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The Silurian of the Çatak and Karadere areas of the Zonguldak Terrane, NW Anatolia

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В. Сачански, М. Чемал Гьончоолу, И. Гедик, Ч. Окуючу – Силур районов Чатак и Карадере (террейн Зонгулдак) – Северо-Западная Анатолия. Проведено исследование силура в новоустановленных разрезах Чатак и Овачык (террейн Зонгулдак), обнаженнх к юго-западу от районов Эфлани и Шафранболу-Карадере. Разрезы принадлежат к свите Фындыклы, которая представлена преимущественно черными силициевыми аргиллитами и лидитами (в нижних отделах), черными аргиллитами и песчанистыми известняками (в средних отделах) и глинами с печанистыми известняками и известковыми алевролитами (в верхних отделах). Снизу вверх по разрезу Чатак установлено четыре интервала с граптолитами. Они принадлежат к следующим биозонам: верхняя *M. riccartonensis – M. belophorus*; верхняя *Cyrt. rigidus – Cyrt. perneri* и *Cyrt. lundgreni*. В разрезе Овачык граптолиты принадлежат к биозонам: *L. convolutus*, к верхней *Str. crispus – Sp. turriculatus*, *O. spiralis* и к верхней *M. riccartonensis – M. belophorus*.

Наличные данные показывают, что, во первых, исследованные последовательности пород находятся в интервале средний Аэрониан – ранний Гомериан. Из новых находок проистекает и второй важный вывод, а именно, что силур района Чатак является типичным для террейна Зонгулдак. Более того, ясен и третий вывод о том, что породы верхнесилурийской последовательности были полностью уничтожены эрозией во время среднедевонских событий.

Abstract. Silurian rocks in the newly discovered Catak and Ovacık sections of the Zonguldak Terrane to the SE of Eflâni and Safranbolu-Karadere areas, respectively, were studied by means of graptolites. They are included in Fındıklı Formation, 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. From bottom to the top four intervals with graptolites belonging to Upper *M. riccartonensis – M. belophorus*, Upper *Cyrt. rigidus – Cyrt. perneri* and *Cyrt. lundgreni* Biozones, respectively, were recognized in the Catak section. In the Ovacık section, the identified graptolites belong to the *L. convolutus,* Upper *Str. crispus-Sp. turriculatus, O. spiralis* and Upper *M. riccartonensis – M. belophorus* Biozones.

The available data indicate that the studies succession includes an interval from mid Aeronian to early Homerian. Another important implication of the new findings is that the Silurian in the Catak area is typical for the Zonguldak Terrane. Moreover, it is obvious that the Upper Silurian succession was completely eroded in this terrane during the Mid Devonian event.

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Key words: Silurian, graptolite, stratigraphy, NW Turkey.

Introduction

More or less continuous Paleozoic successions along the Black Sea coast in NW Anatolia belong to the Istanbul and Zonguldak terranes (Fig. 1), which are considered as Gondwana-derived micro-continents (e.g. Göncüoğlu, 1997; 2001; Göncüoglu et al., 1997; Yanev et al., 2006). They are assumed to be rifted of the northwestern Gondwanan margin in the Early Paleozoic and drifted across the Rheic Ocean during the Mid Paleozoic and successively accreted to Laurussia along the Eastern European Suture of the Variscan Orogenic Belt (Göncüoğlu, 2001).

In both terranes the Silurian rocks are well-developed but vary considerably in regard to their lithostratigraphy (e.g. Göncüoglu, Kozur, 1998; 1999). In the West, in Istanbul Terrane, the Silurian succession comprises, from bottom to the top, arkosic sandstones, chamositic sandstones and a thick package of reef limestones. The transitional rocks are dated as Late Llandovery, whereas the deposition of the overlying shallow marine limestones lasted until the end of Silurian (Haas, 1968; Kaya, 1978; Önalan, 1981; Gedik et al., 2003).

In the East, in the Zonguldak Terrane, a completely different Silurian succession is encountered already in Izmit area and can be followed towards East (Fig. 1) in the Çamdağ (Gedik, Önalan, 2001; Kozlu et al., 2002; Göncüoglu, Sachanski, 2003; Göncüoglu et al., 2003; Lakova, Göncüoğlu, 2005), Ereğli-Gülüc and Safranbolu-Karadere areas (Arpat et al., 1978; Dean et al., 1997; 2000). In these out-

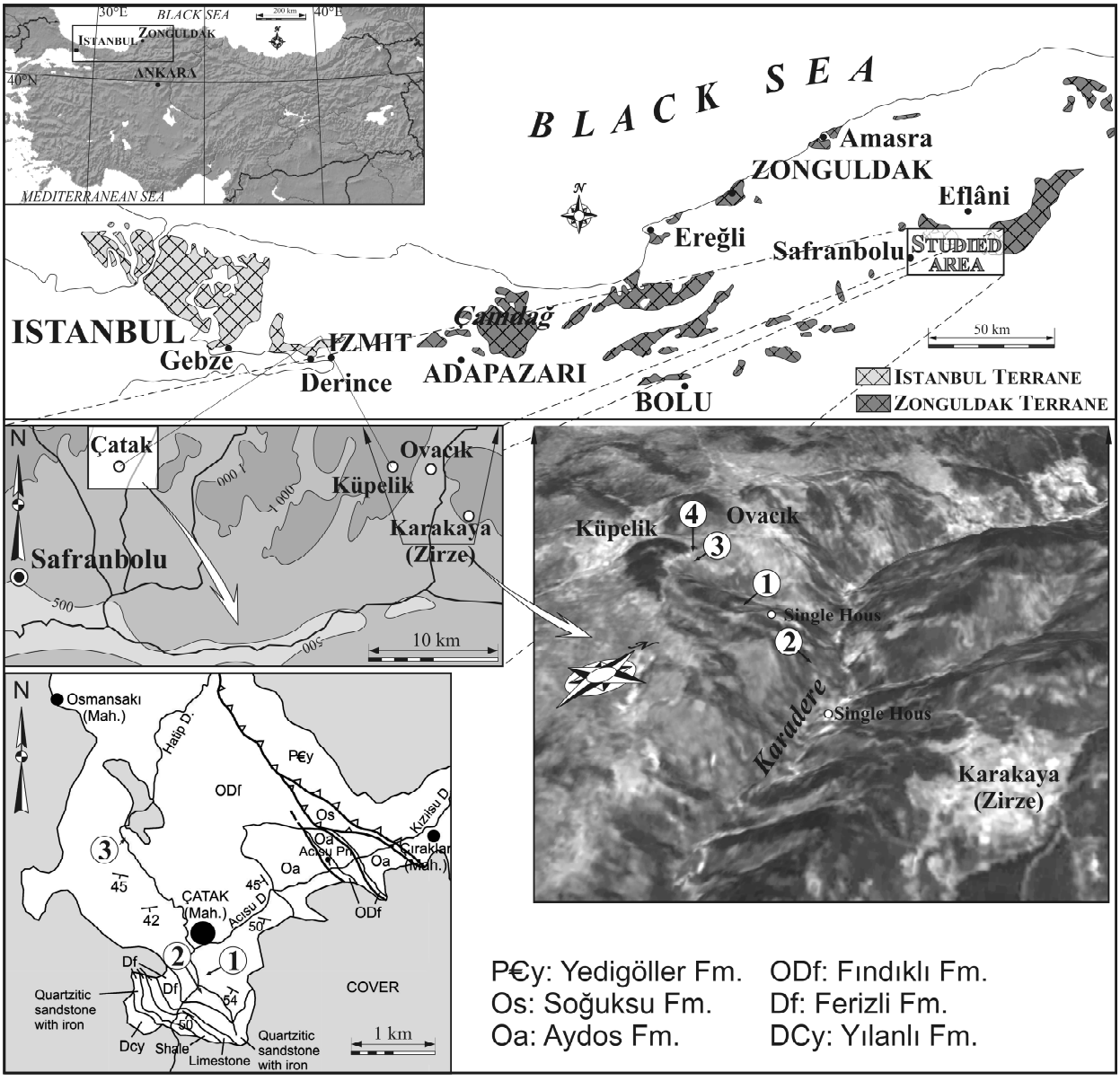

Fig. 1. Location maps

crops, the Silurian is mainly characterized by siliciclastics and graptolite-bearing dark shales with limestone interlayers.

In a recently published map Aksay, Timur (2002) showed the details of the Paleozoic rock-units to the SW of Eflâni, along the Çatak River (Fig. 1) for the first time. This location is situated between the Karadere and Ereğli areas and has not been studied yet. Within the framework of a joint-project on the Paleozoic of Bulgaria and NW Turkey, a preliminary survey was realized by the project-members in this area.

In this study the authors report their new findings on the rock units, stratigraphy and age of the Silurian rocks in the Çatak area. Moreover, new fossil findings from the Silurian of Ovacık Section in Karadere area will be evaluated. This location is located to the NW of the Zirze Section of Dean et al. (2000) and of importance for the stratigraphic correlation.

Geological framework

The Paleozoic rocks of Çatak occur in an inlayer to the SW of Eflâni. It includes a pre-Ordovician basement, mainly characterized by mafic igneous rocks and granitoids intruding them. This basement is known as the Yedigöller Formation, a name adopted from the Bolu Massif in the West (Aydın et al., 1987). The radiometric age data from the neighboring Karadere area (570–590 Ma, Chen et al., 2002) suggest that the basement is of Cadomian age. These basement rocks are thrusted towards the west onto the Paleozoic succession prior to Eocene time (Fig. 1). The Paleozoic section in the area is more than 1000 m thick and is intensively deformed. The succession starts with variegated mudstones and sandstones (Soguksu Formation), followed by quartzites and quartz-arenites of the Aydos Formation. Both Formations are assigned to the Early Ordovician. In the Çatak area, the whole siliciclastic succession with black shales, mudstones, siltstones and siliceous shales between the Aydos Formation at the bottom and the Middle Devonian unconformity at the top is attributed to the Fındıklı Formation (Aksay, Timur, 2002). The Fındıklı Formation includes a Middle Ordovician to Middle Silurian sediments. The siliciclastic rocks of the Fındıklı Formation are unconformably overlain by the Middle Devonian clastics of the Ferizli and Middle Devonian-Carboniferous carbonates of the Yılanlı Formation, respectively. The Paleozoic rocks are evidently affected by Variscan folding and unconformably overlain by Jurassic-Cretaceous rocks. The Alpine deformation in the area is expressed by the thrusting and the post-orogenic cover rocks are Upper Paleocene-Eocene shallow marine sediments.

In the Karadere area, located to the East of the Çatak, a second tectonic inlayer outcrops along the Karadere Valley. The Paleozoic successions in this area have been mapped in detail by Boztuğ (1992) and the Turkish Petroleum Corporation and the litho- and biostratigraphy is studied by Dean et al. (1997, 2000). The Paleozoic stratigraphy of the Çatak and Karadere areas are very similar. However, Dean et al. (1997) introduced two additional formation names for the Middle and Upper Ordovician rocks, Karadere and Ketencikdere formations, respectively. Besides, they restricted the usage of the "Fındıklı Formation" only for the Silurian part of the siliciclastic succession, which they additionally subdivided into two informal members. Different than in the Çatak area, the Devonian quartzites and limestones, unconformably overlying the Fındıklı Formation in Karadere area are named as the Eskibaglar Formation.

Silurian stratigraphy

The studied section is located along the Acısu Dere to the South of Çatak Village, and sampled the length of a SW dipping section. The section begins to the S of the Acısu Bridge (Fig. 1) with greenish-gray sandstone and argillites with thin-bedded and/or lens-shaped, dark colored limestone interlayers (Fig. 2). This part of the succession is barren of fossils. It is included in the Fındıklı Formation by Aksay, Timur (2002) but resembles the Late Ordovician (Caradoc-? early Ashgil) Ketencikdere Formation of Dean et al. (1997) in the Karadere-Zirze area. Upwards it is followed by more or less monotonous succession of greenish gray shales and siltstones. It is yellowish weathered and includes light-colored spots. Mesoscopically the spots are gray in color and are developed along the yellowish tube-like structures, which are like vermes-tubes. This unit is about 30 m thick and resembles the Siltstone Member of the Ketencikdere Formation in Karadere area. Dean et al. (1997, 2000) suggested that this member is younger than Caradoc in age. A similar rocks in Bulgaria are known as Tseretsel Formation and are also Late Ordovician in age (Sachanski, 1994).

The spotted shales are conformably overlain by a series of black graptolitic shales with subordinate limestones and siltstones. Therefore, this part of the succession in the Çatak area has the characteristic features of the Fındıklı Formation (sensu strictu) as defined by Aydın et al. (1987). The succession studied is about 350 m thick. Its lower part is build up of black argillites that alternate with black silicified shales and lydites (Fig. 2). No fossils could be obtained from this lydite-argillite unit. The first graptolite finding from above this succession (level 1 on the Çatak columnar section in Fig. 2), however, yielded the graptolites *Retiolites geinitzianus* and *Monograptus priodon*. The following interval of yellowish weathering shales with sandy limestone bands and lenses, about 50 m-thick, has not yielded graptolites. The overlying black argillites (level 2 on the Çatak columnar section in Fig. 2), 150 m-thick, alternating with sandy limestone and limey siltstone, are again rich in graptolites such as *M. beloforus, M. flemingii, Pristiograptus meneghini, Pr. dubius, Sokolovograptus textor, S. parens, S. telleri, Monoclima-*

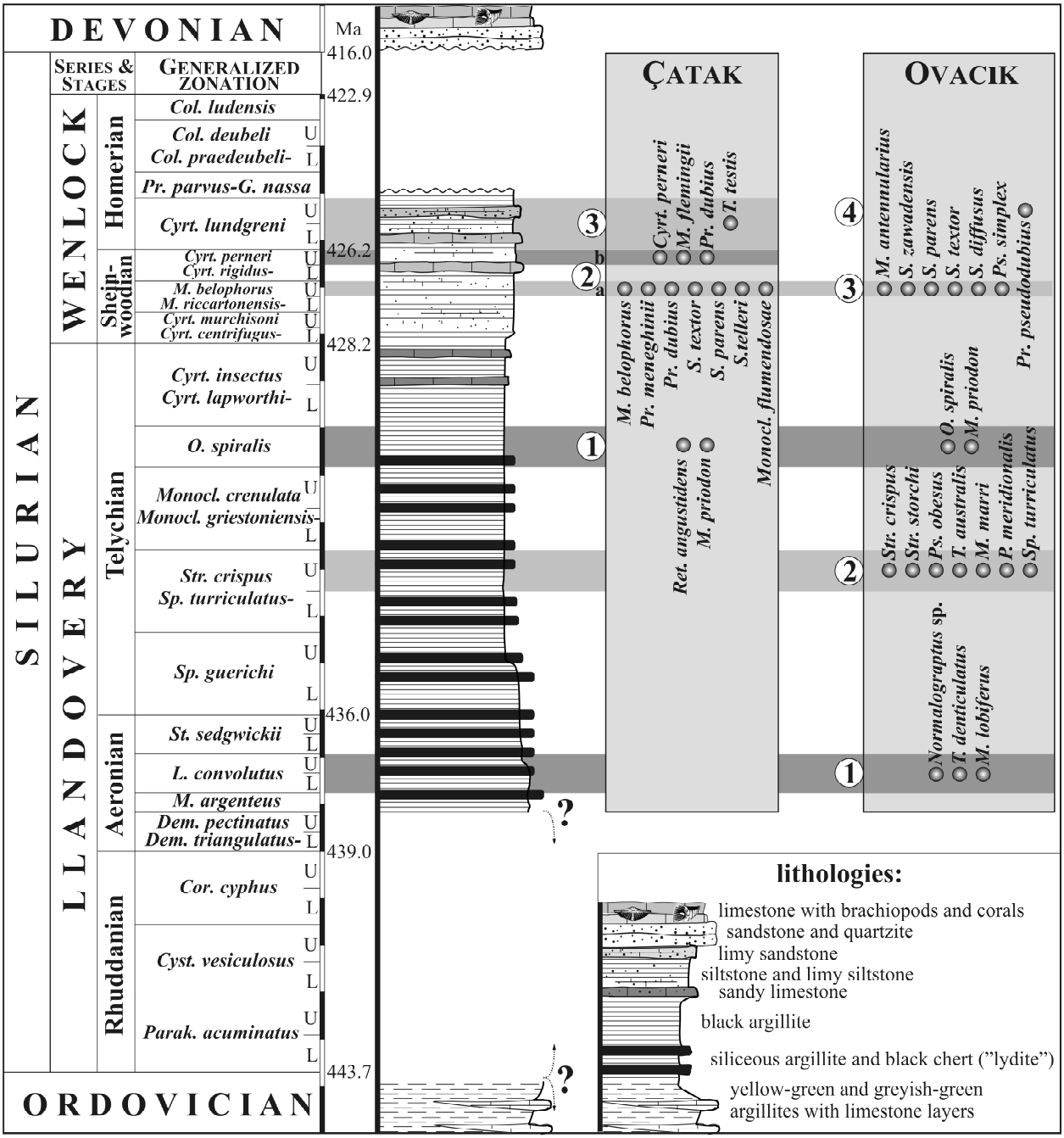

Fig. 2. Summarised columnar section, correlation and graptolites distribution

cis flumendosae and *Cyrtograptus perneri*. The upper 50 meters of the studied succession comprises limey sandstones and barren shales in this section. After an interval of 15 m, covered by recent superficial deposits, Devonian quartzites and quartzitic sandstones unconformably cover the Silurian rocks.

This covered interval, however, is exposed on the road-cuttings to the N of Çatak Village. Except an extensively deformed interval of black shales in the bottom of the road-section, which was excavated for graphite-mining, the succession along the road is almost identical with that along the Acisu Dere. The black shales in the graphite-mine include some tubular foraminifers which are characterized by glomospiroid coiling. It is impossible to make the exact determination of the specimens because of unproductive material but it is clear that forms belong to Ammodiscidae family in care of their general test morphology as well as mode of coiling (glomospiroid coiling) and agglutinated wall structures. The most similar genus for the investigated material is the genus *Glomospira* which is known from Silurian to re-

cent. The maximum diversity of agglutinated foraminifers including *Glomospira* and recently determined forms is shown in shelf and generally bathyal environments (Braiser, 1980; Doyle, 1996). Due to the limited foraminiferal diversity it is not possible to expose more detail explore environment and facies analysis.

The black shales alternating with limy sandstone and siltstone in the upper part of the Silurian succession (Fig. 1, sample location 3 on the geological map and the level 3 on the Çatak columnar section in Fig. 2) in this location yielded *Testograptus testis*.

In the Karadere Valley, about 25 km to the E of Çatak section another well-exposed section with Silurian rocks is studied. The location of this section is to the SW of Ovacık Village, along a forest road along Dorukyol Ridge (Fig. 1). In this section the lower part of the Fındıklı succession is made up of black argillites that alternate with black silicified shales and lydites (Fig. 2). In contrast to the Çatak section two levels in this part of the unit yielded graptolites (Sample location 1 and 2 on the image in Fig. 1 and level 1 and level 2 on the Ovacık columnar section in Fig. 2). Level 1 at the bottom of the lydite-argillite unit yielded graptolites such as *Normalograptus* sp., *M. lobiferus*, *Toerquigraptus denticulatus* and in the level 2 in the middle part we found *T. australis, M. marri, Spirograptus turriculatus, Parapetalolithus meridionalis, Pseudoplegmatograptus obesus, Streptograptus storchi, Str. crispus*. A single sample, 10 m above the top of the lydite-argillite unit, yielded *O. spiralis* and *M. priodon,* probably in a similar stratigraphic position with level 1 in the Çatak section (Fig. 2). The next graptolite-bearing level in this section (level 3 on the Ovacık columnar section in Fig. 2) is rich in *M. antennularius, S. zavadensis, S. parens, S. textor, S. diffusus, Pseudoplectograptus simplex* and correlates with level 2 in the Çatak section. The last sample in this section is from the argillite-black limestone alternation (level 4 on the Ovacık columnar section in Fig. 2) just beneath the Devonian conglomeratic sandstones and contained *Pr. pseudodubius*.

Graptolites and age

There is no regional graptolite subdivision in the investigated region till now. The character of the study also does not give opportunities for this. The Generalized Graptolite zonation (GGZ) proposed by Koren et al. (1996) and Melchin et al. (1998) is adopted here which gives a good opportunity for correlations

Dean et al. (2000) reported two graptolite levels in the Lower Member of Fındıklı Formation south of Karadere-Zirze. They indicate *magnus*-?*convolutus* and *crispus* Biozones. The same stratigraphic levels are recognized in this study in the area of Ovacık. The species *T. denticulatus* is found from Ovacık 1 within a Normalograptids dominated association with rare *M. lobiferus* representatives. *T. denticulatus* is characteristic element for the *convolutus* Zone in Bohemia (Štorch, 1998). The association indicating the upper part of *Sp. turriculatus-Str. crispus* GGZ in Ovacık 2 is much more diverse and rich. The stratigraphic range of the recorded species is shown on Fig. 3. The presence of *P. meredionalis* is very interesting from paleogeographical point of view, since it is considered as a typical Gondwanian species, found in Algeria (Legrand, 1998), Spain (Gutiérrez-Marco, Štorch, 1998; Štorch, 1998) and Libya (Štorch, Massa, 2007).

The zonal-index graptolite species *O. spiralis* and *M. priodon* are documented at the base of the Upper Member of the Fındıklı Formation in the area of Ovacık. The latter associates with *Ret. geinitzianus* in the region of Çatak (level 1). *M. priodon* and *Ret. geinitzianus* have a wide stratigraphic range (Fig. 3), but the position of these finds (immediately above the lydite-argillite unit) gives us a good reason to consider them as indication for the presence of *O. spiralis* GGZ. Moreover, the lithostratigraphic succession in Bulgaria is similar (Sachanski, Tenchov, 1992) — The Saltar Formation (lydite-argillite unit) is followed upwards by Mala reka Formation (black graptolite mudstones), containing *O. spiralis* in the base.

The next recognized graptolite level is the upper part of *M. riccartonensis-M. belophorus* GGZ. The graptolite association in the area of Ovacık is dominated by retiolitids, with species diversity close to that of the East European Platform (Kozłowska-Dawidziuk, 1995). Biostratigraphically important marker is also *M. anntennularis* being characteristic for the *M. belophorus* Zone in Bohemia (Štorch, 1994). The index species of this zone is found in the area of Çatak (level 2a). Approximately 2 m above this level *Cyrt. perneri* is documented (level 2b), being characteristic for the upper part of *Cyrt. rigidus-Cyrt. perneri* GGZ.

The highest stratigraphic level in the area of Çatak is the *Cyrt. lundgreni* Zone, proved by the diagnostic species *Test. testis* for its upper part. In the uppermost part of the Silurian succession near Çatak the species *P. pseudodubius* is found. It commonly occurs within this zone (Rickards, 1965; Rickards, Wright, 2003), but is reported from lower stratigraphic levels as well (Přibyl, 1943; Štorch, 1994).

The analysis of the graptolite fauna gives ground for the conclusion that during the Telychian (Upper *Sp. turriculatus-Str. crispus* Zone) the investigated area was influenced by peri-Gondwana, but from the middle of the Sheinwoodian (Upper *M. riccartonensis-M. belophorus* Zone) the influence of Baltica is considerable.

Discussion and conclusions

The present study introduces the Silurian stratigraphy of the Fındıklı Formation along the newly discovered Çatak section in Çatak and Ovacık section in Karadere. In both sections the Fındıklı Formation comprises from the bottom to the top of black siliceous argillites and lydites, black argillites and sandy

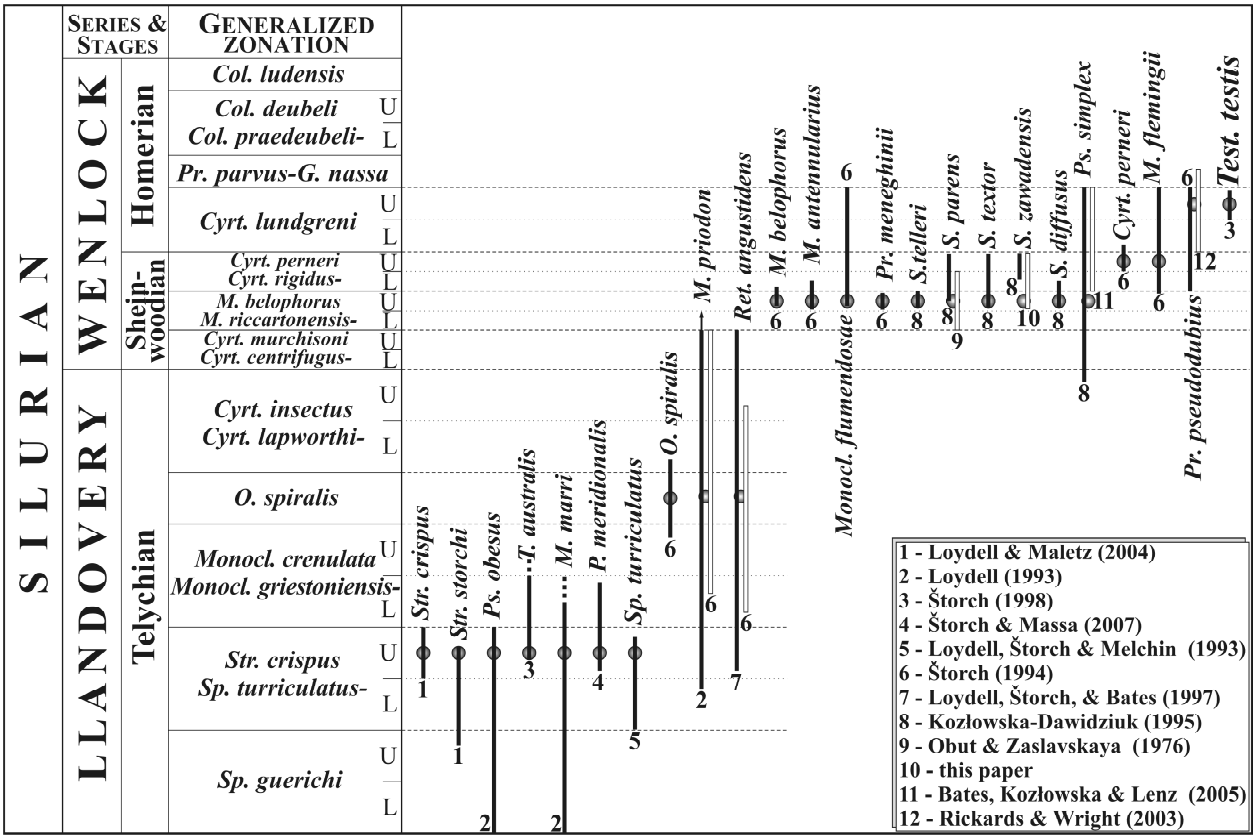

Fig. 3. Graptolite range chart of the established species

limestones, and shales with sandy limestone and limy siltstone.

Four levels with graptolites are recognized, the oldest one being *T. denticulatus* — characteristic element for the *convolutus* Zone. The association indicating the upper part of *Sp. turriculatus-Str. crispus* Zone consists of *T. australis, M. marri, Sp. turriculatus, P. meridionalis, Pseudoplegmatograptus obesus, Str. storchi, Str. crispus*. The zonal-index graptolite species *O. spiralis* is documented at the base of the Upper Member of the Fındıklı Formation in the area of Ovacık. The next recognized graptolite level is the upper part of *M. riccartonensis-M. belophorus* Zone with *M. belophorus*, *Pr. meneghinii*, *S. telleri* (Çatak section) and *M. antennularius, S. zavadensis, S. parens, S, textor, S. diffusus, Ps. simplex* (Ovacık section). The zonal-index graptolite species *Cyrt. perneri* is documented (Çatak section). The highest stratigraphic level in the area of Çatak is the *Cyrt. lundgreni* Zone, proved by the diagnostic species *Test. testis* for its upper part.

Regarding the lithostratigraphic correlation of the Silurian of Çatak, it is completely different from that in the Istanbul Terrane, which is dominated by shallow-marine limestones. This may indicate a quite different paleo-environmental and paleo-geographical setting during the deposition. It also differs considerably from the lithostratigraphy in the Çamdağ and Ereğli-Gülüc successions. In Çamdağ area the Fındıklı Formation consists mainly of a very thick succession of dark shales but graptolitic finds are restricted within a 2 m thick interval in the lower part (Black Shale Member). The graptolite assemblage (Göncüoglu, Sachanski, 2003; Göncüoglu et al., 2003) in this section gives ground to suggest that the time of graptolitic shales deposition in the Çamdağ area corresponds to *spiralis* — lower *lapworthi* Zone. In Gülüc condensed middle Silurian succession, middle and upper part of the Telychian and Sheinwoodian Stage are not represented. The presence of reworked Sheinwoodian conodonts in Homerian of this section is assigned to an regressive period in relation to the global Silurian TR cycles. Therefore the Güluc succession differs significantly from the coeval thick and stratigraphically expanded black shales and siltstones of the same formation in the Çatak area. A correlation with the neighbouring Zirze area is more appropriate. Both in Ovacık and Zirze areas *magnus-?convolutus* and *crispus* Biozones are recognized within the siliceous argillites of the lower Fındıklı Formation. The youngest graptolite assemblage on the other hand is found in the carbonate-rich part of the succession and yielded graptolites of the *Cyrt. lundgreni* Zone of the Lower Homerian. In the Zirze section, however, Dean et al. (2000) report the presence of *M. flemingii* and *Pr.* cf. *parvus*, in-

dicative for the upper half of the Wenlock. These are the youngest Silurian rocks found in the Çatak-Karadere area. The Fındıklı Formation is overlain by quartz-conglomerates and quartz arenites with a distinct angular unconformity. The quartz-arenites are followed then by early Middle Devonian limestones. Considering that the Silurian succession in the Çamdağ area reaches up to Pridoli (Kozlu et al., 2002) a considerable part of the Upper Middle and Upper Silurian may have been eroded in the Çatak-Karadere area. This erosion is by far non-conformable with the global Silurian TR cycles and can be considered as an additional indication for the end-Silurian deformation related to the collision of the Zonguldak Terrane with Laurussia (Göncüoğlu, 2001; Yanev et al., 2006).

On the other hand, even if preliminary, the newly obtained data have an important paleobiogeographical implication. This is due to a change in the provinciality of the Telychian peri-Gondwanan graptolite fauna to a Baltica-influenced one from the mid Sheinwoodian onwards in the eastern Zonguldak Terrane. Such a change is in accordance with the northward drifting of the Zonguldak Terrane across the Rheic ocean during the Silurian (Yanev et al., 2006).

To conclude, the new finds on the Silurian in the Çatak and Ovacık sections together with the previous data from the Zirze area confirm their affiliation to the Zonguldak Terrane. The obtained preliminary age data indicate considerable differences in the depositional features of the Upper Lower and Lower Middle Silurian successions within the Terrane. The foremost suggestion is that some of these differences are due to Silurian global TR cycles. However, tectonic events, especially at the end of the Silurian, may have been responsible for these differences. Hence a more detailed biostratigraphic study is needed for a better understanding of the Silurian events in NW Anatolia.

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Резюме. В. Сачански, М. Ч. Гьончоолу, И. Гедик, Ч. Окуючу – Силурската система в областта на Чатак и Карадере, Зонгулдакски терен, СЗ Турция. В Зонгулдакския терен за първи път са изследвани съдържащи граптолити силурски седименти при селата Чатак (югоизточно от Ефлани) и Овачък (областта на Карадере). Те се отнасят към свитата Фъндъклъ. Долната част на разрезите е изградена от черни силицитизирани аргилити и лидити; средната – от черни аргилити и варовици, а горната – от аргилити с песъчливи варовици и варовити алевролити. В разреза при Чатак са установени следните нива с граптолити: горната част на зона *M. riccartonensis – M. belophorus*, горната част на зона *Cyrt. rigidus – Cyrt. perneri* и зона *Cyrt. lundgreni*. В разреза при Овачък с граптолити се доказват следните зони: *L. convolutus, Sp. turriculatus – Str. crispus* (горната част), *O. spiralis* и *M. riccartonensis – M. belophorus* (горната част). Времевият интервал, който обхващат тези зони е от средата на аеронския до началото на хомерския век.

Доказва се принадлежността на наскоро установените в околностите на Чатак силурски седименти към Зонгулдаксия терен. През теличкия век този терен е все още част от пери-Гондвана, докато в средата на шейнууддския се появяват характерни за Балтика граптолитни видове.