 1 and 2.

Ordovician

New data on Ordovician graptolites have been obtained from the Karadere area (Zonguldak Terrane), as well as from one section in the southern part of the Central Taurides (Kaledibi section).

Karadere–Zirze area

Dean et al. (2000) documented the lower Palaeozoic stratigraphy and palaeontology of the Karadere–Zirze area in the central Pontides of northern Türkiye, describing a well-exposed Ordovician–Silurian succession ranging in age from probable Tremadocian to Wenlock.

Detailed lithostratigraphic analysis, combined with graptolite, trilobite, conodont, and acritarch data, constrains the ages of the Bakacak, Aydos, Karadere, Ketencikdere, and Fındıklı formations and demonstrates continuous deposition from the early Dapingian to Darriwilian, followed by Sandbian carbonates and Llandovery–Wenlock shales.

The Ordovician sequence is characterized by quartz arenites, mostly anoxic graptolitic mudstones and later carbonates yielding trilobites and conodonts of the *Amorphognathus tvaerensis* Biozone, whereas the Silurian is represented by black Llandovery argillites overlain by grey Wenlock shales.

Fossil assemblages, including several new graptolite taxa and trilobites comparable to those of the Welsh Basin, indicate affinities with western Europe rather than with the Gondwanan-type successions of southern Türkiye. These results support the interpretation that the Karadere–Zirze succession developed on a distinct peri-Gondwanan terrane with palaeogeographic links to Avalonia–Armorica during the early Palaeozoic.

Dean et al. (2000) described and illustrated a number of Ordovician graptolite species recovered from the Karadere Formation in the Karadere River and Ketencik Dere sections, east and south of Zirze. They documented the presence of approximately fifteen fossiliferous horizons, which they attributed to the "Arenig", partly to the "Llanvirn", and partly to the "transition" between these two British series.

Some of the species identified in the lower to intermediate Arenig fossiliferous levels, such as "*Didymograptus (Corymbograptus) cf. deflexus*", "*D. (Didymograptellus) protobifidus*", and "*D. (Didymograptellus) minutus*", raise the possibility that these beds might instead be upper Floian in terms of the global Ordovician chronostratigraphic scale (Bergström *et al.*, 2009; Goldman et al., 2020). However, the first two taxa co-occur and the third post-dates the first appearance of *Isograptus caduceus imitatus*, a deep-water pandemic species recorded in beds around the Floian–Dapingian boundary (Maletz et al., 2026, fig. 3).

According to the illustrations in Dean *et al.* (2000), this basal local assemblage contains no unequivocal Floian graptolites belonging to the genera *Didymograptellus* or *Baltograptus*, to which the cited forms are currently assigned. All horizons originally attributed to the Arenig correspond to the present Dapingian (the lower stage of the Middle Ordovician). The four horizons assigned to the "transition beds" correspond to the lower Darriwilian, whereas those identified as "Llanvirn" fall within the lower part of the middle Darriwilian.

The taxonomic list is now markedly outdated, including records of *Aulograptus climacograptoides* (= *A. cucullus*, *A.? feistmantelli*), *Xiphograptus v-deflexus* (= *Didymograptellus protobifidus, Corymbograptus vfractus volucer*), *Corymbograptus?* sp. (= *Didymograptus cf. deflexus*), *Xiphograptus?* or *Expansograptus?* sp. (= *Expansograptus nitidus*), and *Pseudophyllograptus angustifolius elongatus?* (= *Ps. angustifolius angustifolius*) within the Dapingian assemblage. In this assemblage, *Isograptus caduceus imitatus*, *Pseudisograptus manubriatus koi* (poorly preserved juvenile specimens), *Tetragraptus bigsbyi*, and *Azygograptus cf. evionicus* are also recognized. The pendent forms assigned to *"D. (Didymograptellus) minutus"* (Dean et al., 2000, p. 568, fig. 11d, e) are certainly unrelated to *Baltograptus minutus*, as the morphology of their thecae displays a primitive aspect reminiscent of those of *Pendeograptus* or *Pseudobryograptus*. We provisionally identify them here as *Pendeograptus*? sp. *Pendeograptus* is a genus that is common in the Floian but ranges up to the lower Darriwilian (*P. liber*).

Maletz (2005, 2011) and Maletz and Ahlberg (2021) discussed several of the biserial forms represented in the middle assemblage of the lower Darriwilian beds, which in their view corresponds to the upper part (= *Levisograptus sinicus* Subzone) of the *Levisograptus austrodentatus* Biozone. This interval is also characterized by the absence of graptolites of the *Arienigraptus zhejiangensis* group in underlying levels and by the lack of any specimens of *Holmograptus* above. Among the early biserial graptolite species described by Rickards (in Dean *et al.*, 2000), "*Undulograptus? mui*" represents a species of *Levisograptus* very similar to *L. sinicus* but somewhat more robust, whereas "*Eoglyptograptus bouceki*" is probably a species of the genus *Undulograptus*, somewhat resembling *U. novaki* (= *U. klabavensis*). By contrast, "*Prolasiograptus haplus praecursor*" and the material attributed to *Eoglyptograptus jaroslavi* are difficult to evaluate, although the latter resembles a normalograptid (Maletz, 2011; Maletz and Ahlberg, 2021).

Finally, the middle Darriwilian assemblage includes, according to us, *Jenkinsograptus spinulosus*, *Didymograptus* ex gr. *artus*, and *Proclimacograptus angustatus*, and is most probably representative of the *Holmograptus lentus* Biozone (Maletz and Ahlberg, 2021).

Karadere–İncüvez

Göncüoğlu et al. (2014a) reported new graptolite discoveries from the Lower and Middle Ordovician successions in the Karadere area of the Zonguldak Terrane, a region where the boundary between the Cadomian basement and its Palaeozoic sedimentary cover is exceptionally well exposed. These discoveries refine the biostratigraphy and palaeogeographical interpretation of the early Palaeozoic transgressive sequence in northern Türkiye (Figs. 3, 4).

In the basal part of the Bakacak Formation, the authors documented specimens of *Rhabdinopora flabelliformis*, indicating that the initial Ordovician marine transgression in the area began during the Early to Early-Late Tremadocian. A slightly higher horizon yields *Paradelograptus* cf. *antiquus*, a species typical of the upper Tremadocian, confirming continued sedimentation during that interval. These graptolite-bearing dark shales occur above fluvial conglomerates and sandstones directly overlying Precambrian rocks, suggesting an early Tremadoc highstand followed by regression reflected in the overlying red–brown clastics.

Further up-section, within the Karadere Formation, a newly identified graptolite assemblage containing *Levisograptus austrodentatus*, *Levisograptus sinicus*, *Tetragraptus cor*, and other species indicating an early Darriwilian (Dw1) age. Notably, *Tetragraptus cor* (previously known only from Scandinavia and Mongolia) was recorded here for the first time in peri-Gondwanan terranes. Maletz and Ahlberg (2021) emphasized that this assemblage, illustrated by Göncüoğlu et al. (2014a), derives from a single level in the middle part of the Karadere Formation and most probably originated from the *Levisograptus sinicus* Subzone. However, although a pattern-U astogeny is recognizable in the specimen illustrated as *Levisograptus austrodentatus*, in their opinion the apertural thecal spines cannot be clearly distinguished, and the specimen might alternatively be referred to a spined taxon similar to *Levisograptus sinicus* or *Levisograptus mui*. The occurrence of *L. austrodentatus* is nevertheless confirmed here because the natural external mould from which the figured latex cast was obtained clearly demonstrates that the thecae lack spines, thereby confirming the original identification.

In addition to the previously published data, this synthesis presents new graptolite-bearing levels identified in the Karadere–İncüvez section (Fig. 3, point EA). These were discovered by Dr Esen Arpat during the 1960s and communicated to one of the authors (M.C.G.) through a series of photographs of the material dating from 1997. Although the original specimens have not been located and the old photographs lack a graphic scale, the morphology of some of the graptolites is sufficiently distinctive to allow recognition of several Dapingian and Darriwilian levels at this locality. There is also the possibility that these findings represent the first record of certain species previously unknown from the Karadere Formation. Fig. 5 reproduces some of the graptolites identified in the photographs from this newly recognized fossiliferous interval, which in general encompasses a large part of the horizons attributed to the "Arenig" and its transition to the "Llanvirn" by Dean et al. (2000, fig. 13) in previous sections, with the notable absence of the various Darriwilian biserial forms and the scarce Dapingian isograptids–pseudisograptids. Of particular interest is the more than probable presence of the genus *Xiphograptus*, which had already been suggested when revising specimens assigned to *D.* (*Didymograptellus*) *protobifidus* and *D.* (*Corymbograptus*) *vfractus volucer* by earlier authors (see above); as well as the identification of *Expansograptus hirundo* (Fig. 5h), an important index species of the Dapingian. Also noteworthy is the discovery of a possible specimen of *Corymbograptus retroflexus* (Fig. 5n), a species with a wide record in the lower Darriwilian of high and mid-latitudes (e.g. Bouček, 1973; Maletz and Ahlberg, 2011). The middle Darriwilian is indicated only by a pendent *Didymograptus* with a long sicula that might belong to the genus *Jenkinsograptus*.

These new data from the Karadere Formation demonstrate that: (1) the earliest Palaeozoic transgression in this region began no later than the mid-Tremadocian; (2) a second major transgression reached its maximum during the early Darriwilian; and (3) the Zonguldak Terrane shared palaeobiogeographic affinities with other peri-Gondwanan regions during the Early–Middle Ordovician.

The scarcity of early graptolites is attributed to predominance of shallow-marine siliciclastic facies unfavourable for their preservation.

Kaledibi section

Sachanski et al. (2006) documented the first confirmed occurrence in Türkiye of *Hunnegraptus copiosus*, a species characteristic of the upper Tremadocian (Lower Ordovician). Prior to this study, this graptolite had been reliably identified only in Scandinavia, Bolivia, Argentina and Canada. Its discovery in the Seydişehir Formation of the Central Taurides (southern Türkiye) significantly improves regional biostratigraphic resolution for the Lower Ordovician of Anatolia. The fossils were recovered from the base of a shale-rich, quartz arenite-bearing sedimentary succession (Fig. 6). The collected material includes both early two-stiped proximal colonies and multiramous mature forms of *H. copiosus*, with some specimens showing uncommon fourth-order branching. These represent the largest and most completely preserved specimens of *H. copiosus* currently known worldwide (Fig.7).

The occurrence of *H. copiosus* allows precise correlation of the Seydişehir Formation with coeval Tremadocian graptolite biozones globally, refining previous age estimates based on trilobites and conodonts. It also links the Central Taurides specimens with the "young", "mature," and "gerontic" growth stages described for Scandinavian populations, confirming close taxonomic affinity.

This discovery contributes to an improved understanding of Ordovician biogeography, demonstrating that species previously considered restricted to northern palaeocontinents also inhabited peri-Gondwanan regions such as Türkiye. The study highlights the need for further detailed investigations of the Tauride successions, where preservation of early Ordovician fossils is often poor.

Silurian

The Silurian lithological logs and biostratigraphic correlation (following Melchin et al., 2020) are shown in Figure 8. Figures 9–15 contain palaeontological tables with the identified graptolites.

In the sedimentary sequence of the İstanbul Terrane, graptolites have been found only in a single section, located in the eastern part of the Kocaeli Peninsula, north of the port city of Derince. In the Zonguldak Terrane, Silurian graptolites have mainly been described from in the Çamdağ, Ereğli, Çatak, and Karadere (Ovacık) areas. Among the Silurian sections in the Taurides and the SEAA, the Değirmentaş–Halevikdere section in the Eastern Taurides has been most thoroughly investigated.

Derince

The Silurian succession near Derince–İzmit on the Kocaeli Peninsula, NW Türkiye, yielded the first record of Wenlock graptolitic shales in this region (Sachanski et al., 2008). The exposed interval, consisting of alternating dark grey to black limestones and yellowish calcareous shales, contains a graptolite assemblage dominated by *Monograptus flemingii*, *Pristiograptus pseudodubius*, *Monoclimacis flumendosae*, and *Cyrtograptus* cf. *lundgreni*. These taxa indicate an age within the *Cyrtograptus lundgreni* Biozone (upper Wenlock), with a possible extension into the underlying *Cyrtograptus rigidus* Biozone. According to the authors, the lithological and palaeontological characteristics of the Derince succession closely resemble those of the Silurian Fındıklı Formation of the Zonguldak Terrane and differ markedly from the shallow-marine Wenlock carbonates typical of the İstanbul Terrane.

Çatak and Karadere (Ovacık)

New stratigraphic, lithological, and biostratigraphic data on the Silurian succession in two key areas of the Zonguldak Terrane—the Çatak section southwest of Eflâni and the Ovacık (Karadere) section near Safranbolu—were presented in the study of Sachanski et al. (2007). These areas lie between previously studied localities and help to fill a major geographic gap in understanding the Silurian geology of northwestern Anatolia.

Both sections belong to the Fındıklı Formation, a deep-marine siliciclastic sequence that spans the Middle Ordovician to the lower Silurian. The Silurian interval is composed mainly of black shales, lydites, and fine-grained siliciclastics, representing deposition in a relatively deep, low-energy basin.

Mid-Devonian quartz arenites and carbonates overlie these units unconformably, marking a significant erosional hiatus.

Graptolites provide the primary basis for age determination. In the Çatak section, several key graptolite horizons reveal the presence of the *Oktavites spiralis*?, *Monograptus belophorus*, upper *Cyrtograptus rigidus* (*Cyrtograptus perneri* sensu Štorch, 2023), and *Cyrtograptus lundgreni* biozones, covering an interval from the lower Telychian to the lower Homerian (upper Llandovery to Wenlock). The Ovacık section yielded an even richer and more continuous graptolite record, including the *Lituigraptus convolutus*, *Streptograptus crispus*, *Oktavites spiralis*, and *Monograptus belophorus* biozones, indicating a similar but more complete Silurian succession.

Early Silurian assemblages display strong peri-Gondwanan affinities, reflecting the terrane's original position along the northern Gondwana margin.

A major conclusion of the study is the presence of a significant late Silurian hiatus (Ludlow–Přídolí), which appears to be consistent across the Zonguldak Terrane. The authors attribute this gap not to global sea-level fall but to regional tectonic uplift and erosion linked to Early Devonian deformation during the terrane's convergence with Laurussia.

Overall, the cited article enhances understanding of Silurian stratigraphy in NW Anatolia, refines regional biostratigraphic correlations, and strengthens interpretations of the Zonguldak Terrane's movement and tectonic evolution within the Palaeozoic Eastern Mediterranean realm.

Northern Çamdağ

Sachanski et al. (2010) documented newly discovered upper Telychian (lower Silurian) graptolitic black shales from several localities of the Zonguldak Terrane in northwestern Anatolia and interpreted them as representing the maximum Silurian global sea-level highstand. These findings significantly expand the known Silurian record of the region and clarify the relationship between the Zonguldak and İstanbul terranes.

The black shale interval belongs to the lower part of the Fındıklı Formation, a deep-marine Silurian sequence traditionally considered poorly fossiliferous. However, new graptolite collections from the Northern Çamdağ, Çatak, and Karadere (Ovacık) areas yielded rich and well-preserved assemblages, including *Oktavites spiralis*, *Barrandeograptus pulchellus*, and *Retiolites geinitzianus*. The first of these taxa is restricted to the *Okt. spiralis* and lower *Cyrt. lapworthi* biozones, indicating deposition at the peak of a major global marine transgression. Additional forms, such as *Monoclimacis vomerina*, and *Stimulograptus vesiculosus*, further refine the biostratigraphy.

Sedimentologically, the black shales represent deep-water, low-oxygen deposition, characteristic of transgressive maxima when basins rapidly deepen. Correlation with other sections in NW Anatolia shows a distinct facies gradient: deep-marine graptolitic black shales in the Zonguldak Terrane correlate with shallower violet shales in the İstanbul Terrane and even more proximal sandstones with oolitic ironstone beds and brachiopod-bearing limestones in the Soğanlı area. This indicates a broad north–south bathymetric profile across the region during the Telychian.

The study also compares the Anatolian sequence with contemporaneous Silurian sections from Europe, particularly Bulgaria, demonstrating that the Telychian highstand was a regional event across peri-Gondwanan terranes. The authors argue that this widespread transgression corresponds to a well-documented global eustatic maximum, recognized on multiple continents (Loydell, 1998). Overall, the research provides the first clear evidence for the Telychian maximum flooding event in NW Anatolia, significantly improves the biostratigraphic framework of the Silurian in Türkiye, and contributes to broader reconstructions of palaeogeography, sea-level change, and terrane evolution along the northern margin of Gondwana during the early Silurian.

Ereğli

Sachanski et al. (2012) studied the Silurian Fındıklı Formation at the Gülüç section near Ereğli in the Zonguldak Terrane of NW Anatolia. The succession is highly condensed (~20–28 m thick) and comprises three sedimentary packages: greenish-grey limy siltstones (Package 1), black shale–clayey limestone alternations (Package 2), and siltstones and sandy limestones (Package 3).

Using combined graptolite, conodont, and cryptospore biostratigraphy, the study assigns Package 1 to the Llandovery (Rhuddanian–lower Telychian), and Packages 2–3 to the upper Wenlock to lower Ludlow (Homerian–Gorstian).

Graptolites provide the clearest biostratigraphic control. Key biozones identified are:

- *Cyrtograptus lundgreni* Biozone in the lower part of Package 2, indicated by species such as *Testograptus testis*, *Monograptus flemingii*, *Eisenackograptus eisenacki*, and *Pristiograptus* ex. gr. *dubius*.
- *Neodiversograptus nilssoni* Biozone higher in Package 2, with *Lobograptus progenitor*, *Colonograptus colonus*, and *Bohemograptus bohemicus*.
- *Lobograptus scanicus* Biozone across upper Package 2 and Package 3, marked by *Lobograptus scanicus* and *Saetograptus chimaera chimaera*.

These biozones reveal major stratigraphic gaps, including missing upper Telychian–Sheinwoodian strata, attributed to Silurian global sea-level transgressive-regressive (T–R) cycles and local tectonic uplift.

The study also noted that the Gülüç succession differs markedly from thicker Silurian sequences in the nearby İstanbul and Zonguldak terranes, highlighting its uniquely condensed and discontinuous nature.

Akyaka section

Varol et al. (2006) investigated the lower Silurian (lower Telychian) organic-rich black shales from the Akyaka section in the Central Taurides region of Turkey, with a strong emphasis on graptolites as both biostratigraphic markers and indicators of thermal maturity. Graptolite assemblages— including taxa such as *Spirograptus* cf. *guerichi*, *Stimulograptus sedgwickii*, *Rastrites linnaei*, *Glyptograptus incertus*, and *Parapetalolithus dignis*—are used to constrain the strata to the *guerichi* Biozone, enabling precise correlation with other Silurian successions across former Gondwanan margins. Although the assemblage is not highly diverse, it is diagnostically significant and even includes rare occurrences (e.g., first *P. dignis* outside Kazakhstan). The fossils are variably preserved, often pyritized and tectonically deformed, which affects morphological measurements but still allows reliable taxonomic identification and biozonation. Overall, graptolites provide the primary framework for dating and correlating these shales regionally.

Beyond biostratigraphy, graptolites play a crucial geochemical role in the study as proxies for thermal maturity through reflectance analysis, especially important in pre-Devonian rocks lacking terrestrial plant material. Measured graptolite reflectance values (GRmax ~5.0–6.75%) indicate extreme thermal overmaturity, implying deep burial and exposure to high temperatures (≈200–350 °C). This overmaturity explains why, despite moderate total organic carbon (average ~2.86%), the organic matter is inert and has poor hydrocarbon-generating potential. Thus, graptolites serve a dual function: they not only establish the stratigraphic age and palaeoenvironment (dysoxic–anoxic marine deposition following post-glacial transgression) but also provide a quantitative tool for reconstructing burial history and diagenetic evolution of the basin.

Değirmentaş–Halevikdere section

Sachanski et al. (2015) investigated the Silurian–Lower Devonian succession exposed in the Değirmentaş–Halevikdere section of the Eastern Taurides (southern Türkiye) and demonstrated that it exhibits a lithostratigraphy almost identical to the classical "Thuringian-triad" facies known from Saxo-Thuringia (Germany) and other peri-Gondwanan terranes. This triad consists of:

- Lower Graptolite Shale Formation (black graptolitic shales)
- Ockerkalk Formation (ochre-coloured limestones and shales)
- Upper Graptolite Shale Formation (black shales)

The studied ca. 150 m-thick section spans the interval between Hirnantian glaciomarine sedimentary rocks and Lochkovian nodular limestones. The lower ~40 m consist of black, graptolite-rich shales and radiolarian ribbon cherts, which yield a well-preserved graptolite succession. These include Rhuddanian index species (*Akidograptus ascensus*, *Parakidograptus acuminatus*, *Cystograptus vesiculosus*), the lowermost Telychian *Spirograptus guerichi* Biozone, the *Spirograptus turriculatus* and *Streptograptus crispus* biozones, and Wenlock taxa such as *Monograptus belophorus*.

Above these graptolitic intervals lies a ~50 m-thick ochre-coloured shale–limestone succession analogous to the Ockerkalk Formation, distinguished by nautiloid-rich beds in the lower Ludlow and crinoid-rich limestones in the Přídolí—features matching the Thuringian reference sections.

The uppermost ~60 m of the succession consist of barren black shales and siltstones, correlating with the Upper Graptolite Shale Formation. The Silurian–Devonian boundary was placed in the lower part of this unit on the basis of lobolith (scyphocrinoid) evidence (Yalçın et al., 2012; Schindler et al., 2025).

Sachanski et al. (2015) showed that this threefold subdivision is not isolated but closely correlates with Silurian–Lower Devonian successions across many peri-Gondwanan regions: the Sudetes (Poland), Bohemia, Bulgaria, Iberia (Ossa-Morena and Catalonian Ranges), Sardinia, and North Africa. These correlations emphasize that the Eastern Taurides shared the same deep-shelf to basin palaeoenvironmental evolution as the broader northern Gondwanan margin.

The paper proposed a palaeoceanographic model to explain the alternation between anoxic, graptolitic black shales and oxic, limestone-bearing intervals. Key controlling mechanisms include:

- migration of peri-Gondwanan terranes from high to low latitudes.
- shifts in oceanic thermohaline circulation, particularly density-driven downwelling in subtropical arid belts during the Ludlow–Přídolí, allowing oxygenated waters to reach basin floors;
- wind-driven upwelling and downwelling systems, influencing nutrient levels, radiolarian productivity, and bottom-water oxygenation;
- monsoonal conditions during the latest Silurian–earliest Devonian, promoting stratification and the deposition of organic-rich black muds.

This study (Sachanski et al., 2015) provided the first detailed documentation of early Silurian graptolites from the Eastern Taurides and established a robust correlation between Turkish Palaeozoic units and the classical Thuringian and Bavarian facies successions. It also contributed important new data for reconstructing the palaeogeographic evolution of the southern Anatolian segment of peri-Gondwana during the Silurian–Early Devonian.

Tanrıkulu and Loydell (2025) presented an integrated biostratigraphic and chemostratigraphic study of the Upper Ordovician to lower Silurian successions in the Central and Eastern Taurides of Türkiye, combining palynology, graptolite data, and $\delta^{13}C_{org}$ isotopes to refine the position of the Ordovician–Silurian boundary. The studied sections record a transition from glaciomarine Upper Ordovician deposits into finer-grained Silurian shales and lydites, reflecting environmental change associated with glaciation and deglaciation. Palynological assemblages allow broad dating of the Upper Ordovician (notably the Hirnantian), while isotope trends provide additional correlation with global carbon cycle perturbations. However, preservation issues—especially in lower Silurian strata—limit the utility of palynomorphs, increasing the importance of graptolites for precise chronological control.

Graptolites play a central role in constraining the age of the Silurian succession, particularly within the Llandovery Series. Diverse and relatively well-preserved assemblages enable identification of multiple biozones, ranging from the lower Rhuddanian *Akidograptus ascensus*–*Parakidograptus acuminatus* Biozone through the *Cystograptus vesiculosus* Biozone and into Aeronian and Telychian intervals such as the *Spirograptus guerichi* Biozone. These assemblages demonstrate high taxonomic diversity and include numerous species recorded for the first time in Türkiye, allowing detailed correlation with other Gondwanan and peri-Gondwanan regions.

In the Halevikdere section (Tanrıkulu and Loydell, 2025), graptolites provide a detailed and relatively continuous biostratigraphic framework through the Llandovery. The lowest recorded assemblage belongs to the *Akidograptus ascensus–Parakidograptus acuminatus* Biozone, marking the lowermost Silurian (Rhuddanian), followed upward by faunas of the *Cystograptus vesiculosus* Biozone. Higher in the section, graptolites indicate a progression through the Aeronian (including the *Stimulograptus halli* Biozone) and into the Telychian, where assemblages characteristic of the *Spirograptus guerichi* Biozone are present. Although preservation varies and some intervals yield sparse material, the succession demonstrates continuous deposition across the Ordovician–Silurian boundary and enables precise correlation with standard global graptolite biozonations.

Other Silurian sections in the Taurides and the SE Anatolian Autochthone

Monod et al. (2003), Ghienne et al. (2010), and Kozlu et al. (2012a, b), although not illustrating graptolite taxa, described a number of sections from the Taurides and the SE Anatolian Autochthon in which graptolite levels have been identified.

In the Eastern Taurides, a measured sections is in Tufanbeyli–Pekmezköy (=Pekmezli-4 in Tanrıkulu and Loydell, 2025); additional spot samples were taken from Sarız–Mirzaağa, Tufanbeyli–Armutalan and Saimbeyli–Gürleşen sections. In the Central Taurides, Silifke–Ovacık and Bozyazı–Tekmen sections were measured and spot samples were taken from Silifke–Somaklı section.

In SE Anatolia, representing the northern margin of the Arabian Platform, the Çermik–Southern Korudağ section was measured and the Gerger-Çat section was investigated by a number of spot samples. The Gökiçi-1 well in the Korudağ section enabled sampling of the lower Silurian and the underlying Hirnantian glaciomarine sediments. The collection of graptolite specimens from Çermik–Southern Korudağ section and the Gerger-Çat section was donated for safekeeping by Hüseyin Kozlu to the Geological Museum of İstanbul University, and part of it is on display in the museum's exhibition. The results of Hilal Akın's PhD research (following her MRes work in Portsmouth) on graptolites from the Gökiçi-1 well have not yet been published.

Monod et al. (2003) documented an Upper Ordovician glaciomarine succession in southern Türkiye and used graptolite biostratigraphy to constrain precisely the age of glaciation and subsequent deglaciation. Pre-glacial marine strata locally contain “Arenigian” didymograptid graptolites, establishing a Lower Ordovician baseline, whereas the overlying glacial Halevikdere Formation is largely devoid of graptolites, reflecting environmentally stressed Hirnantian glaciomarine conditions and the global decline in graptolite diversity during the Late Ordovician ice age. Age control is provided by graptolite-rich black shales overlying the glacial deposits, which yield assemblages ranging from the Rhuddanian *Akidograptus ascensus* Biozone through Aeronian beds (including the *Demirastrites triangulatus, Pribylograptus leptotheca,* and *Lituigraptus convolutus* biozones). These demonstrate that deglaciation and marine flooding occurred at or immediately after the Ordovician–Silurian boundary. The abrupt reappearance and diversification of graptolites mark the restoration of stable pelagic conditions and confirm a Hirnantian age for the glacial episode. Correlation of these assemblages with coeval successions across North Africa, Arabia, and peri-Gondwanan Europe places southern Türkiye within the northern Gondwanan biogeographic province and highlights the central role of graptolites in correlating Late Ordovician glacial events.

Kozlu et al. (2012a) provided a comprehensive overview of the Silurian stratigraphy of the Taurides and the SE Anatolian Autochthon, emphasizing lithostratigraphy, depositional environments, and graptolite-based age control in a northern Gondwanan context. Following Hirnantian glaciation, a widespread early Silurian transgression led to the deposition of organic-rich black shales and lydites (“hot shales”) across southern Türkiye, with thickness and facies varying from the Eastern to Western Taurides and in SE Anatolia. These units, commonly rich in pyrite and graptolites, record open-marine, locally anoxic offshore conditions during the Llandovery and in places extend into the Wenlock. Thereafter, black shale deposition ceased at maximum sea level and was replaced by shallowing-upward shelf successions dominated by nodular “Orthoceras limestones,” shales, and tempestitic carbonates. Detailed measured sections, particularly at Değirmentaş–

Halevikdere, document a near-complete Silurian succession subdivided into several informal lithological units, with graptolite biostratigraphy providing the primary age constraints from the Rhuddanian through the Přídolí and into the Devonian transition. Regional correlations demonstrate broadly similar depositional evolution across the Taurides and SE Anatolia, despite significant lateral thickness variations in the black shale intervals, and highlight the importance of Silurian graptolite-bearing successions for palaeogeographic reconstruction and assessment of lower Silurian hydrocarbon source-rock potential. Kozlu et al. (2012b) established the stratigraphic position, internal architecture, and age of the lower Silurian "hot shales" in the Taurides and SE Anatolia through graptolite biostratigraphy. Measured sections from the Eastern, Central, and Western Taurides and from the northern margin of the Arabian Platform revealed that the Llandovery succession is largely complete and contains multiple black shale intervals resting transgressively on Hirnantian glaciomarine deposits. Graptolite assemblages constrain these black shales mainly to the Rhuddanian–Telychian interval, with lower Rhuddanian *Akidograptus ascensus* Biozone faunas directly overlying glacial sedimentary rocks in the Eastern Taurides, and successively younger Aeronian to Telychian assemblages (including *Cystograptus vesiculosus* through *Spirograptus guerichi* biozones) documented in several regions. Late Sheinwoodian–Homerian graptolites occur only locally. In SE Anatolia, thick black shale successions yield Rhuddanian to Aeronian graptolites, confirming the presence of the Ordovician–Silurian boundary interval, despite tectonic disturbance.

In the Pekmezli-4 section (Tanrıkulu and Loydell, 2025), graptolite assemblages, similarly to those in the Halevikdere section, begin in the *Akidograptus ascensus–Parakidograptus acuminatus* Biozone, indicating an early Rhuddanian age, and continue into the upper *Cystograptus vesiculosus* Biozone. Additional sparse assemblages suggest proximity to the Rhuddanian–Aeronian boundary, with taxa indicative of either the *Coronograptus cyphus* or *Demirastrites triangulatus* biozones. The section also yields limited but diagnostic middle Aeronian graptolites (e.g., from the *Pribylograptus leptotheca* or *Lituigraptus convolutus* biozones). Overall, the graptolite record here is more fragmentary and less continuous than in Halevikdere, but it confirms that both Rhuddanian and Aeronian strata are present and supports previous regional interpretations of graptolitic Silurian deposition.

In the Hırmanlı Yol-2 section (Tanrıkulu and Loydell, 2025), graptolites are restricted but highly informative, with all identified assemblages assigned to the lower Telychian *Spirograptus guerichi* Biozone. Despite this narrow stratigraphic range, the assemblages are notably diverse, comprising around 25 species, which is unusually high and indicative of deposition in an outer shelf environment. A distinctive feature of this section is the relative rarity of some typically common genera (e.g., *Torquigraptus*), alongside the presence of well-preserved forms, including delicate retiolitines facilitated by shale bleaching. Although it lacks the broader vertical range seen in the other sections, Hırmanlı Yol-2 provides a rich and taxonomically diverse snapshot of early Telychian graptolite faunas in the Central Taurides.

CONCLUSION

The review of graptolite research carried out in Türkiye over the past two decades demonstrates that Anatolian Lower Palaeozoic successions constitute a critical archive for understanding the palaeogeographic and tectonic evolution of peri-Gondwanan terranes. Graptolite biostratigraphy has proven indispensable for constraining the timing of Ordovician marine transgressions, documenting the effects of Late Ordovician glaciation, and resolving the complex architecture of Silurian basins developed across the İstanbul–Zonguldak Composite Terrane, the Taurides, and the SE Anatolian Autochthon.

Ordovician graptolite assemblages refine the chronology of early Palaeozoic sedimentation in northern and southern Türkiye and reveal faunal connections with both western peri-Gondwanan and Avalonian–Armorican realms, emphasizing the composite nature of Anatolian terranes. Silurian records—particularly the widespread development of Llandovery–Wenlock graptolitic black shales—capture major eustatic events and palaeoceanographic changes following Hirnantian deglaciation, whereas condensed sections and regional hiatuses reflect the superposition of global sea-level signals and local tectonic controls. The recognition of Thuringian-type facies successions in the Eastern Taurides further confirms close affinities with classical peri-Gondwanan domains and highlights the value of Anatolian sections for long-distance stratigraphic correlation.

Despite significant advances, important gaps remain, especially in poorly exposed or tectonically disrupted areas and in intervals with sparse fossil preservation. Future progress will depend on integrated approaches combining detailed graptolite taxonomy, high-resolution stratigraphy, sedimentology, and geochemical proxies. Such studies will not only refine regional correlations but also enhance broader reconstructions of early Palaeozoic palaeogeography, basin evolution, and resource potential along the former northern margin of Gondwana.

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REFERENCES

Akın, H., 2021. Graptolite biostratigraphy of the Silurian of the Diyarbakır Basin, Southeastern Turkey. Unpublished MRes Research Manuscript, University of Portsmouth, 15 pp.

Arpat E., Tütüncü K., Uysal S. and Göğer E., 1978. Cambrian Devonian successions in the Safranbolu area. Geological Society of Turkey, Report 32nd Annual Meeting: 67-68.

Bergström, S.M., Chen, X., Gutiérrez-Marco, J.C. and Dronov, A.V., 2009. The new chronostratigraphic classification of the Ordovician System and its relations to major regional series and stages and δ13C chemostratigraphy. Lethaia, 42: 97-107. https://doi.org/10.1111/j.1502-3931.2008.00136.x

Bilgiç T. (compiler), 2002. Geological map of Turkey. General Directorate of Mineral Research and Exploration (MTA), Ankara, scale 1:500,000, Sivas map sheet.

Boncheva I., Göncüoğlu M.C., Leslie S., Lakova I., Sachanski V., Saydam D.G., Gedik I., and Königshof P., 2009. New conodont and palynological data from the Lower Palaeozoic in Northern Çamdag, NW Anatolia, Turkey. Acta Geol. Pol., 59: 157-171.

Boncheva I., Sachanski V., Gedik I., Ozgul N., Göncüoğlu M.C., Okuyucu C., Saydam D.G., Lakova I. and Yanev, S., 2005. Devonian in the Kraishte and Istanbul Units in Bulgaria and Turkey: review and recent data. In: Devonian Land-Sea Interaction: Evolution of Ecosystems and Climate in the Devonian "DEVEC" IGCP-499, International Workshop "Depositional Environments of the Gondwanan and Laurasian Devonian", 26 September-3 October 2005 Turkey, Abstracts & Field Trip Guide Books. İstanbul University of Engineering, Department of Geological Engineering, p. 9-10.

Bouček, B., 1973. Lower Ordovician graptolites of Bohemia. Academia, Praha, 185 pp.

Bozkaya H., Yalçin H. and Göncüoğlu M.C., 2012a. Diagenetic and very low-grade metamorphic characteristics of the Paleozoic series of the İstanbul Terrane (NW Turkey). Swiss J. Geosci., 105: 183-201. https://doi.org/10.1007/s00015-012-0108-2

Bozkaya O., Yalçin H. and Göncüoğlu M.C., 2012b. Mineralogic evidences of a mid-Paleozoic tectonothermal event in the Zonguldak terrane, northwest Turkey: implications for the dynamics of some Gondwana-derived terranes during the closure of the Rheic Ocean. Can. J. Earth Sci., 49: 559-575. https://doi.org/10.1139/e11-076

Boztuğ D., 1992. Lithostratigraphic units and tectonics of the SW part of Daday-Devrekani Massif, W Pontides, Turkey. MTA Bulletin, 114: 1-20.

Cooper R.A. and Sadler P.M., 2012. The Ordovician Period. In: F.M. Gradstein, J.G. Ogg, M.D. Schmitz and G.M. Ogg (Eds.). The Geologic Time Scale 2012. Elsevier, Amsterdam, p. 489-523. https://doi.org/10.1016/B978-0-444-59425-9.00020-2

Dean W.T., Monod O., Rickards R.B., Demir O. and Bultynck P., 2000. Lower Palaeozoic stratigraphy and palaeontology, Karadere-Zirze area, Pontus Mountains, northern Turkey. Geol. Mag., 137: 555-582. https://doi.org/10.1017/S0016756800004635

Elicki O., Meischner T., Gürsu S., Ghienne J.-F., Masri A., Moumani K.A. and Demircan H., 2022. The Ordovician System in the Levant region (Middle East) and southern Turkey: review of depositional facies, fauna and stratigraphy. Geol. Soc. London, Spec. Publ., London, 533. https://doi.org/10.1144/SP533-2022-53

Gedik I. and Önalan M., 2001. New observations in the stratigraphy of the Palaeozoic of Camdag (Sakarya Province). İstanbul Üniv. Müh. Fak. Yerbilimleri Dergisi, 14: 61-76.

Gedik I., Pehlivan S., Duru M. and Timur E., 2005. 1/50.000 scaled geological map and explanations: Sheet Bursa G23b. MTA Bulletin, 17: 1-49.

Ghienne J.-F., Monod O., Kozlu H. and Dean W.T., 2010. Cambrian–Ordovician depositional sequences in the Middle East: a perspective from Turkey. Earth-Sci. Rev., 101 (3-4): 101-146. https://doi.org/10.1016/j.earscirev.2010.04.004

Goldman D., Sadler P.M. and Leslie S.A., 2020. The Ordovician Period. In: F. Gradstein, J.G. Ogg, M.D. Schmidt and G.M. Ogg (Eds.), The Geologic Time Scale. Elsevier, Amsterdam, 631-694. https://doi.org/10.1016/b978-0-12-824360-2.00020-6

Göncüoğlu M.C., 1997. Distribution of Lower Paleozoic Units in the Alpine Terranes of Turkey: paleogeographic constraints. In: M.C. Göncüoğlu and A.S. Derman (Eds.), Lower Paleozoic Evolution in northwest Gondwana, Turkish Assoc. Petrol. Geol., Spec. Publ. No. 3, Ankara, p. 13-24.

Göncüoğlu M.C., 2010. Introduction to the Geology of Turkey: Geodynamic evolution of the pre-Alpine and Alpine terranes. General Directorate of Mineral. Res. Explor., Monography Series, Nr 5, 1-66.

Göncüoğlu M.C., 2019. A review of the geology and geodynamic evolution of tectonic terranes in Turkey. In: F. Pirajno, T. Ünlü, C. Dönmez and M. Bahadır Şahin (Eds.). Modern Approaches in Solid Earth Sciences, Springer, p. 19-72. https://doi.org/10.1007/978-3-030-02950-0_2

Göncüoğlu M.C. and Sachanski V., 2003. First find of Upper Llandoveryan (Telychian) graptolites from the Camdag area, NW Turkey. C. R. Acad. Bulg. Sci., 56 (3): 37-42.

Göncüoğlu M.C. and Sachanski V., 2009. Late Telychian maximum highstand in NW Anatolian Istanbul-Zonguldak Terrane Assemblage. In: D.A.T. Harper and M. McCorry (Eds.). Absolutely final meeting of IGCP 503: Ordovician palaeogeography and palaeoclimate, Copenhagen 2009, Abstracts. Geological Museum, Natural History Museum of Denmark, University of Copenhagen, p. 27.

Göncüoğlu M.C., Boncheva I., Gedik I., Lakova I., Sachanski V., Saydam D.G., Okuyucu C., Özgül N. and Yanev S., 2005. Perigondwanan versus Laurussian origin of the NW Anatolian Paleozoic Terranes: a correlation of Mid-Paleozoic events in İstanbul and Zonguldak. Devonian Land-Sea Interaction: Evolution of Ecosystems and Climate in the Devonian. In: “DEVEC” IGCP-499, International Workshop “Depositional Environments of the Gondwanan and Laurasian

Devonian", 26 September-3 October 2005 Turkey, Abstracts & Field Trip Guide Books. İstanbul University of Engineering, Department of Geological Engineering, p. 11-12.

Göncüoğlu M.C., Dirik K. and Kozlu H., 1994. General characteristics of pre-alpine terranes in Turkey. 7th Field Meeting of IGCP-276, Thesaloniki, 25-27 Mai 1994, Abstracts, 4.

Göncüoğlu M.C., Dirik K. and Kozlu H., 1997. General Characteristics of pre-Alpine and Alpine Terranes in Turkey: Explanatory notes to the terrane map of Turkey. Annales Geologique de Pays Hellenique, 37, 515-536

Göncüoğlu M.C., Lakova I., Kozlu H. and Sachanski V., 2003. The Silurian of the Istanbul unit in the Çamdağ area, NW Turkey. In: G. Ortega and G.F. Aceñolaza (Eds.). Proceedings 7th IGC-FMSSS, INSUGEO, Serie Correlación Geológica, 18, p. 129-131.

Göncüoğlu M.C., Sachanski V., Gutiérrez-Marco J.C. and Okuyucu C., 2014a. Ordovician graptolites from the basal part of the Palaeozoic transgressive sequence in the Karadere area, Zonguldak Terrane, NW Turkey. Est. J. Earth Sci., 63 (4): 227-232. https://doi.org/10.3176/earth.2014.23

Göncüoğlu M.C., Sachanski V. and Kozlu H., 2014b. The lower Silurian "black shales" from SE Anatolia and the Taurides, Turkey. In: H. Bauert, O. Hints, T. Meidla and P. Männik (Eds.). Abstracts & Field Guide, 4th Annual Meeting of IGCP 591, The Early to Middle Paleozoic Revolution, Estonia, 10-19 June 2014; p. 34.

Göncüoğlu M.C., Sachanski V. and Kozlu H., 2015. Correlation and depositional features of the Lower Silurian successions in the Zonguldak and Eastern Tauride terranes, Turkey. In: Abstracts of 31st IAS Meeting of Sedimentology held in Krakow on 22nd–25th of June 2015. Kraków, Polish Geological Society, p. 209.

Göncüoğlu M.C. and Şahin N., 2012. Structural Units of the Eastern Taurides. In: M.C. Göncüoğlu and N. Bozdogan (Eds.). Paleozoic of Eastern Taurides, Guidebook. Turkish Assoc. Petrol. Geol., Spec. Publ. No. 7, Ankara, p. 16-21

Hamilton W.B., 1990. On terrane analysis. Philos. Trans. R. Soc. A, 331 (1620): 511-522. https://doi.org/10.1098/rsta.1990.0086

Howell D.G., 1994. Principles of terrane analysis: new applications for global tectonics (Vol. 8). Springer Science & Business Media, 246 pp.

Johnson M.E., 2006. Relationship of Silurian sea-level fluctuations to oceanic episodes and events. GFF, 128: 123-129. https://doi.org/10.1080/11035890601282115

Johnson M.E., 2010. Tracking Silurian eustasy: alignment of empirical evidence or pursuit of deductive reasoning? Palaeogeogr., Palaeoclimatol., Palaeoecol., 296: 276-284. https://doi.org/10.1016/j.palaeo.2009.11.024

Ketin İ., 1959. The orogenic evolution of Turkey. Bull. Min. Res. Explor., 53: 82-88.

Ketin, İ., 1966. Tectonic Units of Turkey. Bull. Min. Res. Explor., 66: 20-37.

Kozlu H. and Ghienne J.F., 2012. Ordovician. In: M.C. Göncüoğlu and N. Bozdogan (Eds.). Paleozoic of Northern Gondwana and its Petroleum Potential - A Field Workshop, Guidebook. Turkish Assoc. Petrol. Geol., Spec. Publ., 7: 42-60.

Kozlu H., Günay Y. and Sachanski V., 2002. Stratigraphy and graptolite biostratigraphy of the Lower Silurian succession in SE Anatolia and the Taurus Belt. Turkish Petroleum Corporation Exploration Group Report, Ankara.

Kozlu H., Sachanski V. and Göncüoğlu M.C., 2012a. Silurian. In: M.C. Göncüoğlu and N. Bozdogan (Eds.). Paleozoic of Northern Gondwana and its Petroleum Potentia A Field Workshop, Guidebook. Turkish Assoc. Petrol. Geol., Spec. Publ. No. 7, Ankara, p. 61-78.

Kozlu H., Sachanski V., Göncüoğlu M.C. and Günay Y., 2012b. Stratigraphy and graptolite ages of the lower Silurian "hot shale" from the Taurides and SE Anatolia, Turkey. In: M.N. Yalçın, H. Çorbacıoğlu, Ö. Aksu and N. Bozdoğan (Eds.). Paleozoic of Northern Gondwana and its Petroleum Potential A Field Workshop, Extended abstracts. Turkish Assoc. Petrol. Geol., Spec. Publ. No. 6, Ankara, p. 73-75.

Lakova I., Göncüoğlu M.C., Sachanski V., Boncheva I. and Sağlam D.G., 2006a. Silurian graptolite, conodont, and cryptospore biostratigraphy at Gülüç section, Zonguldak Terrane, NW Anatolia. In: CIMP Meeting, Praha 2006, Prague, Sept., p. 33-34.
Lakova I., Sachanski V. and Göncüoğlu M.C., 2006b. Earliest cryptospore record in NW Anatolia dated by graptolites and acritarchs, Lower Ordovician Bakacak Formation, Zonguldak Terrane, Turkey. In: Owen A. (Ed.). Programme, Abstracts & Field Excursion Guides, IGCP 503, Annual Meeting. Glasgow, Scotland. August, 30-September, 1, 2006, p. 30-31.
Lakova I., Sachanski V. and Göncüoğlu M.C., 2006c. Tremadoc graptolites, acritarchs and cryptospores from Karadere Section, Zonguldak Terrane, NW Turkey. In: CIMP Meeting, Praha 2006, Prague, Sept., p. 34-35.
Loydell D.K., 1998. Early Silurian sea-level changes. Geol. Mag., 135: 447-471. https://doi.org/10.1017/S0016756898008917
Maletz J., 2005. Early Middle Ordovician graptolite biostratigraphy of the Lovisefred and Albjära drill cores (Scania, southern Sweden). Palaeontology, 48: 763-780. https://doi.org/10.1111/j.1475-4983.2005.00482.x
Maletz J., 2011. The identity of the Ordovician (Darriwilian) graptolite *Fucoides dentatus* Brongniart, 1828. Palaeontology, 54: 851-865. https://doi.org/10.1111/j.1475-4983.2011.01068.x
Maletz J. and Ahlberg P., 2011. The Lerhamn drill core and its bearing for the graptolite biostratigraphy of the Ordovician Tøyen Shale in Scania, southern Sweden. Lethaia, 44: 350-368. https://doi.org/10.1111/j.1502-3931.2010.00246.x
Maletz J. and Ahlberg P., 2021. Upper Darriwilian (Middle Ordovician) graptolite biostratigraphy and correlation of the Krapperup drill core, Scania, Sweden. GFF, 143: 360-383. https://doi.org/10.1080/11035897.2021.1936156
Maletz J., Wang C.-S. and Wang X.-F., 2026. Graptolite biostratigraphy of the Dapingian GSSP and its global correlation. Palaeoworld, 35: 201028. https://doi.org/10.1016/j.palwor.2025.201028
Melchin M.J., Sadler P.M. and Cramer B.D., 2020. The Silurian Period. In: F.M. Gradstein, J.G. Ogg, M.D. Schmitz and G.M. Ogg (Eds.). The Geological Time Scale 2020. Elsevier, Oxford, p. 695-732. https://doi.org/10.1016/B978-0-12-824360-2.00021-8
Moix P., Beccaletto L., Kozur H.W., Hochard C., Rosselet F. and Stampfli G.M., 2008. A new classification of the Turkish terranes and sutures and its implication for the paleotectonic history of the region. Tectonophysics, 451 (1-4): 7-39. https://doi.org/10.1016/j.tecto.2007.11.044
Monod O., Kozlu H., Ghienne J.-F., Dean W.T., Günay Y., Le Hérissé A., Paris F. and Robardet M., 2003. Late Ordovician glaciation in southern Turkey. Terra Nova, 15 (4): 249-257. https://doi.org/10.1046/j.1365-3121.2003.00495.x
Murphy J.B., Nance R.D. and Wu L., 2023. The provenance of Avalonia and its tectonic implications: a critical reappraisal. In: A.J. Hynes and J.B. Murphy (Eds.). The Consummate Geoscientist: A Celebration of the Career of Maarten de Wit. Geol. Soc. London, Spec. Publ., London, 531: 207-247. https://doi.org/10.1144/SP531-2022-176
Okay A.I., 2008. Geology of Turkey: a synopsis. Anschnitt, 21: 19-42.
Okay A.I. and Tüysüz O., 1999. Tethyan sutures of northern Turkey. Geol. Soc. London, Spec. Publ., London, 156: 475-515. https://doi.org/10.1144/GSL.SP.1999.156.01.22
Özgül N. 1976. Some geological aspects of the Taurus orogenic belt. Geol. Bull. Turk., 19: 65-78
Özgül N., 2012. Stratigraphy and some structural features of the İstanbul Paleozoic. Turkish J. Earth Sci., 21 (6): 817-866. https://doi.org/10.3906/yer-1111-6
Papanikolaou D.I., 2021. Orogenic Model. In: D.I. Papanikolaou (Ed.). The Geology of Greece, Springer, p. 45-80. https://doi.org/10.1007/978-3-030-60731-9_4
Sachanski V. and Göncüoğlu M.C., 2009. Correlation of Early Silurian graptolitic shales in NW Anatolia and E European terranes. 2nd International Symposium on the Geology of the Black Sea Region, 5-9 October 2009, Congress Center of MTA, Ankara, Turkey, p. 174.
Sachanski V., Göncüoğlu M.C. and Gedik I., 2008. Wenlock (Silurin) graptolitic shales from the Kocaeli Peninsula (Derince-Izmit), NW Turkey. Acta Geol. Pol., 58 (4): 387-393.

Sachanski V., Göncüoğlu M.C. and Gedik I., 2010. Late Telychian (early Silurian) graptolitic shales and the maximum Silurian highstand in the NW Anatolian Palaeozoic terranes. Palaeogeogr., Palaeoclimatol., Palaeoecol., 291 (3-4): 419-428. https://doi.org/10.1016/j.palaeo.2010.03.011

Sachanski V., Göncüoğlu M.C., Gedik I. and Okuyucu C., 2007. The Silurian of the Çatak and Karadere areas of the Zonguldak Terrane, NW Anatolia. Geol. Balc., 36 (3-4): 103-110. https://doi.org/10.52321/GeolBalc.36.3-4.103

Sachanski V., Göncüoğlu M.C., Lakova I., Boncheva I. and Saydam Demiray G., 2012. Silurian Graptolite, Conodont and Cryptospore Biostratigraphy of the Gülüç Section in Eregli, Zonguldak Terrane, NW Anatolia, Turkey. Turkish J. Earth Sci., 21: 867-903. https://doi.org/10.3906/yer-1004-4

Sachanski V., Kozlu H. and Göncüoğlu M.C., 2015. Thuringian affinity of the Silurian–Lower Devonian succession from the Eastern Taurus, Turkey. Turkish J. Earth Sci., 24: 303-324. https://doi.org/10.3906/yer-1411-27

Sachanski V., Özgül N. and Arpat E., 2006. The graptolite species *Hunnegraptus copiosus* Lindholm, 1991 from the Lower Ordovician of Central Taurus, Turkey. In: Yanev, Y. (Ed.), Proceedings of the National Conference "Geosciences 2006", p. 49-52.

Schindler E., Haude R., Yalçın M.N., Brocke R., Nazik A., Zor E.Ş., Wehrmann A., Wilde V. 2025. First record of scyphocrinoids in Türkiye and recognition of the Silurian/Devonian boundary interval (Halevikdere Section, Eastern Taurides). Turkish J. Earth Sci., 34: 479-503. https://doi.org/10.55730/1300-0985.1971

Şenalp M. and Tetiker S., 2024. Sequence stratigraphy and hydrocarbon potential of the Paleozoic successions on the Arabian Platform and southeast Türkiye. Turkish J. Earth Sci., 33 (6): 592-624. https://doi.org/10.55730/1300-0985.1932

Şengör A.M.C. and Yılmaz Y., 1981. Tethyan evolution of Turkey: A plate tectonic approach. Tectonophysics, 75: 181-241. https://doi.org/10.1016/0040-1951(81)90275-4

Şengör A.M.C., Yılmaz Y. and Ketin I., 1982. Remnants of a pre-Late Jurassic ocean in northern Turkey: Fragments of Permian-Triassic Paleo-Tethys? Discussion and reply: Reply. Geol. Soc. Am. Bull., 93 (9): 932-936. https://doi.org/10.1130/0016-7606(1982)93<932:ROAPJO>2.0.CO;2

Şengör A.C., Lom N., Sunal G., Zabcı C. and Sancar T., 2019. The Phanerozoic palaeotectonics of Turkey. Part I: an inventory. Mediterr. Geosci. Rev., 1 (1): 91-161. https://doi.org/10.1007/s42990-019-00007-3

Şengör A.M.C., Altıner D., Zabcı C., Sunal G., Lom N. and Aylan E., 2025. Japan-like ribbon continent rifted from a Sumatra-like continental arc system: The Cimmerian Continent. Journal of Applied & Regional Geology / ZDGG, 176 (1): 1-29. https://doi.org/10.1127/zdgg/2025/0447

Štorch P. 2023. Graptolite biostratigraphy and biodiversity dynamics in the Silurian System of the Prague Synform (Barrandian area, Czech Republic). Bull. Geosci., 98 (1): 1-78. https://doi.org/10.3140/bull.geosci.1862

Tanrıkulu S. and Loydell D.K., 2025. Integrated bio- and chemostratigraphy of the Upper Ordovician and lower Silurian of the Central and Eastern Taurides, Türkiye. Bull. Geosci., 100 (4): 505-528. https://doi.org/10.3140/bull.geosci.1931

Tarhan N. (compiler), 2002. Geological map of Turkey. General Directorate of Mineral Research and Exploration (MTA), Ankara, scale 1:500,000, Erzurum map sheet.

Ulu Ü. (compiler), 2002. Geological map of Turkey. General Directorate of Mineral Research and Exploration (MTA), Ankara, scale 1:500,000, Adana map sheet.

Ustaömer P.A., Ustaömer T., Gerdes A. and Zulauf G., 2021. Detrital zircon ages from a Lower Ordovician quartzite of the Istanbul exotic terrane (NW Turkey): evidence for Amazonian affinity. Int. J. Earth Sci., 100 (1): 23-41. https://doi.org/10.1007/s00531-009-0498-1

Varol Ö.N., Demirel I.H., Rickards R.B. and Günay Y., 2006. Source rock characteristics and biostratigraphy of the Lower Silurian (Telychian) organic-rich shales at Akyaka, central Taurus region, Turkey. Mar. Pet. Geol., 23: 901-911. https://doi.org/10.1016/j.marpetgeo.2006.07.003

Yalçın M.N., Wehrmann A., Schindler E., Yılmaz I., Wilde V., Nazik A., Bozdoğan N., Özkan R., Kozlu H., Brocke R., 2012. Devonian. In: M.C. Göncüoğlu and N. Boz dogan (Eds.). Paleozoic of Northern Gondwana and its Petroleum Potentia A Field Workshop, Guidebook. Turkish Assoc. Petrol. Geol., Spec. Publ. No. 7, Ankara, p. 79-97.

Yanev S., Göncüoğlu M.C., Boncheva I. , Gedik I. , Lakova I., Maliakov Y., Özgül N., Sachanski V., Saglam G. and Timur E., 2004. Correlation of the Paleozoic terranes in Bulgaria and NW Turkey: preliminary results. In: 5th International Symposium on Eastern Mediterranean Geology, Thessaloniki, Greece, 14-20 April 2004, p. 215-219.

Yanev S., Göncüoğlu M.C., Gedik I., Lakova I., Boncheva I., Özgül N., Sachanski V., Timur E., Malyakov Y. and Saydam G., 2006. Stratigraphy, correlations and palaeogeography of Palaeozoic terranes of Bulgaria and NW Turkey: a review of recent data. Geol. Soc. London, Spec. Publ., London, 260: 51-67. https://doi.org/10.1144/GSL.SP.2006.260.01.04

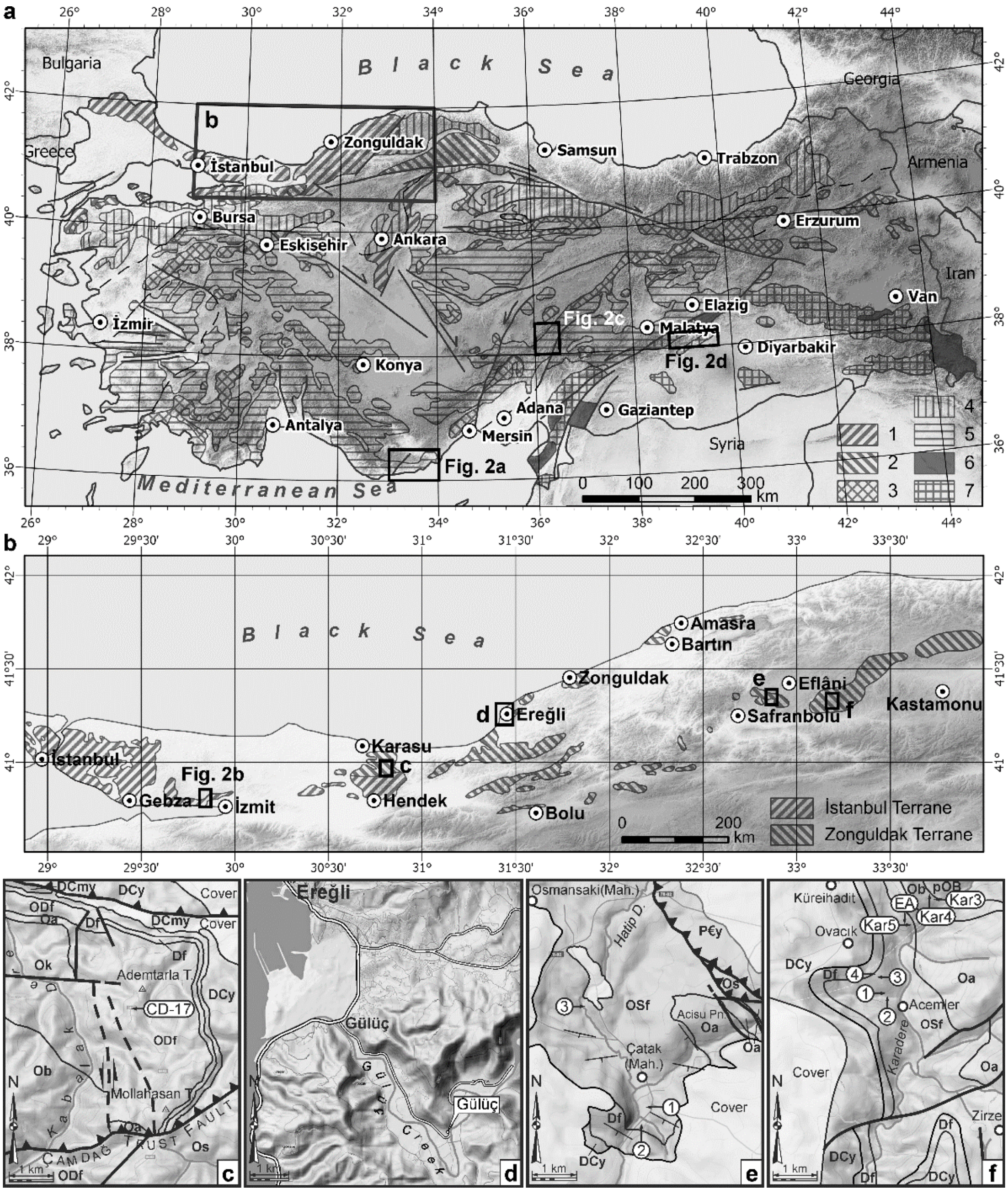

Fig. 1 - The locations of the sections in which graptolites have been found: a - Distribution of the main Alpine tectonic units of Türkiye (modified after Göncüoğlu, 2019) 1 - İstanbul-Zonguldak Composite Terrane, 2 - Intra-Pontide Ophiolite Belt, 3 - Izmir-Ankara-Erzincan Ophiolite Belt, 4 - Sakarya Composite Terrane, 5 - Tauride-Anatolide Unit, 6 - Amanos-Elazığ-Van Ophiolite Belt, 7 - SE Anatolian Belt. b - Distribution of Palaeozoic rocks in NW Anatolia (modified from Göncüoğlu in Sachanski et al., 2010) and the location of the studied sections: c - Northern Camdag (modified from Gedik and Önalan, 2001); d - Gülüç (modified from Sachanski et al., 2012); e - Çatak (modified from Gedik in Sachanski et al., 2007); f - Ovacık and Karadere (modified from Boztuğ, 1992 in Sachanski et al., 2010 and Göncüoğlu et al., 2014a), the sections studied by Dean et al., 2000 are mainly south of Zirze. Abbreviations: P€y - Yedigöller Fm.; pOB - pre-Ordovician Basement; Os - Soğuksu Fm.; Ob - Bakacak Fm.; Ok - Kurtköy Fm.; Oa - Aydos Fm.; ODf - Fındıklı Fm.; OSf - Karadere, Ketencikdere, and Fındıklı fms.; Df - Ferizli Fm.; DCy - Yılanlı Fm.; DCmy - Manastır Mb.; PTraky - Permotriassic continental conglomerates.

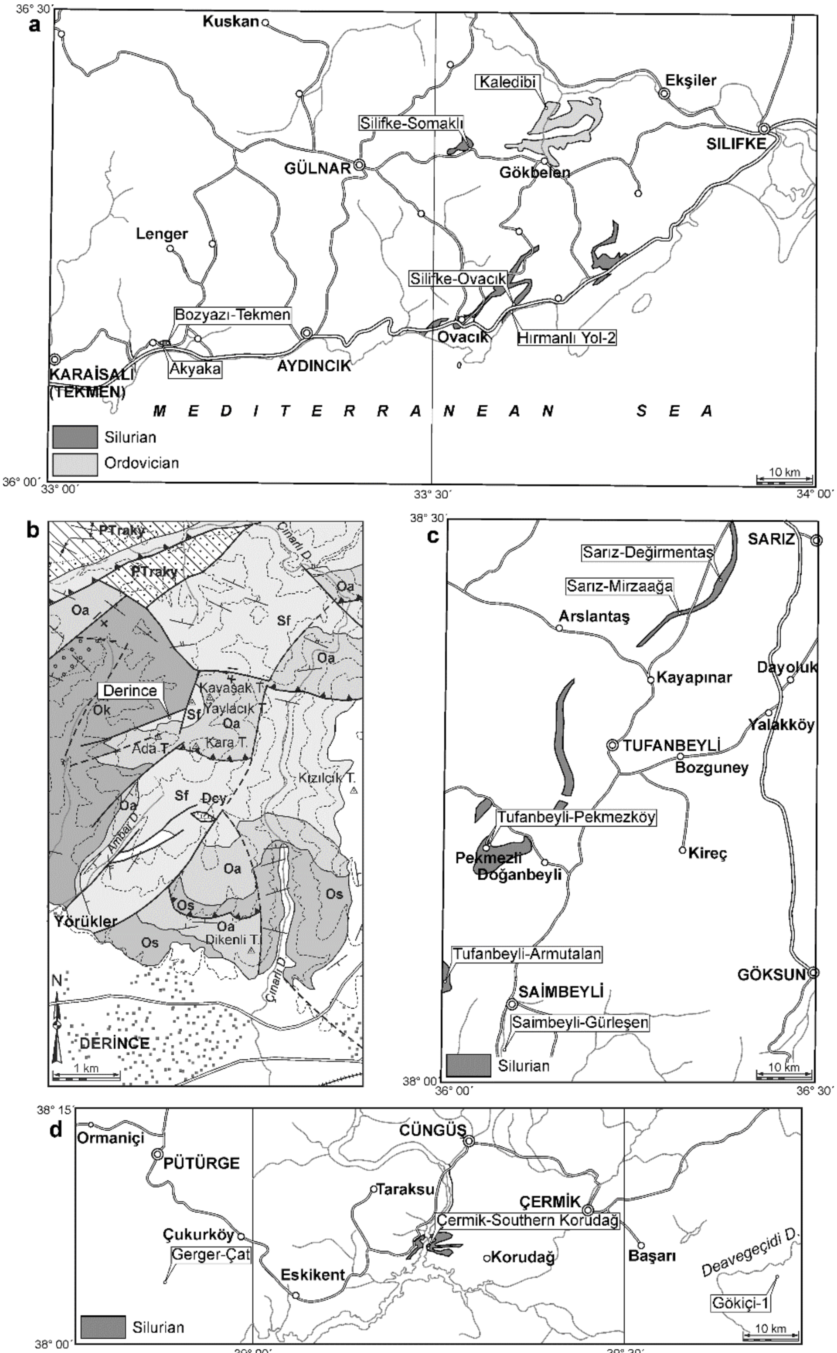

Fig. 2 - The location of the studied sections: a - in the Eastern Taurides (modified from Ulu, 2002); b - in the Kocaeli Peninsula, NW Türkiye (modified from Gedik et al., 2005 in Sachanski et al., 2008; for abbreviations see Fig. 1); c - in the Central Taurides (modified from Bilgiç, 2002); d - in SE Anatolia (modified from Bilgiç, 2002 and Tarhan, 2002).

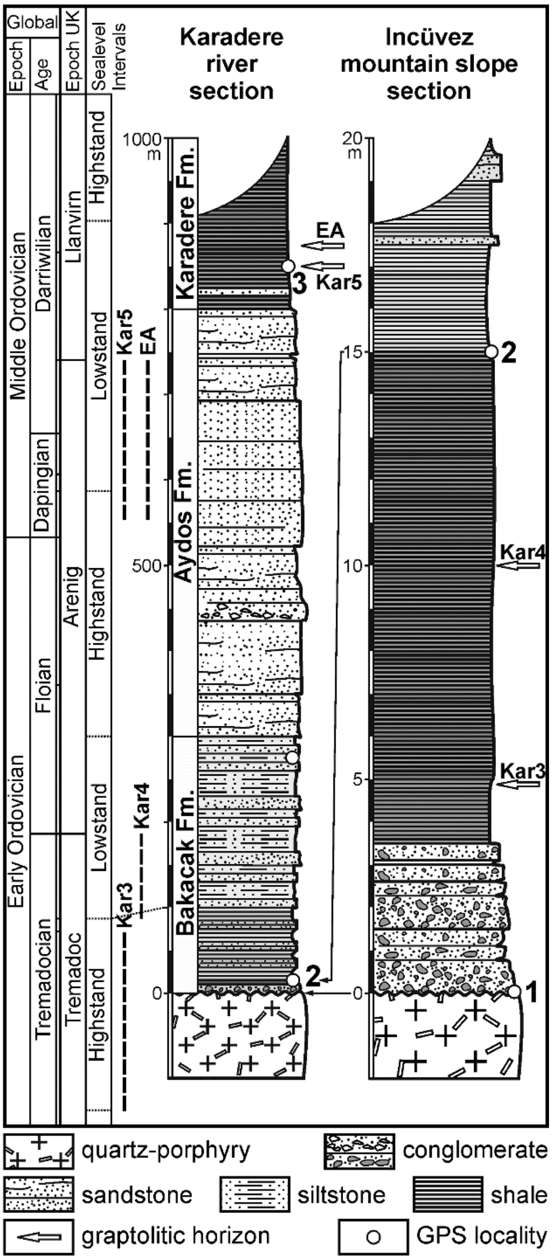

Fig. 3 - Ordovician litho- and chronostratigraphy of the studied sections and location of graptolite horizons Kar3, Kar4, Kar5 (Göncüoğlu et al., 2014a), and EA (Esen Arpat's sample, this study). The chronostratigraphy and sea-level intervals are by Cooper and Sadler (2012). The GPS localities of the starting and end points of the Incüves section are: point 1 (41°20′50.11″N; 33°04′43.98″E) and point 2 (41°20′34.98″N; 33°05′09.09″E). The sample Kar5 from point 3 (41°20′21.29″N; 33°04′30.27″E).

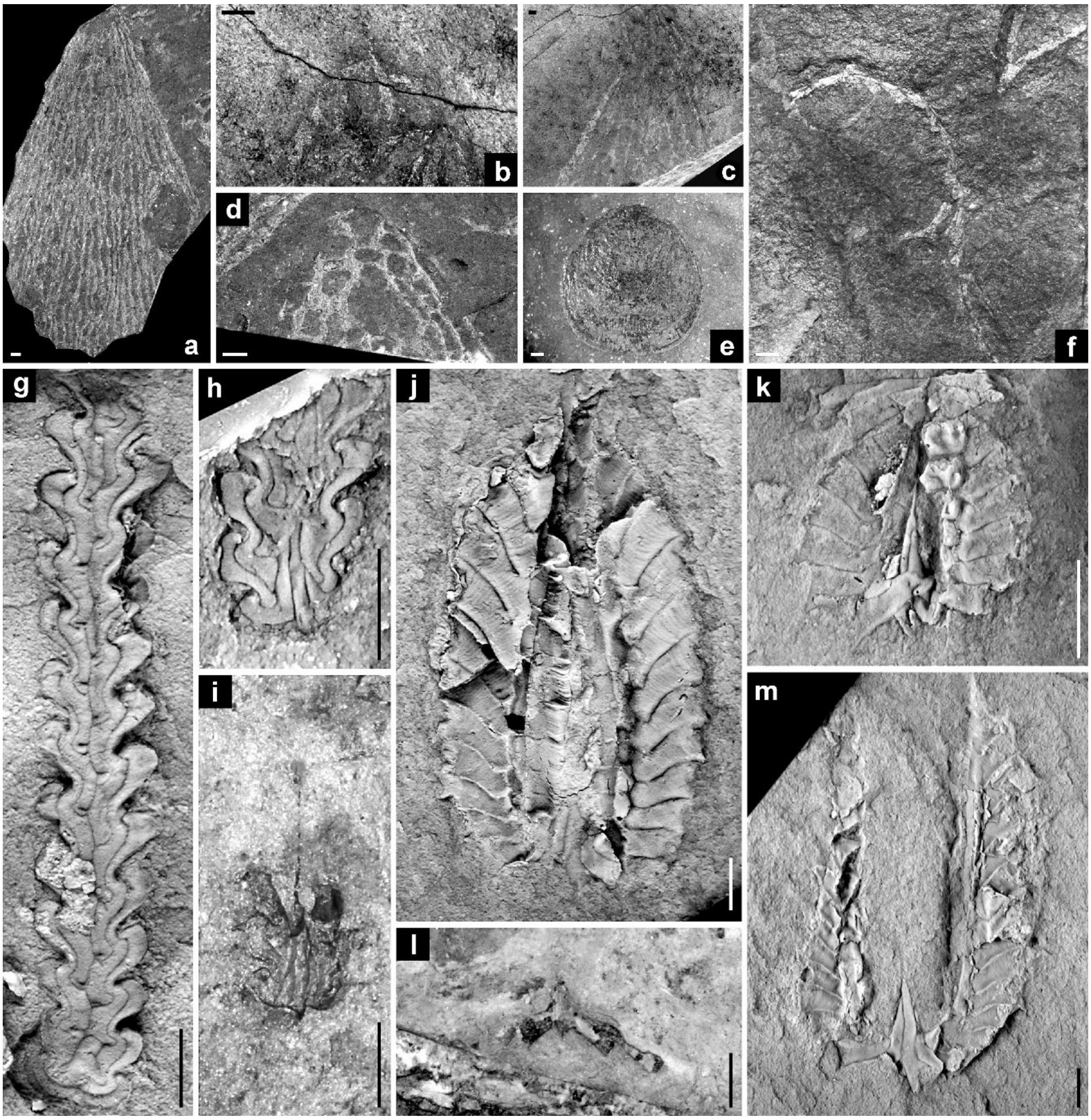

Fig. 4 - Ordovician fossils from the Karadere and Incüves sections: a-d - *Rhabdinopora flabelliformis* (Eichwald) ssp.: a - fragment of a somewhat compressed rhabdosome, b - detail of a young colony showing sicula, c - flattened rhabdosome in lateral view, d - proximal fragment flattened obliquely to axis (a, d - Kar3-1; b, c - Kar3-4); e - dorsal valve of linguliform brachiopod (Kar4-b1). f - *Paradelograptus* cf. *antiquus* (T.S. Hall), incomplete rhabdosome with reclined stipes of first-order and one second-order dichotomy (Kar4-2); g - *Levisograptus austrodentatus* (Harris & Keble), latex cast of a pyritized rhabdosome in reverse view showing pattern U astogeny (Kar5-1); h, i - *Levisograptus sinicus* (Mu & Lee), latex cast of a pyritized proximal region in obverse view (Kar5-1B/3) and counterpart of a flattened immature colony in obverse view, with small nematularium and spiny thecal apertures (Kar5-1B,); j, k - *Tetragraptus cor* (Strandmark), latex casts of two pyritized specimens showing 1-2 stipe preservation in obverse view (Kar5-10, Kar5-4); l - flattened proximal end of declined didymograptid (Kar5-15); m - *Tetragraptus bigsbyi* (J. Hall), latex cast of a pyritized specimen showing 1-2 preservation (Kar5-5/5). All scale bars represent 1 mm.

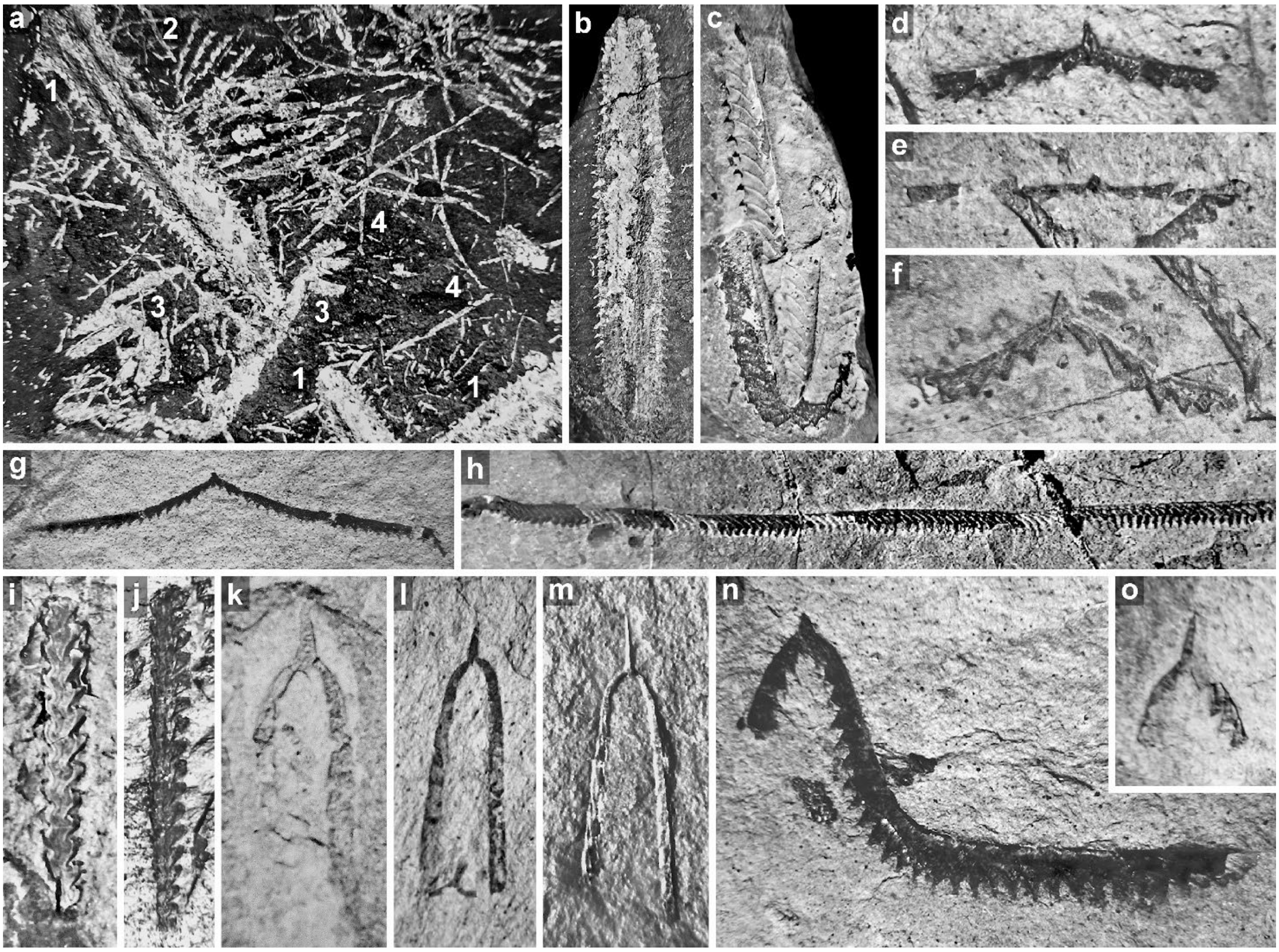

Fig. 5 - Selection of Middle Ordovician graptolites collected by E. Arpat in the 1960s from the Karadere–İncüvez locality and currently of unknown repository. These original photographs, without scale, show a Dapingian assemblage in a - with 1 - *Pseudophyllograptus angustifolius* cf. *elongatus*, 2 - *Pendeograptus*? sp., 3 - *Tetragraptus* cf. *reclinatus* and 4 - *Azygograptus* sp.; b - *Pseudophyllograptus angustifolius* cf. *elongatus* (Bulman); c - *Tetragraptus* cf. *reclinatus* Elles & Wood; d - *Expansograptus* sp.; e - *Xiphograptus*? cf. *lofuensis* (Lee); f, g - *Xiphograptus*? cf. *robustus* (Ekström); h - *Expansograptus* cf. *hirundo* (Salter); i - *Levisograptus* cf. *sinicus* (Mu & Lee); j - unidentified biserial (*Undulograptus*?); k, l, m - *Aulograptus climacograptoides* (Bulman); n - *Corymbograptus* cf. *retroflexus* (Perner); o - *Jenkinsograptus*? sp.

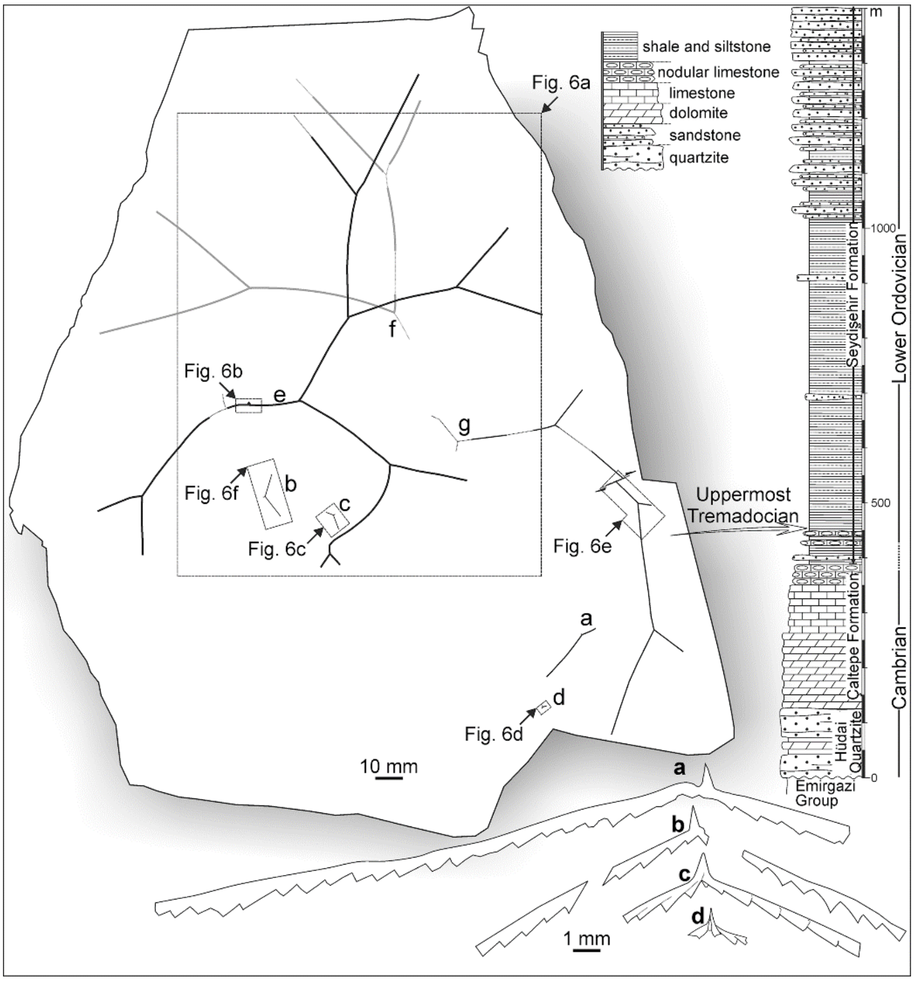

Fig. 6 - Lower Palaeozoic sequence in the Kaledibi section and the position of the studied sample TS-85-1 with *Hunnegraptus copiosus* Lindholm: a-d - immature specimens showing the long first-order stipes; e-g - views of a multiramous mature specimen. The dotted lines show the areas depicted in Fig. 7.

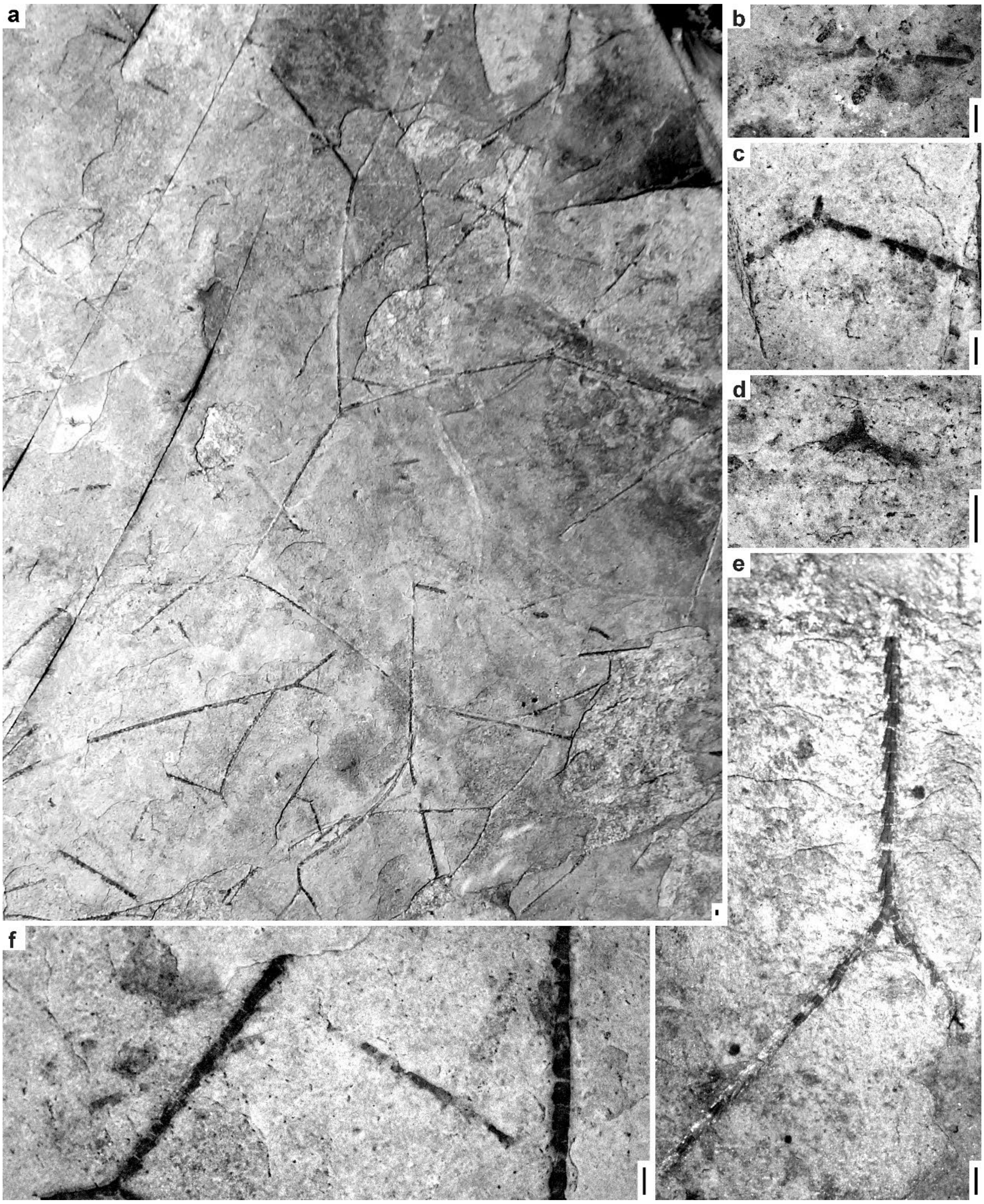

Fig. 7 - *Hunnegraptus copiosus* Lindholm: a - slab showing some multiramous mature specimens, mostly fragmentary; b - the sicula of a multiramous mature specimen; c, d, and f - early two-stiped proximal colonies; e - a stipe fragment in profile view. All scale bars represent 1 mm.

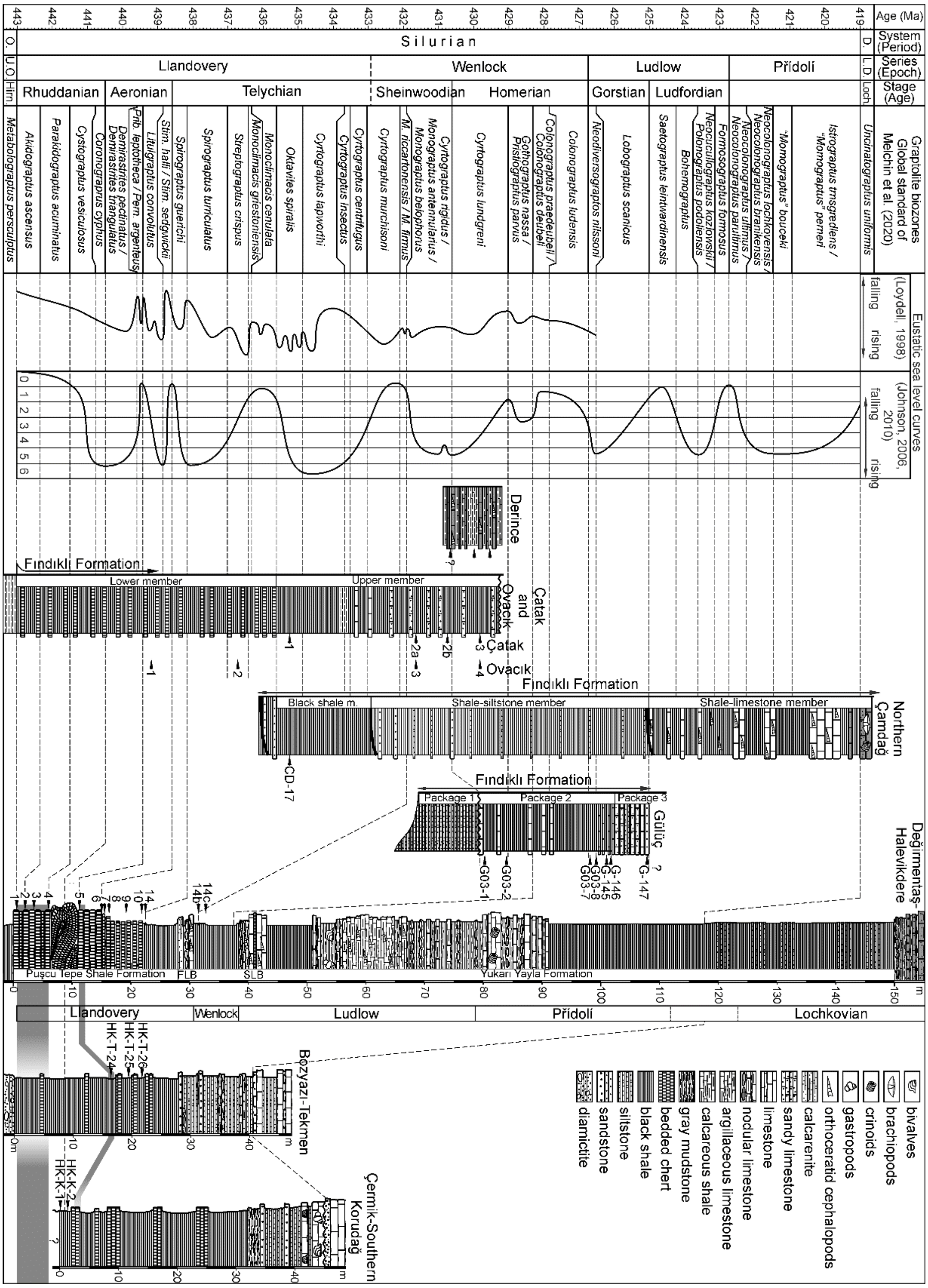

Fig. 8 - The Silurian lithological logs and levels with the graptolites, and biostratigraphic correlation of the sections: Derince (İstanbul Terrane); Çatak, Ovacik, Northern Çamdağ, Gülüç (Zonguldak Terrane); Değirmentaş-Halevikdere (Eastern Taurides); Bozyazı-Tekmen (Central Taurides); Çermik-Southern Korudağ (SE Anatolia, representing the northern margin of the Arabian Platform).

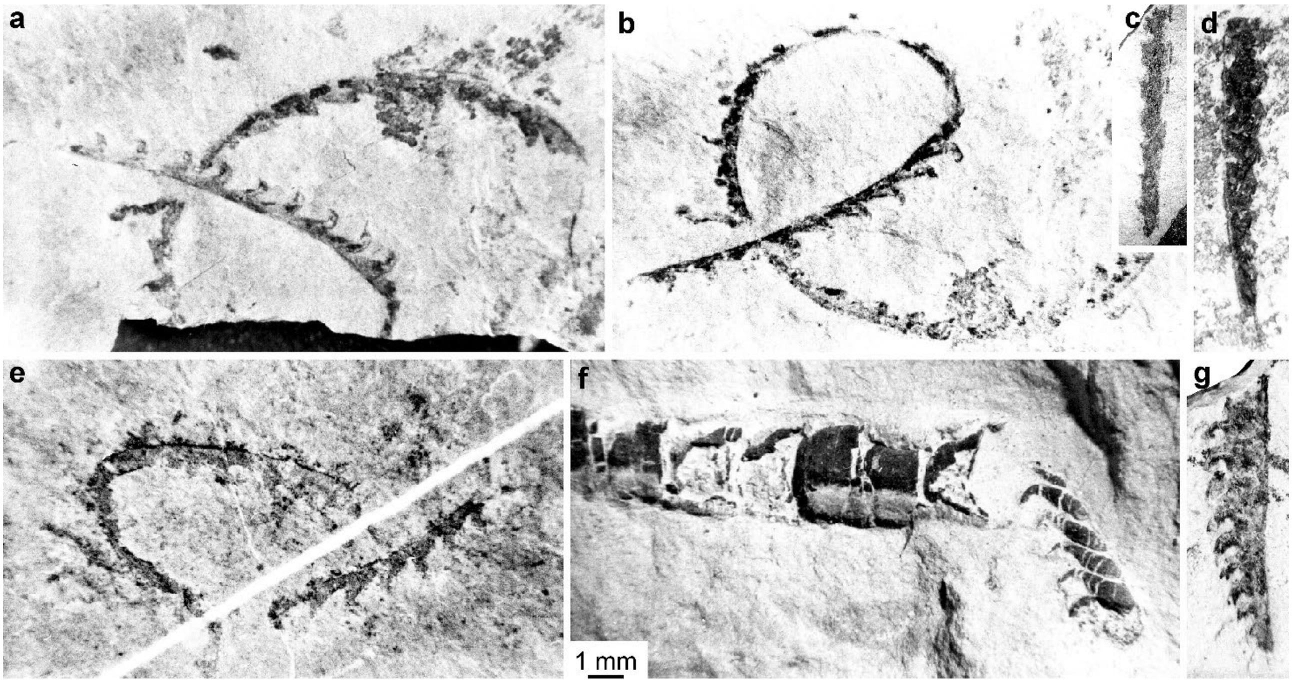

Fig. 9 - Graptolites from Derince–İzmit area: a, b, e - *Cyrtograptus*. cf. *lundgreni*, specimens Der 1-3; c - *Monoclimacis flumendosae* (Gortani), specimen Der 12; d - *Pristiograptus pseudodubius* (Bouček), specimen Der 2; f - cephalopod and *Monograptus flemingii* (Salter), specimen Der 11; g - *Monograptus flemingii* (Salter), specimen Der 9.

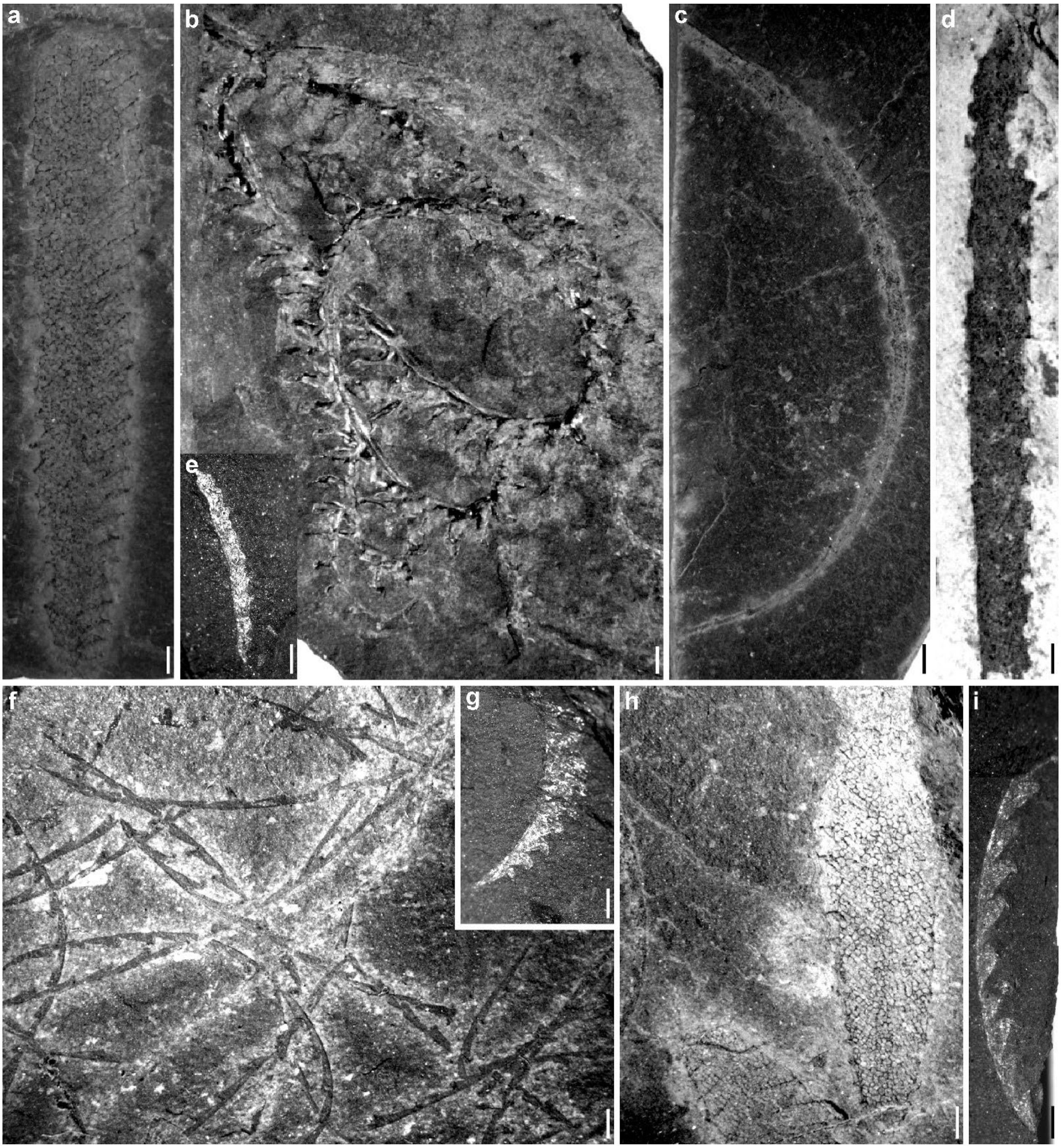

Fig. 10 - Graptolites from Northern Camdağ area: a - *Retiolites genitzianus* (Barrande), specimen CD-17.03.7; b - *Oktavites spiralis* (Geinitz), specimen CD-17.03.12; c - *Streptograptus nodifer* (Törnquist), specimen CD-17.03.10; d - *Monoclimacis* vomerina (Nicholson), specimen CD-17.03.19; e - *Pristiograptus* sp., specimen CD-17.03.13; f - *Barrandeograptus pulchellus* (Tullberg), CD-17.03.3'; g - *Stimulograptus vesiculosus* (Perner), specimen CD-17.03.2'; h - *Retiolites genitzianus* (Barrande), specimen CD-17.03.6; I - *Monograptus curvus* Manck, CD-17.03.22. All scale bars represent 1 mm.

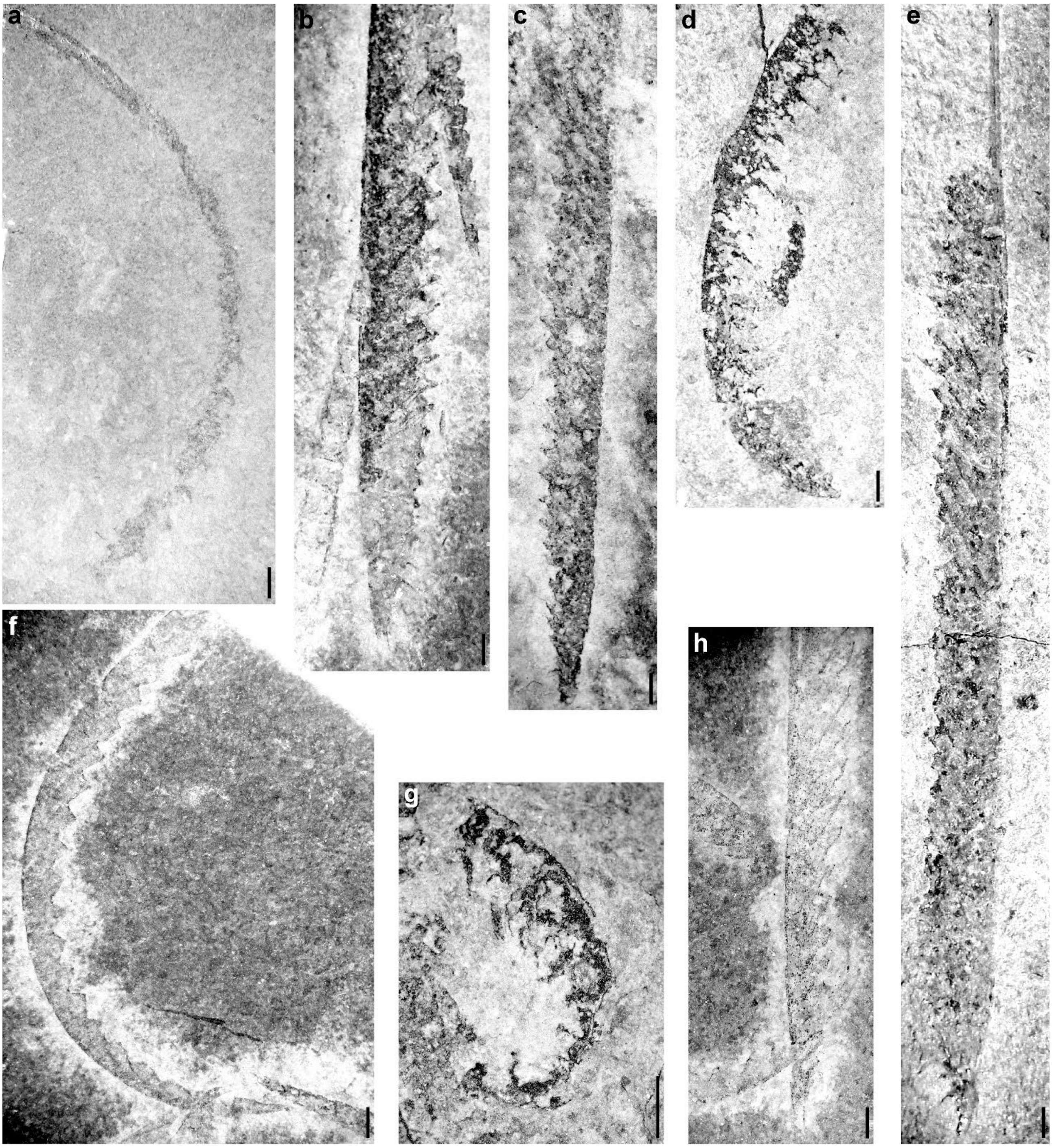

Fig. 11 - Graptolites from Ereğli area (Gülüç section): a - *Cyrtograptus* sp., sample G03-2, *lundgreni* Biozone; b, e - *Saetograptus chimaera semispinosus* (Elles & Wood), sample G03-8, *nilssoni* Biozone; c - *Colonograptus colonus* (Barrande), sample G03-7, *nilssoni* Biozone; d, g - *Testograptus testis* (Barrande), sample G03-1, *lundgreni* Biozone; f - *Bohemograptus bohemicus* (Barrande), sample G03-8, *nilssoni* Biozone; h - *Pristiograptus* ex. gr. *dubius* and *Bohemograptus bohemicus* (Barrande), sample G-145, *scanicus* Biozone. All scale bars represent 1 mm.

Fig. 12 - Graptolites from Ereğli area (Gülüç section): a, d - *Monograptus flemingii* (Salter), sample G03-2, *lundgreni* Biozone; b - *Lobograptus scanicus* (Tullberg), sample G-146, *scanicus* Biozone; c - *Lobograptus progenitor* Urbanek, sample G03-7, *nilssoni* Biozone; e - *Pristiograptus dubius pseudodubius* (Bouček), sample G03-1, *lundgreni* Biozone; f - *Eisenackograptus eisenacki* (Obut & Sobolevskaya), sample G03-1, *lundgreni* Biozone; g - *Lobograptus scanicus* (Tullberg), sample G-145, *scanicus* Biozone; h, i - *Saetograptus chimaera semispinosus* (Elles & Wood), sample G03-8, *nilssoni* Biozone; j, k - *Saetograptus chimaera chimaera* (Barrande, 1850); sample G-147, *scanicus* Biozone; l - *Gothograptus*? sp., sample G03-1, *lundgreni* Biozone. All scale bars represent 1 mm.

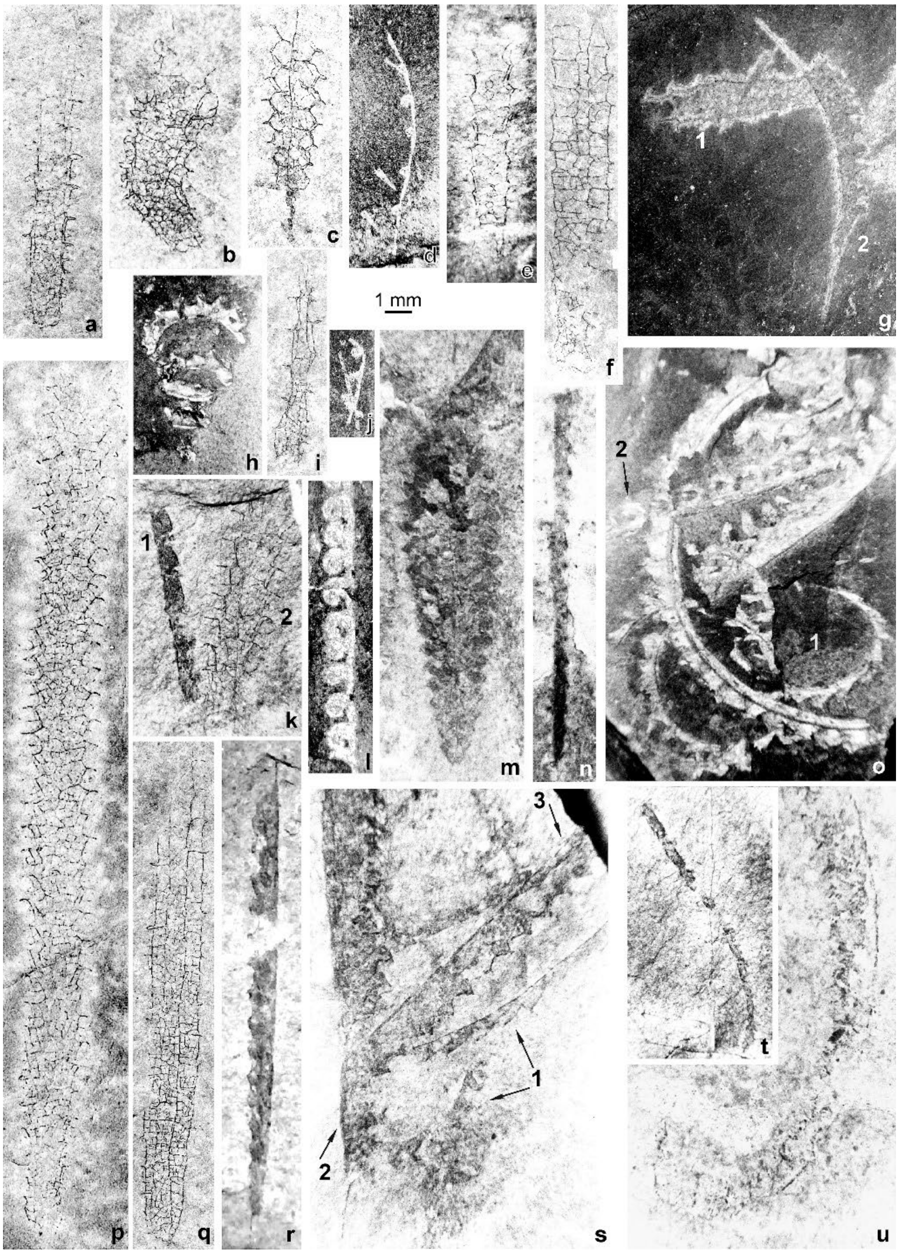

Fig. 13 - Graptolites from Çatak and Karadere (Ovacık) areas: a - *Sokolovograptus zawadensis* Kozłowska-Dawidziuk, sample Ds04-1-02.1, level Ovacık 3; b - *Sokolovograptus diffusus* Kozłowska-Dawidziuk, Ds04-1-02.9, Ovacık 3; c - *Pseudoplectograptus simplex* Kozłowska-Dawidziuk, Ds04-1-02.8, Ovacık 3; d - *Streptograptus crispus* (Lapworth), Ds04-2-07, Ovacık 3;

e - *Sokolovograptus telleri* Kozłowska-Dawidziuk, As04-8, Çatak 2a; f - *Sokolovograptus parens* Obut, Zaslavskaya, Ds04-1-02.7, Ovacık 3; g - with 1 - *Sokolovograptus telleri* Kozłowska-Dawidziuk, As04-2, Çatak 2a; 2 - *Monograptus belophorus* (Meneghini), As04-2, Çatak 2a; h - *Spirograptus turriculatus* (Barrande), Ds04-2-04, Ovacık 3; i - *Sokolovograptus zawadensis* Kozłowska-Dawidziuk, Ds04-1-02.2, Ovacık 3; j - *Streptograptus crispus* (Lapworth), Ds04-2-08, Ovacık 3; k - with 1 - *Sokolovograptus textor* (Bouček, Münch), Ds04-1-01, Ovacık 3; 2 - *Monograptus antennularius* (Meneghini), Ds04-1-01, Ovacık 3; l - *Streptograptus crispus* (Lapworth) distal part, Ds04-2-11, Ovacık 2; m - *Parapetalolithus meridionalis* (Legrand), Ds04-2-01, Ovacık 2; n - *Streptograptus storchi* Loydell, Ds04-2-03, Ovacık 2; o - with 1 - *Toerquigraptus australis* Štorch, Ds04-2-02, Ovacık 2; 2 - *Monograptus marri* Perner, Ds04-2-02, Ovacık 2; p - *Sokolovograptus textor* (Bouček, Münch), Ds04-1-03, Ovacık 3; q - *Sokolovograptus parens* Obut, Zaslavskaya, Ds04-1-02.3, Ovacık 3; r - *Pristiograptus pseudodubius* (Bouček), 06-39, Ovacık 4; s - 1 - *Cyrtograptus perneri* Bouček, As04-5, Çatak 2b; 2 - *Monograptus flemingii* (Salter), As04-5, Çatak 2b; 3 - *Pristigraptus dubius* (Suess), As04-5, Çatak 2b; t - *Monograptus antennularius* (Meneghini), Ds04-1-01, Ovacık 3; u - *Testograptus testis* (Barrande), As30.2, Çatak 3.

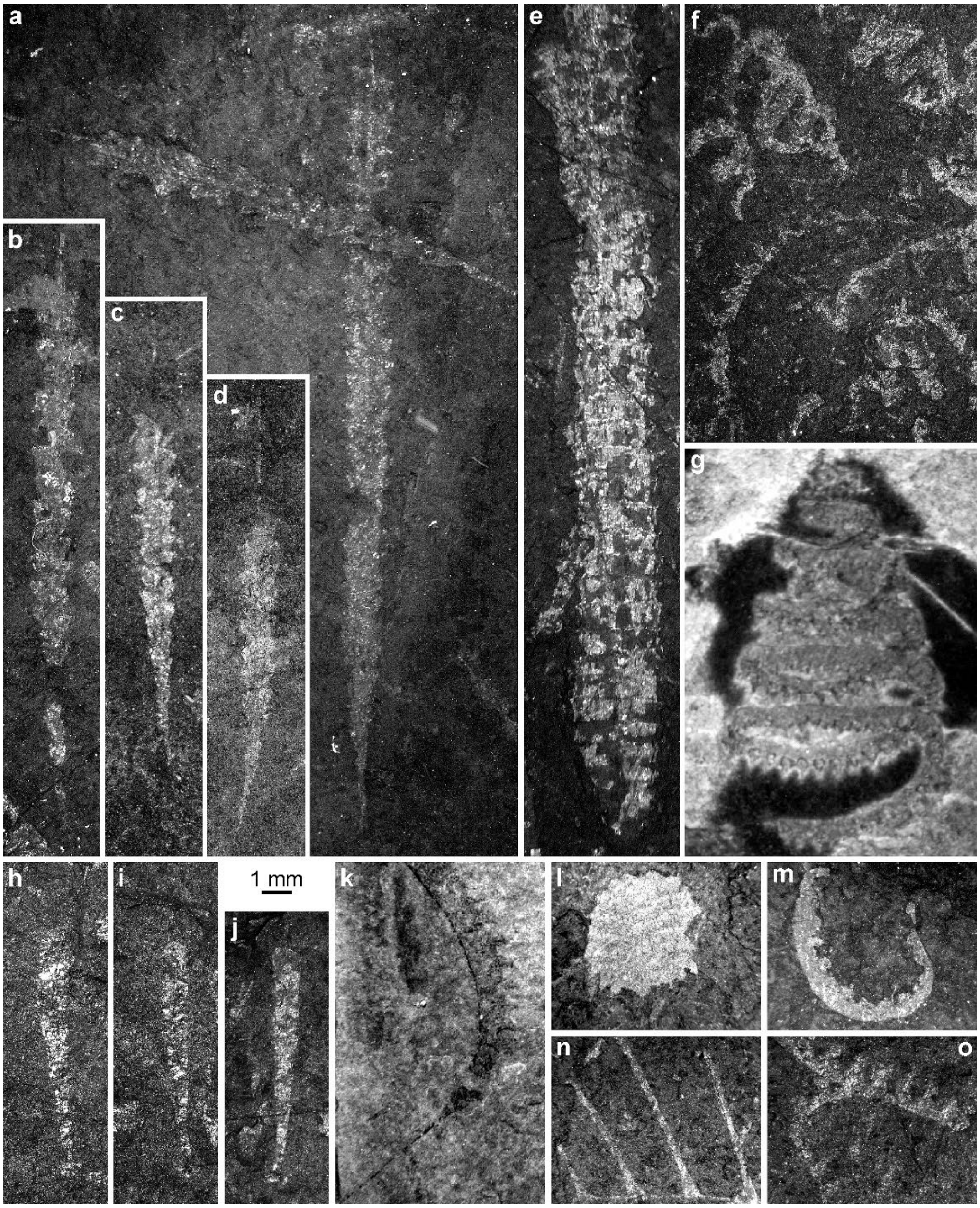

Fig. 14 - Graptolites from Değirmentaş-Halevikdere section: a, b, c, d - *Parakidograptus acuminatus* (Nicholson), specimen 2.1, level 2; e - *Cystograptus vesiculosus* (Nicholson), specimen 4.2, level 4; f - *Spirograptus guerichi* Loydell, Štorch & Melchin with *Torquigraptus planus* (Barrande) in the lower left corner of the picture, specimen 10.1, level 10; g - *Spirograptus turriculatus* Barrande, specimen 19.1, level 14; h, i, j - *Akidograptus ascensus* Davies, h and j specimen 1.2, j specimen 1.3, level 1; k - *Monograptus belophorus* (Meneghini), specimen 14b.6, level 14b; l - *Parapetalolithus ovatus* (Barrande), specimen HK-D-16e, level 9; m - *Pseudostreptograptus williamsi* Loydell (*Streptograptus plumosus* (Baily) in Sachanski et al., 2015), specimen HK-D-16f, level 9; n - *Rastrites linnaei* Barrande, specimen HK-D-16b, level 9; o - *Torquigraptus decipiens* (Tornquist), specimen HK-D-12a, level 5.

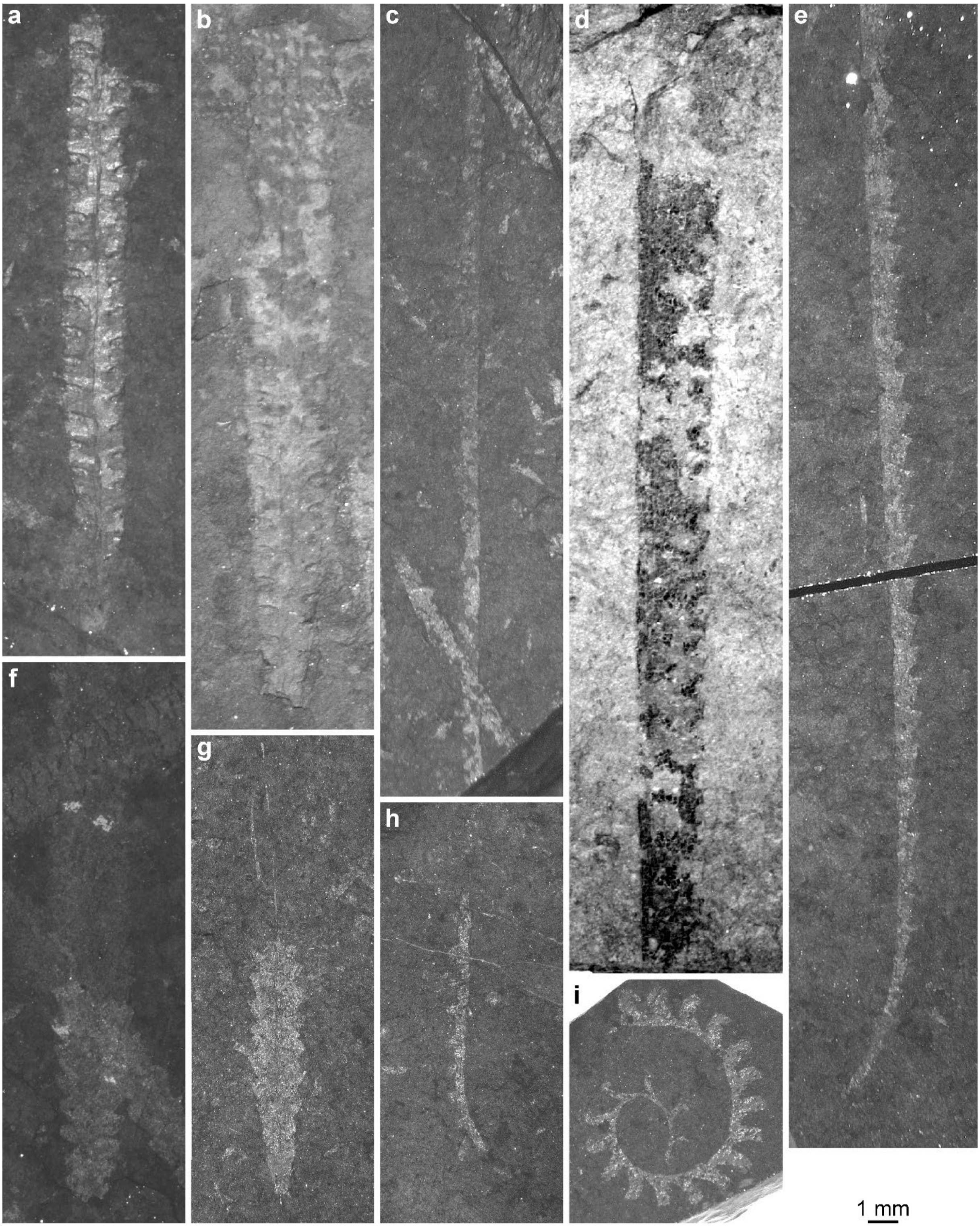

Fig. 15 - Graptolites from Değirmentaş-Halevikdere section: a - *Normalograptus normalis* (Lapworth), specimen 14.6, level 2; b - *Normalograptus medius* (Tornquist), specimen 3.1, level 3; c - *Atavograptus atavus* (Perner), specimen 4.2, level 4; d - *Monoclimacis flumendosae* (Gortani), specimen 14b.5, level 14b; e - *Pristiograptus renaudi* (Philippot), specimen 6.1, level 6; f - *Neodiplograptus lanceolatus* Štorch & Serpagli, specimen 14d.2, level 1; g - *Parapetalolithus elongatus* (Bouček & Přibyl), specimen 8.1, level 8; h - *Stimulograptus halli/sedgwickii*, specimen 7.3, level 7; i - *Oktavites contortus* (Perner), specimen 7.1, level 7.