Ordovician graptolites from the basal part of the Palaeozoic transgressive sequence in the Karadere area, Zonguldak Terrane, NW Turkey

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Abstract. The Karadere area to the east of Safranbolu in NW Anatolia is one of the very few localities in Turkey where the contact between the Cadomian basement and the Lower Palaeozoic transgressive succession is well exposed. The Ordovician graptolite *Rhabdinopora flabelliformis* (Eichwald) ssp. was found in the basal part of the Bakacak Formation, indicating an Early to early Late Tremadocian age for the beginning of the Palaeozoic transgression in the Zonguldak terrane. A few metres above this occurrence, another horizon contains *Paradelograptus* cf. *antiquus* (T. S. Hall), which mainly ranges into the Late Tremadocian. Higher up in the Ordovician succession, a new graptolite bed confirms an early Darriwilian (Dw1) age for the middle part of the Karadere Formation with the occurrence of the biozonal index *Levisograptus austrodentatus* (Harris & Keble) and the first record of *Tetragraptus cor* (Strandmark) in the area. The palaeobiogeographic distribution of these Karadere fossils is in agreement with a peri-Gondwanan affinity of the Zonguldak Terrane of the Pontides, NW Anatolia, during the Early–Middle Ordovician.

Key words: Ordovician, graptolites, Zonguldak Terrane, Pontides, NW Turkey.

INTRODUCTION

In contrast to the relatively well documented Ordovician successions known from the SE Anatolian Gondwanan Autochthon and the Tauride-Anatolide units (e.g. Ghienne et al. 2010 and references therein), fossil data from the Lower and Middle Ordovician rocks are relatively scarce in the Istanbul and Zonguldak terranes of NW Anatolia (e.g. Yanev et al. 2006; Bozkaya et al. 2012). In the Eastern part of the Zonguldak Terrane, the Safranbolu-Karadere area (Fig. 1) shows a well-exposed Lower Palaeozoic succession discovered by Arpat et al. (1978). Dean et al. (1997, 2000) studied the Ordovician part of the succession in detail. They described four Ordovician formations and reported diverse occurrences of trilobites, graptolites, acritarchs and conodonts, ranging in age from a probable Tremadocian to probable Sandbian (or even younger) beds.

The purpose of this article is to report new bio-stratigraphic data from the Ordovician of the Bakacak and Karadere formations in the Zonguldak Terrane (Karadere generalized section and Incüves measured section representing its lower part), not recognized in previous studies but of interest for correlation with the Istanbul Terrane in the west and with the Taurides Gondwanan succession in the south. They confirm the record of Tremadocian deposits at the base of the Palaeozoic sequence and also of Middle Ordovician beds that include the index graptolite for the basal Darriwilian Stage.

GEOLOGICAL SETTING

Lower Palaeozoic rocks of NW Anatolia range from the Istanbul area in the west to the Eflani-Karadere area in the east (Fig. 1A, B). In the Istanbul area, imperfectly known Late Ordovician fossil assemblages are recorded from the lower and middle part of the Gözdag Group (Sayar & Cocks 2013 and references therein). In the Karadere area, the stratigraphy and fossils from the Lower to Upper Ordovician formations was described by Dean et al. (1997, 2000). This is one of the very few areas where the disconformable contact between the 'Cadomian Basement Complex' (Göncüoglu 1997; Göncüoglu et al. 1997) and its Lower Palaeozoic cover is observed (e.g. Arpat et al. 1978). Previous studies have shown that the oldest Palaeozoic unit (Bakacak

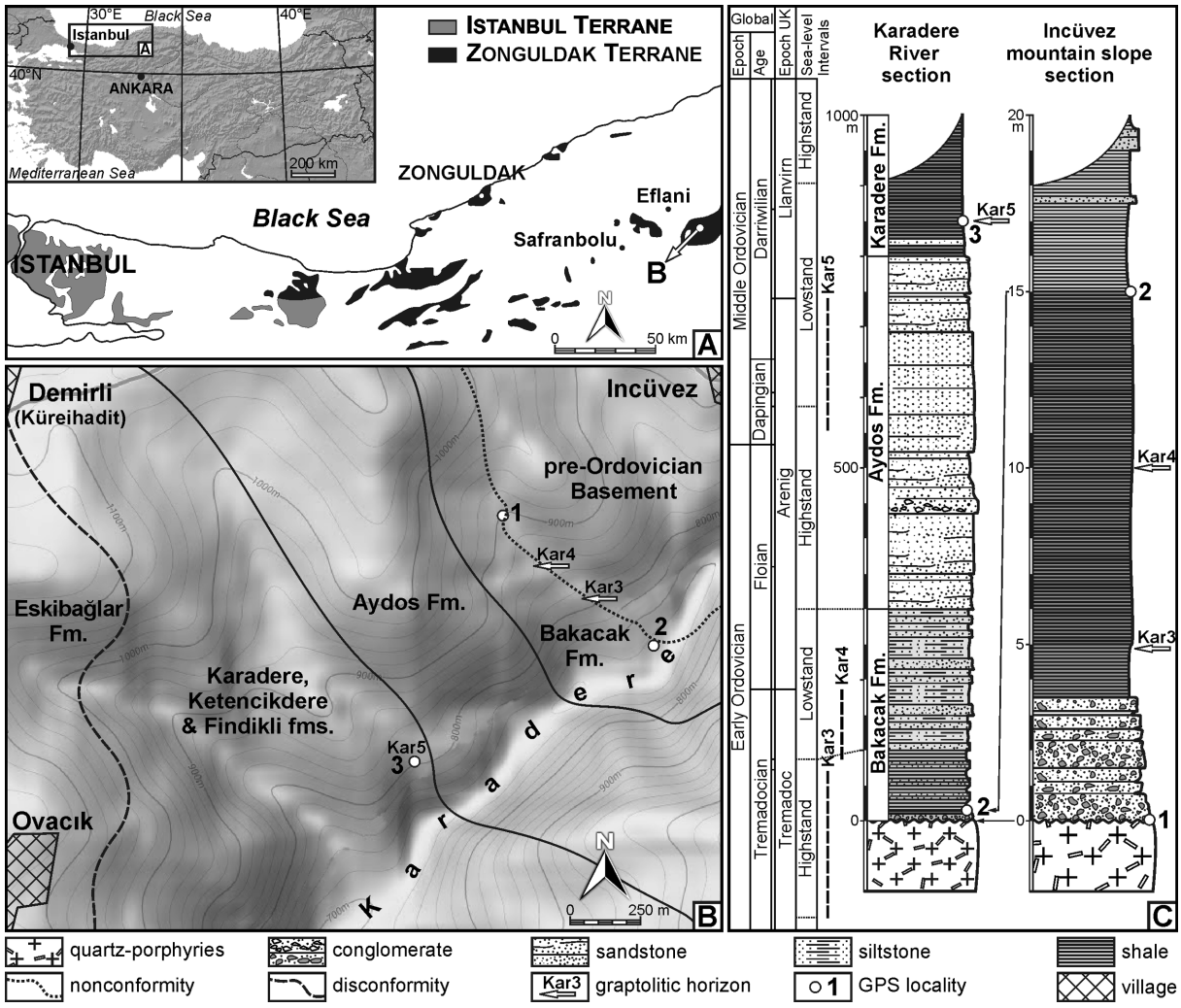

Fig. 1. A, distribution of Palaeozoic rocks in NW Anatolia (modified from Göncüoglu et al. 2006); **B**, location of the studied successions. The geological map is modified from Boztuğ (1992). The GPS localities of the starting and end points of the Incüves section are: point 1 (41°20′50.11″N; 33°04′43.98″E) 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). **C**, Ordovician litho- and chronostratigraphy of the studied sections and location of graptolite horizons Kar3, Kar4 and Kar5. The chronostratigraphy and sea-level intervals are by Cooper & Sadler (2012).

Formation) included fluvial conglomerates and conglomeratic sandstones. In a small creek to the SW of Incüves Mahallesi (GPS locality: x: 06.684; y: 77.174) we found a section where these basal conglomerates of the Bakacak Formation directly overlie the Precambrian quartz-porphyries. They are followed by 1.5 m of grey shales with small unidentified linguliform brachiopods; 10 m of dark shales and by a 100 m thick succession of grey–green laminated shales and sandstones (Fig. 1C). The dark shale facies was discovered for the first time in this area and provided the Tremadocian graptolites listed below (Kar3 and Kar4 horizons in Fig. 1C). Upwards, the succession ends with a thick (200 m) unfossiliferous sequence of medium- to thin-bedded, laminated, brown, pink and brick-red quartz-siltstones and sandstones.

The Bakacak Formation is transgressively (Boztuğ 1992) overlain by grey–white, thick-bedded quartzite with conglomeratic horizons and represents the eastward extension of the Aydos Formation of the Istanbul area (Kaya 1978). This unit is more than 500 m thick and does not contain fossils. The Aydos Formation is conformably overlain by the Karadere Formation of Dean et al. (1997), through a transitional contact formed by alternating grey–dark grey mudstones followed by black and dark grey, thin-bedded, partly silicified, pyrite-bearing shales and mudstones of the Karadere Formation (Arpat et al. 1978; Dean et al. 2000). A palaeontological

sample (Kar5) bearing lower Darriwilian graptolites was collected about 50 m above the base of the Karadere Formation in the homonymous gorge (Fig. 1B, C). There, the upper part of the unit is not well represented but packages of dark grey–black, siliceous, thin-bedded mudstones with thin carbonate bands may locally occur.

NEW GRAPTOLITE DATA

Four specimens of *Rhabdinopora flabelliformis* (Eichwald) ssp. indet. (Fig. 2A–D) have been found in the lowermost part of the Bakacak Formation. Their state of preservation does not allow a more precise identification. According to Cooper (1999), the stratigraphic range of the *R. flabelliformis* subspecies extends from the lower Tremadocian (*R. f. parabola* Biozone) to the lower upper Tremadocian (*Kiaerograptus* plus *Aorograptus victoriae* biozones). Typical lower Tremadocian graptolites of the *R. flabelliformis* group are very rare over all of the Mediterranean region, being only reported from scattered occurrences in Morocco (Destombes & Willefert 1959), Algerian Sahara (Blain 1963; Legrand 1966, 1973, 1974), SW Sardinia (Italy: Taricco 1920; Pillola & Gutiérrez-Marco 1988) and Montagne Noire (SW France, Aceñolaza & Gutiérrez-Marco 1995). Single Turkish records of '*Dictyonema flabelliforme* (?)' and '*Dictyonema sociale* (?)' from NW Anatolia were reported near Izmit and Babadag by Yalçinlar (1959, 1963) and may also be collected from the Bakacak Formation. However, these occurrences were questioned by Dean (1980, p. 16), who considered them unreliable in those partly metamorphic rocks.

In the same section, and 5 m above the previous graptolitic horizon, sample Kar4 has yielded remains of linguliform brachiopods (Fig. 2E), fragments of *Rhabdinopora*? sp. and one incomplete rhabdosome of *Paradelograptus* cf. *antiquus* (T. S. Hall) (Fig. 2F), which is a characteristic graptolite for the upper Tremadocian (Jackson & Lenz 2000) that might range into the basal Floian (Maletz & Egenhoff 2001).

These fossil occurrences prove that deposition of the graptolite-bearing dark shales and siltstones of the Bakacak Formation in the Karadere area started in the Tremadocian, a speculation so far only supported by very poorly preserved acritarchs from the same formation (Dean et al. 1997, 2000). Thus, the sedimentation of the lowermost part of the Bakacak Formation could be somewhat related to the global early–middle Tremadoc Highstand, whereas the overlying red–brown sandstones, higher-up in the Bakacak succession, were probably deposited during the global late Tremadoc–early Arenig Lowstand (Nielsen 2004; Cooper & Sadler 2012). The quartzites of the succeeding Aydos Formation are here attributed to a new transgression that reached its maximum during the deposition of the black mudstones of the Karadere Formation (Fig. 1C). Dean et al. (2000) reported the occurrence of *Didymograptellus protobifidus* (Elles) at the very base of the Karadere Formation, a graptolite commonly reported from upper Floian (Fl3) beds. However, according to J. Maletz (written comm. 2014), identification of the Turkish specimens is problematic. The figured specimens of '*Didymograptus* (*Didymograptellus*) *protobifidus*' (Dean et al. 2000, fig. 11f–h) have a short, wide sicula that may belong to *Xiphograptus vdeflexus* (Harris), a species recorded from the middle Dapingian (Dp2) *Arienigraptus gracilis* Biozone to the lower Darriwilian (Dw1) *Levisograptus austrodentatus* Biozone (Maletz 2010). This would mean a significantly younger (ca middle Dapingian) age for the base of the Karadere Formation, which was correlated by Dean et al. (2000) to the 'Lower Arenig' (ca Floian *sensu lato*). The 'mixed' occurrence of some Floian and Dapingian species such as *Baltograptus minutus* (Törnquist), *B.* cf. *deflexus* (Elles & Wood), *Azygograptus* cf. *eivionicus* Elles & Wood, *Isograptus imitatus* Harris and *Pseudisograptus manubriatus koi* Cooper & Ni, listed by Dean et al. (2000) below the first appearance of *L. austrodentatus* in the Karadere Formation, should also be investigated.

A graptolite assemblage from the middle part of the Karadere Formation collected by us (sample Kar5 in Fig. 1B, C) consists of *Levisograptus austrodentatus* (Harris & Keble) (Fig. 2G), *Levisograptus sinicus* (Mu & Lee) (Fig. 2H, I), *Tetragraptus cor* (Strandmark) (Fig. 2J, K), *Tetragraptus bigsbyi* (J. Hall) (Fig. 2M) and an unidentified declined didymograptid (Fig. 2L). *Tetragraptus cor*, presently known only from Scandinavia and Mongolia (Cooper & Lindholm 1985; Maletz 2005; Maletz & Ahlberg 2011), is restricted to the lower Darriwilian (Dw1) *Levisograptus austrodentatus* Biozone. This finding is in agreement with Dean et al. (2000), who reported graptolites of the *L. austrodentatus* Biozone, including the nominal species, from their 'Upper Arenig' beds in the lower part of the Karadere Formation. The record of *L. sinicus* in our assemblage is indicative of the homonymous subzone of the *L. austrodentatus* Biozone, according with the widely distributed subzones introduced by Mitchell & Maletz (1995) and Chen & Bergström (1995).

In contrast to the regional early Tremadocian transgression in the Zonguldak Terrane, the coeval lithofacies in the Taurides, representing the northern Gondwana shelf, are composed of siliciclastic strata conformably overlying open-marine nodular limestones of Cambrian age (Göncüoglu et al. 2012). The storm deposits of Tremadocian to Floian age recorded in the Eastern Taurides were interpreted as the products of the

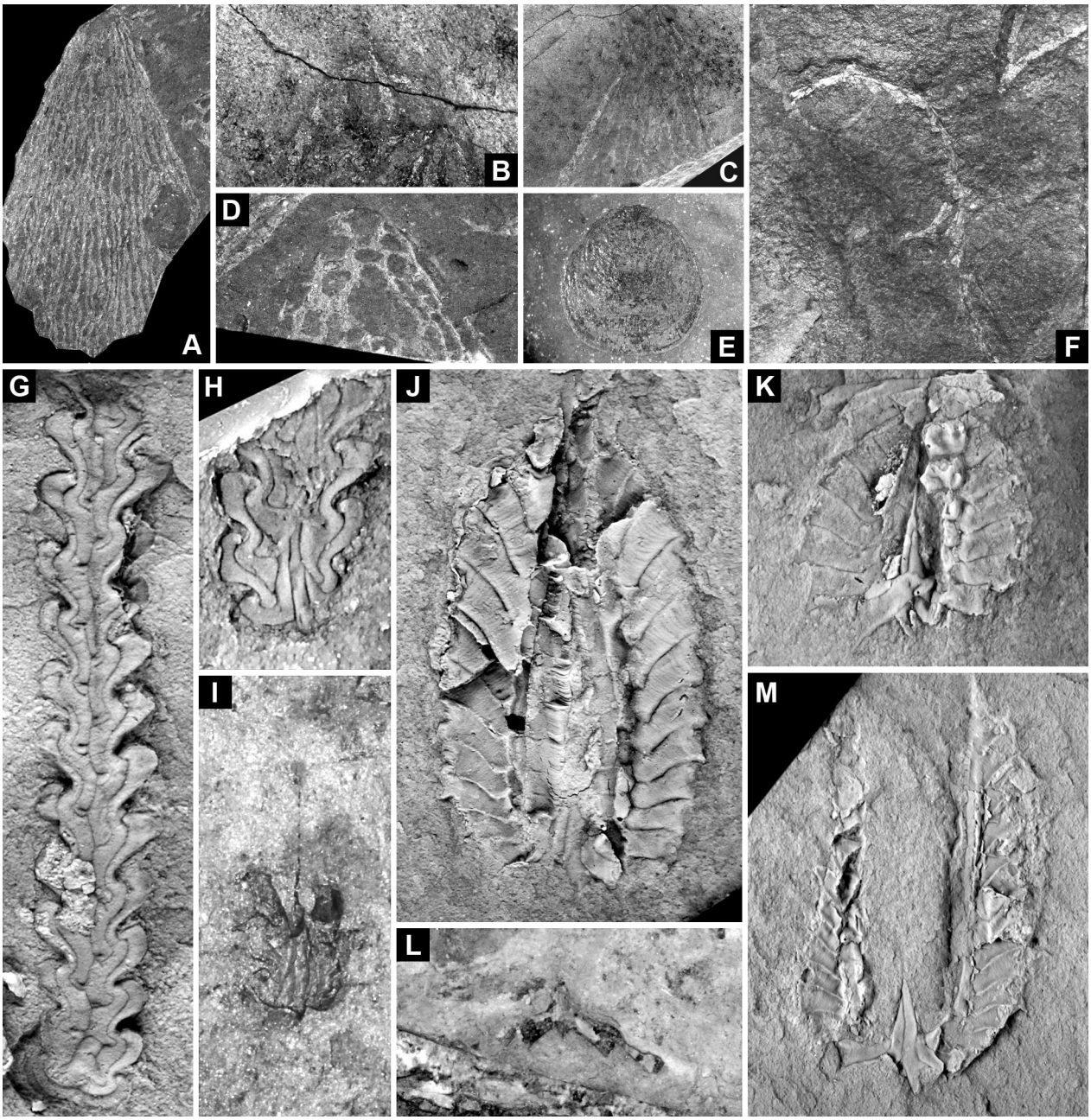

Fig. 2. Ordovician fossils from the Karadere and Incüves sections, NW Anatolia. **A**–**D**, *Rhabdinopora flabelliformis* (Eichwald) ssp.: A, fragment of a somewhat compressed rhabdosome; B, detail of a young colony showing sicula; C, flattened rhabdosome in lateral view; D, proximal fragment flattened obliquely to axis (A, D, Kar3-1 ×1.5 and ×3.7, respectively; B, C, Kar3-4 ×5 and ×1.2). **E**, dorsal valve of linguliform brachiopod (Kar4-b1, ×2). **F**, *Paradelograptus* cf. *antiquus* (T. S. Hall), incomplete rhabdosome with reclined stipes of first-order and one second-order dichotomy (Kar4-2, ×3.5). **G**, *Levisograptus austrodentatus* (Harris & Keble), latex cast of a pyritized rhabdosome in reverse view showing pattern U astogeny (Kar5-1, ×12). **H**, **I**, *Levisograptus sinicus* (Mu & Lee), latex cast of a pyritized proximal region in obverse view (Kar5-1B/3, ×17) and counterpart of a flattened immature colony in obverse view, with small nematularium and spiny thecal apertures (Kar5-1B, ×13). **J**, **K**, *Tetragraptus cor* (Strandmark), latex casts of two pyritized specimens showing 1-2 stipe preservation in obverse view (J, Kar5-10, ×8; K, Kar5-4, ×15). **L**, flattened proximal end of declined didymograptid (Kar5-15, ×8.3). **M**, *Tetragraptus bigsbyi* (J. Hall), latex cast of a pyritized specimen showing 1-2 preservation (Kar5-5/5, ×6). The samples are reposited at METU Geology Museum (Repository No. METU-2014-P-1).

maximum flooding interval, whereas the overlying late Middle to Late Ordovician sand- to siltstone-dominated successions were ascribed to the formation of a sag basin (Ghienne et al. 2010). Thus, the sedimentary record on the northern Gondwana shelf represented in the Taurides does not match with the depositional sequences of the Zonguldak Terrane.

CONCLUSIONS

New graptolite discoveries in NW Anatolia suggest a minimal mid-Tremadocian age for the earliest Palaeozoic transgression onto the Cadomian basement of the Zonguldak Terrane. The deposition of the graptolite-bearing dark shales until the Late Tremadocian or the earliest Floian was followed by a regression that is recorded by red–brown fluvial clastics in the upper part of the Bakacak Formation. The time of onset of the following transgression, represented by the Aydos Formation, is not known. However, the transgression may have continued and reached its peak during the earliest Darriwilian, when black shales with graptolites of the *L. austrodentatus* Biozone (a.o.) accumulated.

Palaeogeographically, the Lower Ordovician graptolites of the studied area are similar to other scattered records occurring in South-Polar Peri-Gondwanan terranes, where the scarcity of *Rhabdinopora* and other anisograptid graptolites is linked with the extensive development of shallow-water facies dominated by sandstones and green micaceous shales. They are little suitable for life and preservation of these primitive planktic graptoloids. Besides this, Middle Ordovician assemblages from the *L. austrodentatus* Biozone are composed by almost pandemic species of the cosmopolitan epipelagic biotope (Cooper et al. 1991; Goldman et al. 2013), plus some characteristic species from the high- to mid-palaeolatitude 'Atlantic Province'. Among the latter we selected the record of *Oelandograptus oelandicus* (Bulman) and *Aulograptus cucullus* (Bulman) mentioned by Dean et al. (2000), to which we can add the unexpected occurrence of *Tetragraptus cor*, a rare Scandinavian species found for the first time in peri-Gondwana.

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