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New conodont and palynological data from the Lower Palaeozoic in Northern Çamdağ, NW Anatolia, Turkey

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ABSTRACT:

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Two main thrust slices in the Camdag area (NW Anatolia), were informally named the Southern and Northern Çamdağ units. New micropaleontological and palynological data about the Ordovician, Silurian and Devonian in the Northern Çamdağ have allowed a better understanding of the Early Palaeozoic evolution of this critical area between the Istanbul Terrane in the west and the Zonguldak Terrane in the east. The Middle Ordovician age obtained from the conodont-bearing limestone band within the Aydos Formation in this study is in agreement with the data from the Zonguldag Terrane. Acritarch evidence suggests a Late Ordovician age of the upper part of Aydos Formation.

This paper concerns the Northern Unit. Three members are distinguished in the Fındıklı Formation and dated biostratigraphically. The lower member (Black Shale Member) of the Findiklı Formation is absent from the Kabalak Dere section, but was assigned elsewhere to the Llandovery on the basis of graptolites. The middle member (Shale–Siltstone Member) is dated as Wenlock and Ludlow on the basis of acritarchs. The upper member (Shale–Limestones Member) spans a continuous Upper Silurian – Lower Devonian succession. The overlaying Ferizli Formation is assigned to the Middle Devonian on the basis of conodonts.

The new stratigraphic data indicate that the Southern Çamdağ Unit corresponds to the Istanbul Terrane and the Northern Çamdağ Unit to the Zonguldak Terrane. The tectonic contact between the Northern and the Southern units is a steep south-verging thrust-fault.

Key words: Lower Palaeozoic; Stratigraphy; Conodonts; Palynomorphs; NW Turkey; Çamdağ.

INTRODUCTION

The Palaeozoic of NW Anatolia between Istanbul and Cide (Text-fig. 1) along the Black Sea coast is incorporated in the "Istanbul Nappe" of Sengör *et al.* (1984) or "Istanbul Unit" of Okay (1989). The Palaeozoic formations in this unit are known as the "Palaeozoic of Istanbul" and considered a part of the eastern European

"Variscan Chain" (e.g. Görür *et al.* 1997). The stratigraphy of the Palaeozoic formations in the unit has been the subject of numerous studies since the 1860s. Paeckelmann (1938) carried out the first detailed biostratigraphic work in Istanbul and the Kocaeli Peninsula, followed by a series of comprehensive studies (see Haas 1968 for a review of the previous studies). The most recent review of new data was given by Yanev *et al.* (2006).

Relatively little is known about the Lower Palaeozoic stratigraphy of a number of tectonic inliers east of the Kocaeli Peninsula (Text-fig. 1) (e.g. Camdag, Kaplandede Dag, Eregli, and Kastamonu-Arac) (e.g. Derman and Tuna 2000); Göncüoğlu and Kozur (1998) suggested the presence of two Early Palaeozoic terranes based on significant stratigraphic dissimilarities (Göncüoğlu 1997) between the Palaeozoic successions in Istanbul (Istanbul Terrane) and further east (Zonguldak Terrane). The critical area in these interpetations is the Çamdağ area, representing the westernmost outcrops of the Zonguldak terrane (Göncüoğlu and Kozur 1998, 1999). The state-of-art information on the Palaeozoic stratigraphy of the Çamdağ area is based on local studies (e.g. Kaya 1978, 1982; Yazman and Cokugras 1984; Kipman 1974; Aydin *et al.* 1987, Derman and Özcelik 1993; Derman 1997; Kozlu *et al.* 2002; Göncüoğlu *et al.* 2003; Lakova and Göncüoğlu 2005). However, an overall evaluation of these studies shows that there is no consensus on the stratigraphic positions of the lithostratigraphic units or the nomenclature (see below). Discrepancies are mainly due to the lack of reliable biostratigraphic data, which has hampered correlation between similar rock-units. Moreover, new work based on recent re-mapping in the Çamdağ region (Gedik and Önalan 2001) revealed the presence of two separate tectonic slivers, which differ in their lithostratigraphy. This indicates that the Palaeozoic succession in the Çamdağ area is more complex than previously thought.

The authors of the present paper studied the more or less "complete" sections of the Ordovician, Silurian and Devonian and sampled them for conodonts, graptolites, brachiopods, acritarchs, nautiloids, macroflora and micro-vertebrates. The biostratigraphic results of this study are presented to emphasize the complex tectonic relationships of the Palaeozoic units of this critical area between the Istanbul and the Zonguldak Terranes.

GEOLOGICAL SETTING

The Çamdağ area is located to the east of Istanbul between the towns of Hendek and Karasu to the northeast of the town of Adapazarı (Text-fig. 1). It covers an intensively forested area of approximately 400 km^2 with poor accessibility. Recent mapping in the Çamdağ area by Gedik and Onalan (2001) has revealed the presence of two main thrust slices which were informally named the Southern Çamdağ and Northern Çamdağ units. The tectonic contact between them is a steep south-verging thrust-fault. The Southern Unit includes, in ascending order, green and pink mudstones with sandy interbeds (Soğuksu Formation; Kaya 1982), quartzites (Karadere Formation: Kaya 1982; Aydos Formation: Gedik and Önalan 2001) and grey-green shales alternating with black-grey, fissile shales. The tectonically overlying Northern Unit forms an E-W-trending anticline with the following rock units, in ascending order: green-grey laminated mudstones (Kocatöngel Formation: Kaya 1982) followed by green and pink mudstones and sandstones (Bakacak Formation; Kaya 1982), red fluvial clastics (Alabalıklı Formation: Kipman 1974; Kurtköy Formation: Yazman and Cokugras 1984), quartzites (Aydos Formation), green mudstones and black graptolitic shales with limestone bands (Yayla Formation: Kipman 1974; Fındıklı Formation: Aydın *et al.* 1987), red and pink clastics with oolithic iron ore deposits (Bıckı Formation: Kipman 1974; Ferizli Formation, Gedik and Önalan 2001) and finally massive carbonates (Yılanlı Formation) (Saner *et al.* 1980) and siliciclastics (Text-fig. 2).

During the fieldwork in 2005 and 2006 the sampling was concentrated along the Kabalak Dere, one of the main creeks, which runs across the E-W-trending anticline and cuts through all the formations of the Northern Unit, the thrust contact between the Northern and Southern units and the upper parts of the Southern Unit.

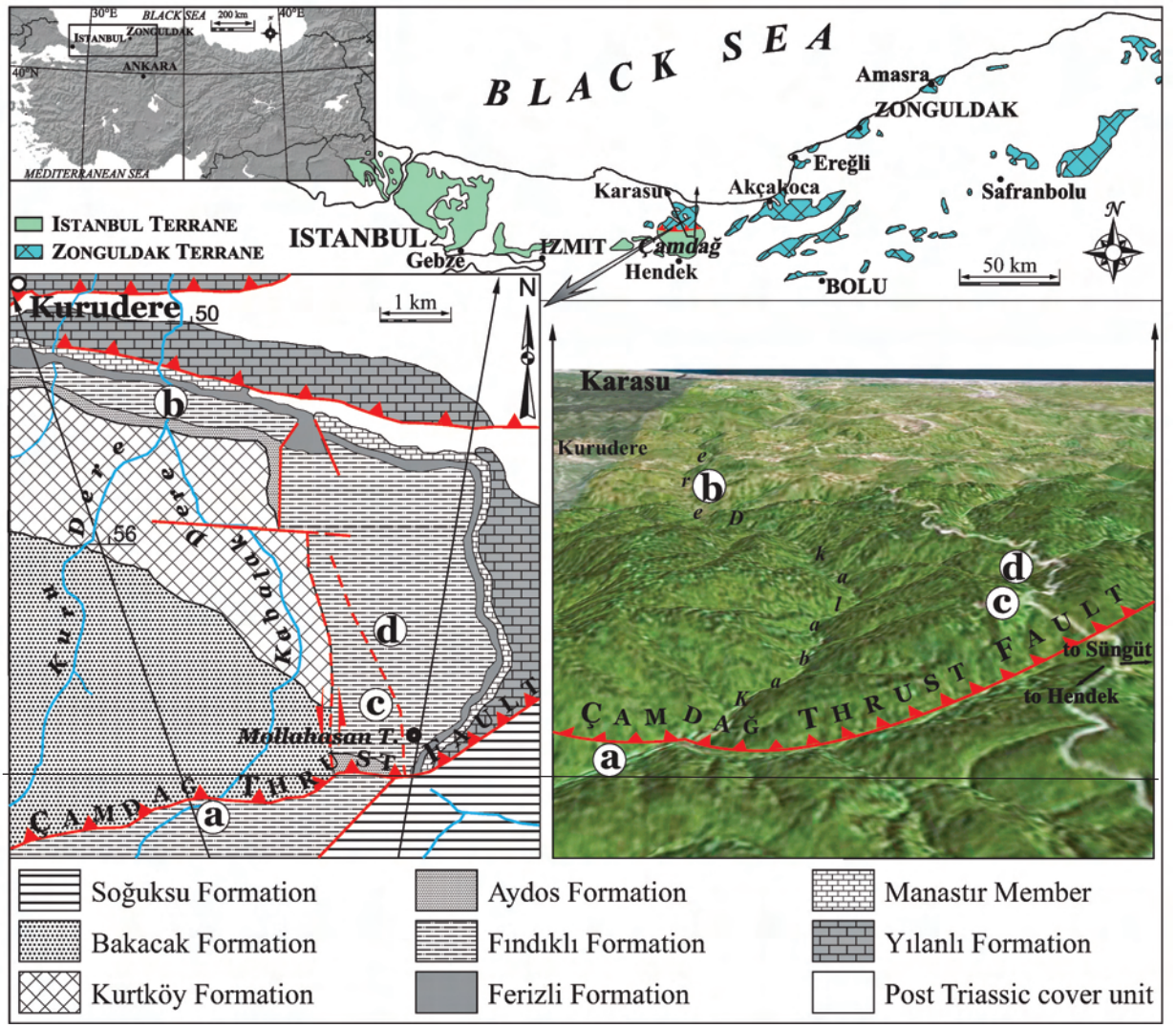
The uppermost part of the Southern unit in the Kabalak Dere section is represented by greenish-grey, quartzarenites with thin grey-black shale interlayers (Text-fig. 2). The sandstones include burrows and organic detritus together with some brachiopods. The organic material consists of macrofloral fragments. Gedik and Önalan (2001) assigned this succession to the Fındıklı Formation and suggested it was of Middle Ordovician age.

The Northern Unit starts with the Bakacak Formation, composed of greenish-pink and violet siliciclastics. The lower part of the succession in the Kabalak Dere includes grey-green mudstones and shales, alternating with shales and fine-grained sandstones. The middle part is represented by pale violet shales with increasing amounts of coarser-grained grey sandstones. The upper part of the formation comprises coarse-grained sandstones with silicified violet mudstones that grades into coarse clastics of the Kurtköy Formation. It is interpreted as a regressive succession including shallow-marine (deltaic) sediments in the middle and upper part, followed by flu-

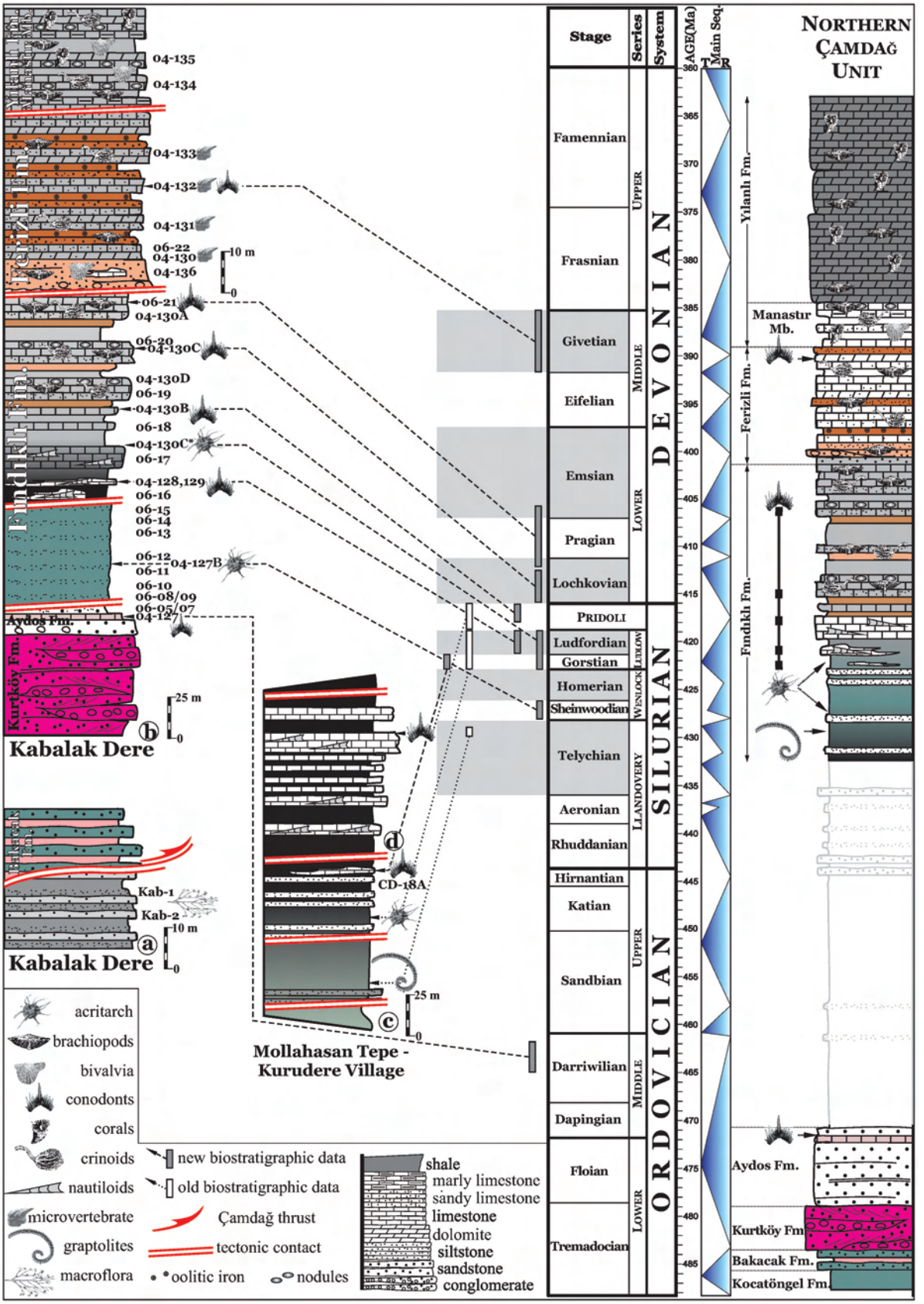
vial sediments of the Kurtköy Formation (Gedik and Önalan 2001). The thickness of the formation in Kabalak Dere is about 400 m.

The Kurtköy Formation is made up of violet, red and grey conglomerates, sandy conglomerates, arkoses, subarkoses, lithic arenites with subordinate pink and brick-red mudstones and shales. The conglomerates include up to 8 cm clasts of well-rounded quartz, feldspar, quartzite, granite, aplite, rhyolite, gneiss, micaschist, lydite and sandstone. The dominant clasts are white-pink quartz and leucogranites with perthitic K-feldspar, microcline and white mica, indicating a crystalline source area. The heavy mineral fraction consists of zircon and apatite. The sandstone packages display rare cross-bedding and cross-lamination. The formation has a transitional boundary towards the overlying Aydos Formation. The transitional sequence is dominated by a 3 m thick quartzo-feldspatic sandstone level. The observed thickness of the Kurtköy Formation in the Kabalak Dere is about 2000 m.

The Aydos Formation is composed mainly of white, pale violet and grey quartz-arenites. The lower part contains thick-bedded conglomeratic interlayers with well-rounded quartz pebbles. The quartz-arenites include well-rounded and slightly deformed quartz grains, with rare white-mica flakes. They are silica-cemented and comprise prismatic zircon grains. The violet quartzites are hematite-rich. In the Kabalak Dere, a 60 cm thick grey–pinkish-grey dolomitic limestone layer just above the conglomeratic basal layers was sampled (sample 04–127, Text-fig. 2) for conodonts. The upper 5 m of the formation consist of an



Text-fig. 1. The Palaeozoic outcrops in NW Anatolia, Turkey (modified from Göncüoğlu *et al*. 1997; Göncüoğlu 1997); geological map (after Gedik and Önalan 2001) of the Northern Çamdağ Unit and positions of the sections studied: **a** – Kabalak Dere section in Southern Çamdağ Unit, **b** – Kabalak Dere section in the Northern Çamdağ Unit, **c** and **d** – sections on the road between Mollahasan Tepe and the village of Kurudere


Northern Çamdağ Unit
Stage
Series
System
AGE(Ma)
Main Seq.
TAR
Famennian
Frasnian
Givetian
Eifelian
Emsian
Pragian
Lochkovian
Pridoli
Ludfordian
Gorstian
Homerian
Sheinwoodian
Telychian
Aeronian
Rhuddanian
Hirnantian
Katian
Sandbian
Darriwilian
Dapingian
Floian
Tremadocian
Upper
Middle
Lower
Wenlock
Ludlow
Llandovery
DEVONIAN
SILURIAN
ORDOVICIAN
Yılanlı Fm.
Manastır Mb.
Ferizli Fm.
Fındıklı Fm.
Aydos Fm.
Kurtköy Fm.
Bakacak Fm.
Kocatöngel Fm.
Kabalak Dere
Mollahasan Tepe - Kurudere Village
04-135
04-134
04-133
04-132
04-131
06-22
04-130
04-136
06-21
04-130A
06-20
04-130C
04-130D
06-19
04-130B
06-18
04-130C*
06-17
04-128,129
06-16
06-15
06-14
06-13
06-12
06-11
04-127B
06-10
06-08/09
06-05/07
04-127
Kab-1
Kab-2
CD-18A
10 m
25 m
acritarch
brachiopods
bivalvia
conodonts
corals
crinoids
nautiloids
microvertebrate
graptolites
macroflora
oolitic iron
nodules
new biostratigraphic data
old biostratigraphic data
Çamdağ thrust
tectonic contact
shale
marly limestone
sandy limestone
limestone
dolomite
siltstone
sandstone
conglomerate

calternation of quartzites with thin quartz-siltstones (palynological sample 06–05) and a conglomeratic layer at the tectonic contact with the overlying Fındıklı Formation. The thickness of the formation in the Kabalak Dere is about 15 m, which is indicative of tectonic truncation, when compared with its normal thickness of 45–50 m in the Istanbul area.

The Aydos Formation displays well-developed cross-bedding and ripples. Previous studies (Kipman 1974; Gedik and Önalan 2001) supported the idea that the formation was transgressive in nature.

The Fındıklı Formation in Çamdağ is not represented by a single and continuous succession but by several sections, bounded by tectonic contacts (Göncüoğlu *et al.* 2003). Although there is still no consensus on the actual successions, Kozlu *et al.* (2002) informally subdivided the formation into a lower member (Black Shale Member), a middle member (Shale-Siltstone Member) and an upper member (Shale-Limestone Member). The upper part of the Black Shale Member yielded Upper Llandovery (Telychian, Göncüoğlu and Sachanski 2003) graptolites, whereas the Shale-Siltstone Member was dated as early Ludlow based on palynomorphs (Lakova and Göncüoğlu 2005). The "Orthoceras Limestone" interlayers in the upper part of the Shale-Limestone Member were dated as Pridoli (Kozlu *et al.* 2002).

In the Kabalak Dere section, the lower member (Black Shale Member) is absent. The lower part of the middle member is composed of 30 m thick grey-green mudstones and sandstones. It resembles the Shale-Siltstone Member described by Lakova and Göncüoğlu (2005) and yielded acritarchs of Wenlock and Ludlow age. Upwards, the interval is followed by pyrite-rich black shales with bands and lenses of "Orthoceras Limestones". The thickness of the Shale-Limestone Member is reduced, very probably due to tectonic truncation. The upper part of the succession in the Kabalak Dere is mainly represented by green, greenish-grey and black shales with dark grey-black Orthoceras-bearing limestone bands, followed by an alternation of green shales, sandy limestones, brown and pink-red mudstones and nodular limestones. This part of the succession is characterized by the abundance of brachiopods and crinoids. The contact between the Fındıklı and red sandstones of the overlying Ferizli Formation is probably faulted, as the basal Quartzite Member of the Ferizli Formation, observed elsewhere, is missing here.

The Ferizli Formation in the Kabalak Dere includes in its lower part about 8 m of red-pink conglomeratic sandstones with some mudstone bands and sandy limestones. Its upper part is characterized by an alternation of grey dolomitic and sandy limestones and red sandstones and chamositic mudstones. The striking features of this formation are oolitic ironstones and chamositic mudstones. In the type-locality of the formation, southwest of the Kabalak Dere, Kipman (1974) described eleven separate bands of oolitic ironstone that alternate with dolomites and sandstones, which he referred to as the Coskun Ironstone Member. In the Kabalak Dere this member is about 35 m thick and includes dolomitic limestone bands alternating with chamositic mudstones.

The Ferizli Formation is conformably overlain by the Manastır Member of the Yilanlı Formation, which consists of marls, marly limestones, nodular limestones and dolomitic limestones and was described by Gedik and Önalan (2001). The Manastır Member is characterized by the abundance of macrofossils, mainly corals, brachiopods, bivalves and echinoids. The upper contact of the Manastır Member is transitional to medium- to thick-bedded grey limestones and dolomitic limestones that are known as the Yilanlı Formation. The Yilanlı Formation in the Kabalak Dere was sampled only in its lower part to find out the onset of platform-type carbonate deposition. Brachiopods (Kipman 1974; Gedik and Önalan 2001) from the lower part indicate a Middle Devonian age.

NEW BIOSTRATIGRAPHIC DATA FROM THE KABALAK DERE SECTION

The Middle Ordovician to Middle Devonian succession in the Kabalak Dere in Çamdağ was sampled for micropalaeontological studies. The samples Kab-1 and Kab-2 are from an alternation of grey quartzitic sandstones interlayered with grey and black thin-bedded siltstones (Text-fig. 2). The siltstones contain burrows and are rich in organic material, consisting of macrofloral remains. In previous studies these rock units were assigned to the lower part of the Fındıklı Formation (Gedik and Önalan 2001). However, the succession as a whole is quite different from that of the Fındıklı Formation in the Northern Çamdağ Unit described above and in Kozlu *et al.* (2002). The macroflora found in samples Kab-1 and Kab-2 is under investigation, its complex morphology suggests that it is younger than the primitive Silurian flora, and is not older than Early and Middle Devonian. These

Text-fig. 2. Stratigraphy of Ordovician to Devonian in Northern Camdag Unit. The left-hand and central columns are of the sections studied and the right-hand column is a generalized stratigraphy of the Northern Camdag Unit in NW Anatolia, Turkey

preliminary data have important tectonic implications as will be discussed later.

From the Northern Çamdağ Unit conodont samples were collected from the top of the Aydos Formation, the limestone bands within the Orthoceratid-bearing Shale-Limestone Member of the Fındıklı Formation, and from the predominantly carbonate rocks of the Ferizli and Yılanlı formations. The conodonts are the main paleontological tool for the new age determinations in the Kabalak Dere section. Conodonts are moderately abundant in the Middle Ordovician of the Aydos Formation, less common in the Silurian of the Fındıklı Formation, rare in the presumed Lower Devonian part of the Ferizli Formation and fairly diverse in its Middle Devonian part. No conodonts were found in this section from the Manastır Member of Yilanlı Formation.

Palynological samples come from the Shale–Siltstone and Shale–Limestone members of the Fındıklı Formation. The Shale-Siltstone Member is of Wenlock-Ludlow age in the Kabalak Dere and elsewhere in Northern Çamdağ (Göncüoğlu and Sachanski 2003; Lakova and Göncüoğlu 2005). Acritarchs from the overlaying Shale–Limestone Member suggest a late Silurian (Ludlow–Pridoli) age.

Aydos Formation – Middle Ordovician

A limestone bed of the Aydos Formation (sample 04–127) yielded abundant conodonts of Middle Ordovician age. The bed is about 1 m thick, brown weathered, dolomitic and laminated. It contains a low diversity, moderately abundant conodont fauna. Approximately 155 identifiable elements and at least the same number of unidentifiable fragments were recovered (Text-fig. 3). The fauna is dominated by *Baltoniodus prevariabilis* (Fåhræus) and *Protopanderodus varicostatus* (Sweet and Bergström). The remainder of the fauna consists of *Drepanoistodus basiovalis* (Sergeeva), *Dapsilodus*? sp. cf. *D. viruensis* (Fåhræus), *Scolopodus? peselephantis* Lindström, *Semiacontiodus* sp. cf. *S. cornuformis* (Sergeeva), *Walliserodus* sp., *Panderodus* sp., a platform element fragment tentatively identified as *Eoplacognthus* sp., and 7 coniform elements that are an unidentified genus and species. This fauna does not provide enough evidence for a precise biostratigraphic assignment. However, the faunal content does support a Darriwilian age (Middle Ordovician), and is most likely late Darriwilian. The oldest probable age is the *Eoplacognathus suecicus* Zone, and it is unlikely that it is younger than the *Pygodus anserinus* Zone (see Löfgren 1978; Dzik 1994; Zhang 1998, and references therein for discussions and descriptions of similar faunas and the biostratigraphy of this interval). Additional sampling of the limestone beds in this interval should lead to a more precise biostratigraphic placement. The CAI (Epstein *et al.* 1978) of the conodonts is 5, indicating thermal maturation of 300+˚C. In addition to conodonts, 10 inarticulate brachiopod fragments and one specimen of *Ptiloncodus simplex* (Harris) were recovered.

Conodont Species	Number of Elements
Baltoniodus prevariabilis	90
Protopanderodus varicostatus	51
Eoplacognthus? sp	1
Drepanoistodus basiovalis	5
Dapsilodus? sp. cf. *D. viruensis*	4
Scolopodus? peselephantis	2
Semiacontiodus sp. cf. *S. cornuformis*	1
Walliserodus? sp.	6
Panderodus sp.	2
Cornuodus sp.	5
Genus and species indet.	7

The lowermost palynological sample 06–05 from the base of the Fındıklı Formation (Text-fig. 5) yielded diverse acanthomorphic acritarchs. These include species of the genus *Orthosphaeridium* which is known to occur only in the Upper Ordovician.

Fındıklı Formation – Upper Ordovician, Silurian and Lower Devonian

The greenish-grey shales of the Shale–Siltstone Member in the lower part of the Fındıklı Formation have been sampled in detail (samples 04–127B and 06–08 to 06–16).

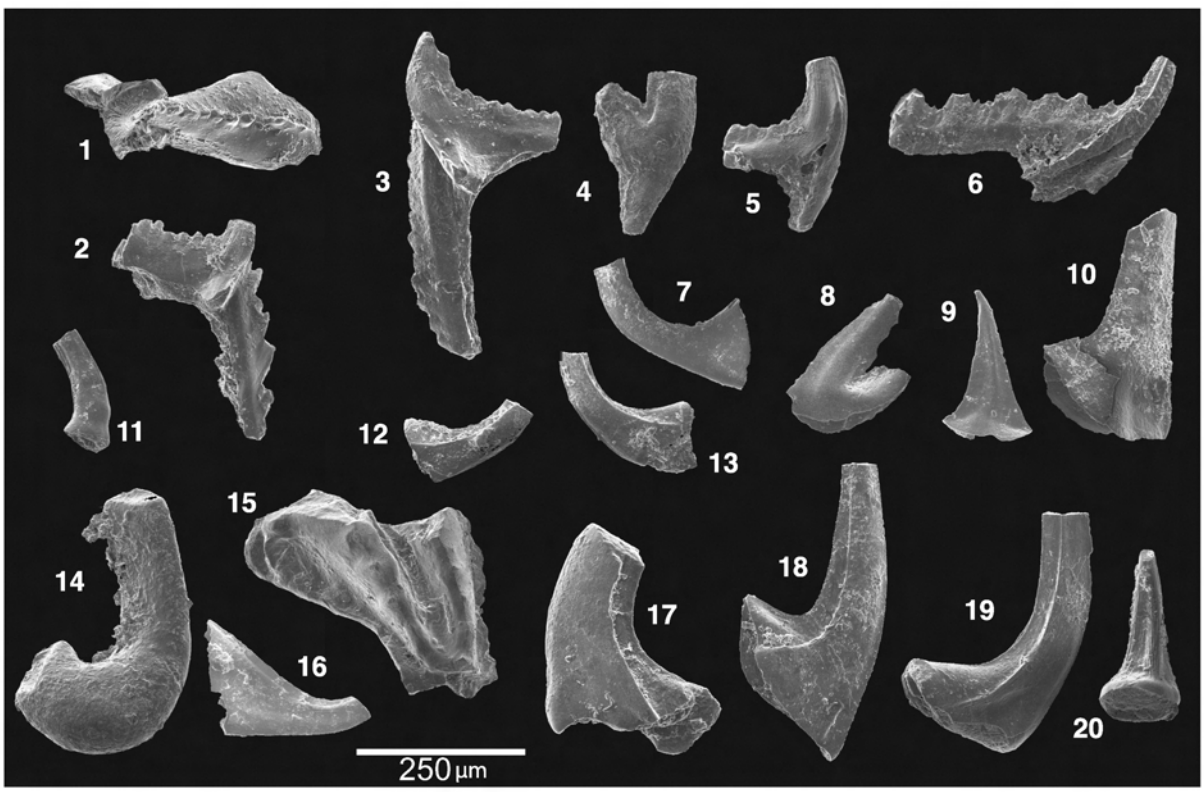
The acritarch association suggests an Early Wenlock (Sheinwoodian) age in sample 127b. The fauna consists of *Ammonidium listeri* Smelror, *Ammonidium* sp., *Deunffia brevisponosa* Downie, *Diexallophasis sanpetrensis* (Cramer) Dorning, *Dilatisphaera* cf. *willierae* Martin, *Gorgonisphaeridium citrinum* (Downie) Mullins, *Leiosphaeridia* sp., *Micrhystridium stellatum* Deflandre and *Polygonium polygonale* (Eisenack) Le Herisse.

The occurrence of *Deunffia brevispinosa* suggests a latest Telychian – earliest Sheinwoodian age. This species is known to be restricted to the Llandovery – Wenlock boundary in England (Downie 1960; Dorning 1981), Gotland (Le Herisse 1989), Ukraine (Kirjanov 1978), Czech Republic (Dufka and Pacltova 1988), Brazil (Cardoso 2001) and USA (Cramer and Diez 1970). *Ammonidium listeri* was reported only from the Llandovery in Norway (Smelror 1987). *Dilatisphaera willierae* is known from the

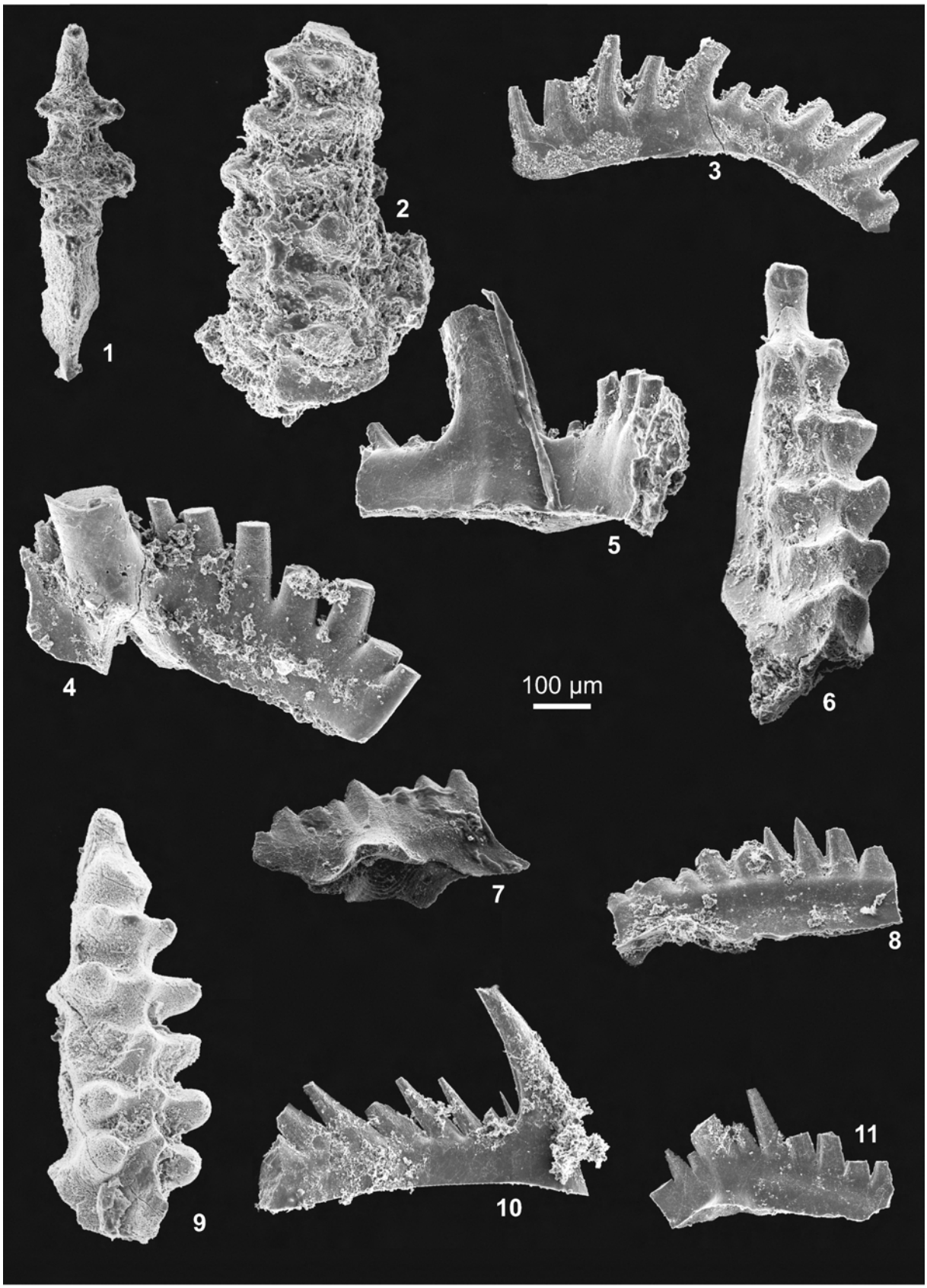
Llandovery in Belgium (Martin 1968), the Ludlow in Ukraine (Kirjanov 1978), the Llandovery – Wenlock boundary in Gotland (Le Herisse 1989) form the Llandovery in Canada, and from the Llandovery to Ludlow in England. *Gorgonisphaeridium citrinum* is known only from the Sheinwoodian – lower Gorstian type areas of the Wenlock and Ludlow in England (Downie 1963; Mullins 2001). *Diexallophasis sanpetrensis, Micrhystridium stellatum* and *Polygonium polygonale* are long-ranging species. *D. sanpetrensis* ranges from the Silurian to the Lower Devonian in Spain and the USA (Cramer 1964; Cramer and Diez 1972), and has a more restricted distribution of Llandovery to Ludlow in Gotland, Belgium, England, Turkey, Austria and the Czech Republic (Le Herisse 1989; Martin 1968; Erkmen and Bozdogan 1979; Preıwalder 1987; Dufka and Pacltova 1988). *Polygonium polygonale* ranges from the Middle Ordovician to the Ludlow in Gotland, Ukraine, Lithuania, Canada and Argentina (Le Herisse 1989; Rubinstein 1995). As a whole, the assemblage suggests an Early Wenlock age for the Shale–Siltstone member of the Fındıklı Formation.

The Orthoceras-bearing Shale–Limestone Member comprises dark shales with dolomitic limestone interlayers, the latter yielding Late Silurian conodont faunas of Ludfordian and Pridoli age. The presence of *Ozarkodina crispa* (Walliser) in samples 04–128 and 04–129 (Text-fig. 4) indicates *crispa* Zone (Late Ludlow). In the sample 04–129 *Oz. confluens* (Branson and Mehl) occurs. According to Walliser (1964), this form ranges from the Ludlow (*siluricus* Zone) to the base of the Lower Devonian. The only P elements present are those of *Oz. confluens* and *Oz. crispa.* The presence of *Ozarkodina excavata excavata* (Branson and Mehl) does not add to the resolution of the age because of the long range of this taxon (Late Silurian through Early Devonian). There are many skeleton elements of *Oz. excavata excavata* like M elements and Sc elements. All elements are assigned to the *crispa* Zone (Upper Ludlow) by the presence of *Oz. confluens* and *Oz. crispa.*

Acritarchs from sample 130C* from the upper part of the Fındıklı Formation mainly include (Text-fig. 5) species of the simple-spined genera *Dorsenidium, Micrhystridium* and *Veryhachium*, together with *Multipli-*



Text-fig. 3. Middle Ordovician conodonts recovered from the Aydos Formation, sample 04–127; 1-6 – *Baltoniodus prevariabilis* Fåhræus; 7 – *Cornuodus* sp.; 8-10 – *Drepanoistodus basiovalis* (Sergeeva); 11 – *Scolopodus*? *Peselephantis* Lindström; 12-13 – *Walliserodus* sp.; 14 – *Ptiloncodus simplex* (Harris); 15 – *Eoplacognathus*? sp.; 16 – *Dapsilodus*? sp. cf. *D. viruensis* Fåhræus; 17-19 – *Protopanderodus varicostatus* (Seet and Bergström); 20 – *Semiacontiodus* sp. cf. *S. cornuformis* (Sergeeva)


1
2
3
4
5
6
100 µm
7
8
9
10
11

cisphaeridium. The association of *Gorgonisphaeridium succinum* Lister, *Dorsenidium pyramidale* Mullins and *Veryhachium valiente* Cramer suggests a Ludlow age (Lister 1970; Fensome *et al*. 1990; Mullins 2001) and supports the age determined by conodonts from samples 04–128 and 04–129. The other acritarch species (Text-fig. 5) *Dorsenidium europaeum, Do. inflatum, Micrhystridium stellatum, Oppilatala ramusculosa*, *Veryhachium trispinosum* and *Multiplicisphaeridium* spp. are long-ranging, cosmopolitan forms spanning the Silurian and Devonian (Le Herisse 1989; Mullins 2004).

Limestone sample 04–130B is younger than the *crispa* Zone and could belong to the *eosteinhornensis* conodont Zone (Late Pridoli – Early Lochkovian). The sample also contains *Ozarkodina eosteinhornensis* (Walliser), and *Oulodus elegans detortus* (Walliser) (Text-fig. 4), the association characteristic of the latest Silurian – earliest Devonian. *Ozarkodina eosteinhornensis* ranges from the uppermost Přídolí Series into the Lochkovian, and co-occurs with *Oulodus elegans detortus*, in the lowermost Lochkovian. It is assumed therefore that the Silurian–Devonian boundary occurs somewhere within the limestones above the "*Orthoceras*" limestones in sample 04–130B.

Sample 04–130C contains fragments of *Icriodus woschmidti* cf. *woschmidti* Ziegler. The stratigraphic position of this sample is above the Silurian–Devonian boundary.

Samples 04–130A and 06–21 from the uppermost brachiopod-rich limestone (Text-fig. 2) yielded *Peleksygnathus serratus serratus* Jentzsch. Although this subspecies starts already in the *pesavis* Zone of the Late Lochkovian, recent investigations in Sardinia (Olivieri and Serpagly 1990) and in the Barrandian (Slavic 2001) indicate that it is most characteristic of a middle Pragian age.

Ferizli Formation – Lower–Middle Devonian

Sample 04–132 from the sandy limestones in the middle part of the Ferizli Formation (Text-fig. 2) includes an *Icriodus*-dominated association characteristic of the Lower Givetian. The standard conodont subdivision for the Middle Devonian could not be applied in the Kabalak Dere because of the lack of diagnostic taxa. The polygnathid lineage is absent from this section. The combined presence of an *Icriodus*-dominated association, brachiopods, vertebrates and crinoids is related to a shallow subtidal platform habitat. The co-occurrence of conodonts, vertebrates, crinoids and, in particular, the appearance of fauna with *Icriodus obliquimarginatus* Bischoff and Ziegler, *I. amabilis* Bultynck and Hollard, *I. arkonensis* Stauffer, *I. brevis* Stauffer suggests that the boundary between the Eifelian and Givetian is within the Ferizli Formation (Text-fig. 4). The combined range of these conodont associations is from the Upper Eifelian into the Givetian (Bultynck 2003) and we assign it to the *ensensis* and *hemiansatus* zones (Lower Givetian) in the absence of zonal determining species.

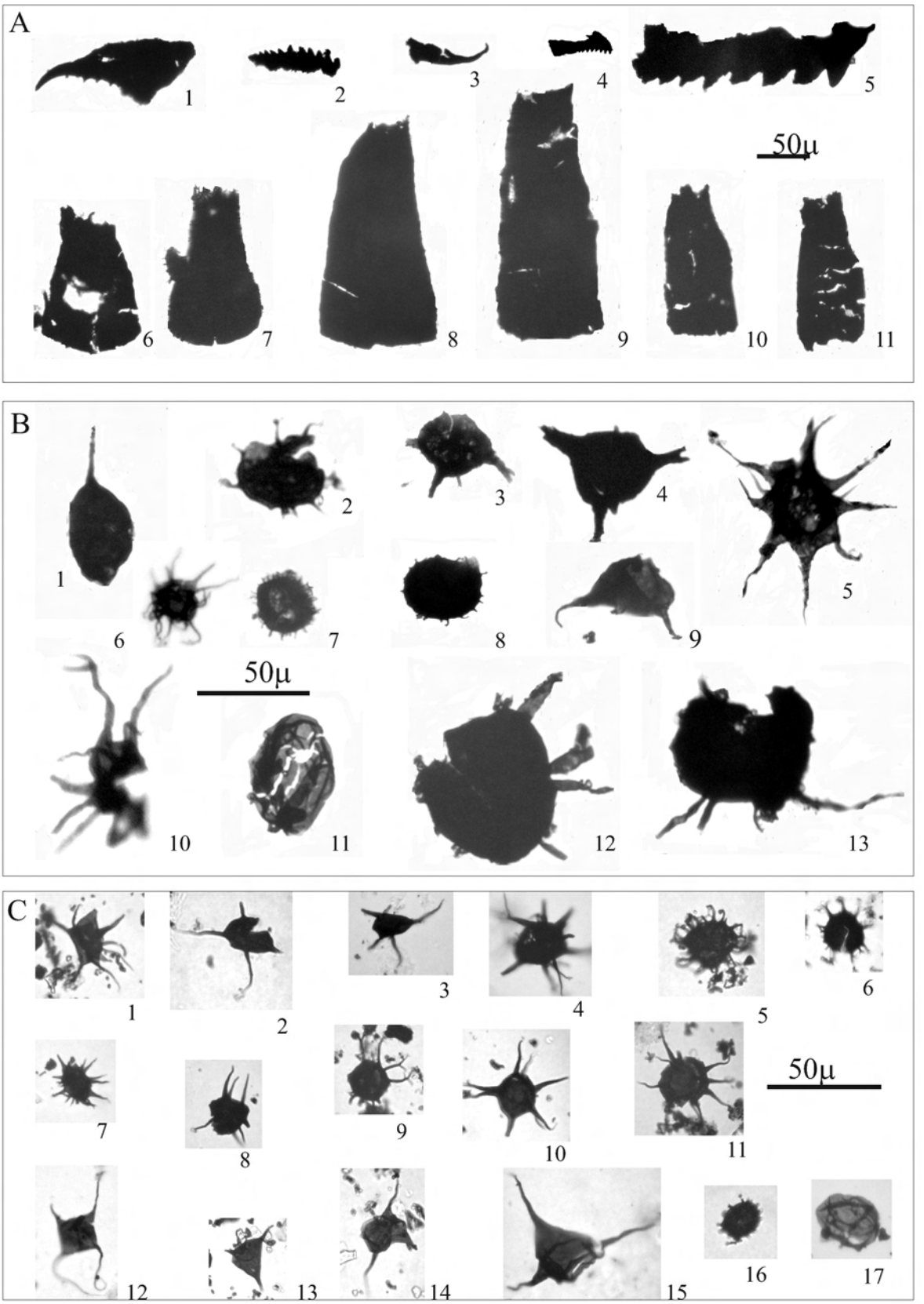
In the studied section (Text-fig. 2), numerous vertebrates were obtained from lithofacies varying from siliciclastic to carbonate (samples 04–130, 04–131, 04–132). There are fragments of acanthodians and placoderms (possible chondrichthyan scales and dermal bone fragments), *Ohiolepis* specimens, a few *Cheiracanthus* (known from Middle Devonian in Australia, Scotland and Canada) and placoderms resembling the Eifelian *Aspidichthys*.

Sample	Conodont Species	Number of Elements
04–128, 04–129	*Ozarkodina crispa*	4
04–128, 04–129	*Ozarkodina confluens*	5
04–128, 04–129	*Ozarkodina excavata excavata*	56
04–130B	*Ozarkodina eosteinhornensis*	5
04–130B	*Oulodus elegans detortus*	4
04–130C	*Icriodus woschmidti* cf. *woschmidti*	2
04–130A, 06–21	*Peleksygnathus serratus serratus*	11
04–132	*Icriodus obliquimarginatus*	6
04–132	*Icriodus amabilis*	2
04–132	*Icriodus arkonensis*	2

Yılanlı Formation (Manastır Member)

The conodont samples 04–134 and 04–135 taken from the massive limestones (Text-fig. 2) are barren probably due to unfavorable conditions. The age

Text-fig. 4. Silurian and Devonian conodonts from Fındıklı and Ferizli Formation. Scale bar 100 µ; 1 – *Icriodus brevis* Stauffer; sample 132; 2 – *Icriodus* cf. *arkonensis* Stauffer; sample 132; 3 – *Ozarkodina excavata excavata* (Branson and Mehl) Sc element; sample 129; 4 – *Ozarkodina excavata excavata* (Branson and Mehl); Sa element; sample 129; 5 – *Oulodus elegans detortus* (Walliser); sample 130B; 6 – *Icriodus arkonensis* Stauffer; sample 132; 7 – *Ozarkodina eosteinhornensis* (Walliser), sample 130B; 8 – *Ozarkodina excavata excavata* (Branson and Mehl) Pa element; sample 129; 9 – *Icriodus angustoides alcoleae* Carls ; sample 130 C; 10 – *Ozarkodina excavata excavata* (Branson and Mehl) M element; sample 129; 11 – *Ozarkodina excavata excavata* (Branson and Mehl) Pb element; sample 129


A
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C
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6
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17

range of the Manastır Member of the Yılanlı Formation is Frasnian – late Mississippian according to recent and unpublished fossil finds of the present authors in the Zonguldak area to the east of the study area (Text-fig. 1).

IMPLICATIONS OF THE NEW FINDS ON THE GEOLOGY AND PALAEOZOIC STRATIGRAPHY IN ÇAMDAĞ

The sampling of the Palaeozoic successions in Çamdağ has contributed to the stratigraphy and hence to a better correlation of the successions in the Istanbul–Gebze, Çamdağ, Eregli and Karadere areas. This correlation is of critical importance in determining the affiliation of these areas to the Zonguldak or Istanbul terranes in NW Anatolia.

Southern Çamdağ Unit

The new macrofloral finds suggesting a post-?Early Devonian age are very important because it implies that this unit may have been misidentified as the Fındıklı Formation in previous studies (e.g. Gedik and Önalan 2001). The Fındıklı Formation of Aydin *et al.* (1987), wherever observed, includes graptolitic black shales, cephalopod, crinoid- and brachiopod-rich limestone bands and its currently understood age ranges from the Llandovery to Lochkovian. However, none of these lithologies was encountered so far in the Southern Çamdağ Unit. In the Çamdağ area as a whole, macrofloral remains were reported in previous studies from the sandstones of the Ferizli Formation (Kozlu *et al.* 2002), which also include a very rich macrofauna of Middle Devonian age. Other macroflora-bearing units in NW Anatolia are the Kartal Formation (late Emsian – Eifelian) and the Trakya Formation (Late Tournaisian) in the Istanbul and the Tarlaagzı Formation (Serphukovian) in Zonguldak areas. Another clue to the dissimilarity between the Southern and Northern Çamdağ units is that the former does not include the Kocatöngel, Bakacak and Kurtköy formations. In this unit, quartz-arenites, ascribed to the Aydos Formation in the Northern Unit of Çamdağ, transgressively cover the Soğuksu Formation, which in turn is conformably overlain by an alternation of "green-gray quartz-arenites with gray shale interlayers" of the Fındıklı Formation with ?Early Ordovician bivalves (Gedik and Önalan 2001). The recent finding of macroflora in this sandstone-shale alternation in this study, however, suggests that this unit is very probably not the Fındıklı Formation but a younger (Middle Devonian or even younger) unit. Moreover, the underlying quartzite unit is not the equivalent of the Aydos Formation but represents the quartz-sandstones beneath the Middle Devonian clastics (Eskibağlar Member of Aydın *et al.* 1987). The Eskibağlar Member is a typical clastic unit at the base of the early Middle Devonian regional transgression (Göncüoğlu *et al.* 2005; Yanev *et al.* 2006) and occurs in Inkumu, Karadere and Çatak Dere sections of the Zonguldak Terrane. If the above correlation is supported by additional data, the "Çamdag Thrust Fault" of Gedik and Önalan (2001) not only separates the Southern and Northern Units of Çamdag but also represents the boundary between the Istanbul and Zonguldak terranes.

Northern Çamdağ Unit

The new conodont fauna of Middle Ordovician age is crucial for dating of the Aydos Formation and hence the Lower Palaeozoic in NW Turkey, as this unit occurs in several areas and is considered as a good marker for correlation. Originally the name is from the Istanbul area (Kaya 1978), where this unit transgressively covers the fluvial clastics of the Kurtköy Formation and is conformably overlain by greenish sandstones and shales (Gözdağ Formation, Gedik *et al.* 2003). No reliable fossil data were reported in previous studies to date the unit except some trace fossils (*Cruziana* sp., Kaya 1978) indicating Early to Middle Ordovician. The most recent data from the Istanbul area (Göncüoğlu *et al.* in prep.), however, indicate a Late Ordovician (Ashgillian) age. In the Karadere area (Dean *et al.* 1997) of the Zonguldak Terrane, on the other hand, quartzites transgressively covering the

Text-fig. 5. Silurian palynomorphs from the Fındıklı Formation. A – Scolecodonts and chitinozoa from sample 127 b; 1-5 – Scolecodonts; 6 – 7 – *Cingulochitina* spp.; 8-11 – *Conochitina* spp. B – Acritarchs from sample 127 b; 1 – *Deunffia brevispinosa* Downie; 2 – *Ammonidium* sp. 3 -4 – *Diexallophasis sanpetrensis* (Cramer) Dorning; 5 – *Polygonium polygonale* (Eisenack) Le Herisse; 6 – *Mirhystridium stellatum* Deflandre; 7 – *Ammonidium listeri* Smelror; 8 – *Gorgonisphaeridium citrinum* (Downie) Mullins; 9 – *Veryhachium* sp.; 10 – Acritarch indet.; 11 – *Leiosphaeridia* sp.; 12-13 – *Dilatisphaera* cf. *willierae* Martin. C – Acritarchs from sample 127c; 1, 8 – *Dorsenidium inflatum* (Downie) Sarjeant and Stancliffe; 2-3 – *Dorsenidium pyramidale* Mullins; 4, 5, 9 – *Multiplicisphaeridium* spp.; 6 – *Oppilatala ramusculosa* (Deflandre) Dorning; 7 – *Micrhystridium stellatum salopiense* Lister; 10-11 – *Micrhystridium inflatum* Deflandre; 12 – *Veryhachium valiente* Cramer; 13 – *Veryhachium trispinosum* (Eisenack) Stockmans and Williere; 14 – *Dorsenidium europeum* (Stockmans and Williere) Sarjeant and Stancliffe; 15 – *Veryhachium checkleyensis* Dorning; 16 – *Gorgonisphaeridium succinum* Lister; 17 – *Leiosphaeridia* sp.

Kurtköy coarse clastics are directly overlain by Darriwilian graptolitic shales with carbonate-bearing interlayers. Thus, the Middle Ordovician conodont age obtained from the limestone band at the top of the Aydos Formation in this study is in agreement with the data from the Karadere area. Nevertheless, it should be pointed out that there is more than one "quartzite member" in the NW Anatolian Palaeozoic successions. For example, the late Landovery Aydınlı Member of the Gözdağ Formation in Istanbul or the Early Devonian Eskibağlar Member of the Kartal Formation are also quartzites and quartz-arenites and may be misleading in regional correlations without fossil data.

A continuous Silurian succession was not observed in the Northern Çamdağ Unit. However, fossil data from fault-bounded sections imply that almost the entire Silurian is represented within the different members of the Fındıklı Formation. In Kabalak Dere, the Upper Llandovery (Telychian) lower member (Black Shale Member) is obviously truncated by a major fault juxtaposing the Middle Ordovician limestone and the gray-green mudstones and sandstones of the Shale-Siltstone Member. The rare acritarchs found at this level are in accordance with the previous dating of Göncüoğlu and Sachanski (2003). Moreover, additional conodont data have been obtained from calcareous interlayers (CD-18A) in the upper part of the Shale-Siltstone Member (Text-fig. 2, section d). The fauna include elements of *Kockelella variabilis* Walliser and *K. crassa* (Walliser), which are restricted to the *K. crassa* Zone, Homerian-Gorstian boundary. The new conodont (Ludfordian and Pridoli) and acritarch (Ludlow) ages from the Shale-Limestone Member from the Kabalak Dere also strengthen the previous findings (Kozlu *et al.* 2002; Göncüoğlu *et al.* 2003; Lakova and Göncüoğlu 2005).

New and very important data have been obtained from the upper part of the Fındıklı Formation. In Kipman (1974), the succession above the orthoceratid limestones was considered as a separate formation (Bıçkı Formation), but this was subsequently rejected by Gedik and Önalan (2001). The sampling of this unit in Kabalak Dere section provided a good opportunity not only to recognize the rock units in detail, but also to locate the approximate position of the Silurian-Devonian boundary. Of critical importance is sample 130B with *Oz. eosteinhornensis* (Walliser) and *Oulodus elegans detorta* (Walliser), which mark the S–D boundary interval. The sample is located just above the orthoceratid limestones and below the dark gray, brachiopod-rich limestone beds alternating with green, pink and grey sandstones and mudstones with shell-debris and crinoids. The Silurian–Devonian boundary is located within the upper part of the Fındıklı Formation, between samples 130B and 130C where *Icriodus woschmidti* cf. *woschmidti* was recovered. The last limestone band (sample 06–21) within the Fındıklı Formation, on the other hand, yielded *Peleksygnathus serratus serratus* Jentzsch, showing that the deposition of the formation lasted until the late Lochkovian-middle Pragian. From this level on, there are some irregularities in the succession, caused by small-scale faulting. The conglomeratic sandstone at the base of the following succession is considered as the lower member of the overlying Ferizli Formation.

Disregarding the tectonic discontinuity, there is a change from the regressive character of the upper Fındıklı Formation to oolitic ironstone-bearing carbonate-clastic deposition within the Ferizli Formation across the contact. Samples 130–133 are from the dolomitic limestone bands within the upper part of the Ferizli Formation and have yielded vertebrates and conodonts indicative of the Middle Devonian. Hence, the Lower–Middle Devonian boundary should be within the lower part of the Ferizli, whereas the Eifelian-Givetian boundary should be located within the upper part with carbonate bands.

Another critical issue in the Kabalak Dere section is the advance dating of the oolitic ironstones. Similar occurrences are encountered in the Karadere area to the east and dated as early Eifelian. Young (1992) pointed out that the ooidal ironstones represent sediments formed under extremely low sedimentation rates and were most commonly developed as the initial deposits above an unconformity. Events producing this lithofacies occurred almost synchronously over wide areas of the Gondwanan shelf, including northern Africa (N African Palaeozoic Ironstone Belt; Guerrak 1987) and southeast Europe (Galle *et al.* 1995) during Early-Middle Devonian and reflect the uniform sedimentary conditions across large areas of the shallow, low-gradient shelf. Their temporal distribution shows strong correlation with periods of high relative sea level (e.g. Dreesen 1989). Sedimentological study of examples in southwest Europe (Young 1992) indicate that they separate transgressive systems tracts from the early part of the following highstand systems tracts and are therefore interpreted to lie on maximum flooding surfaces. It is also important to note that in the Istanbul Terrane, the same time-interval is represented by ramp-type deposits (Kartal Formation) and sedimentation was obviously not been affected by these changes (Dojen *et al.* 2004).

The Ferizli Formation is transitional to the Manastır Member of the Yılanlı Formation. This unit consists of grey-greenish gray shales and mudstones at the base, followed by an alternation of marls and

sandy limestones. It is very rich in macrofossils (corals, brachiopods, echiniods, bivalves, etc) and grades first into nodular limestones and then into the massive dolomitic limestones of the Yılanlı Formation. The sampling in the Kabalak Dere has not provided biostratigraphic data on the exact age of this member. However, Kipman (1974) reports Upper Devonian brachiopods from the nodular limestones in Kabalak Dere.

CONCLUSIONS

The Palaeozoic successions in northwest Anatolia mostly occur as distinct tectonic units with important differences in lithostratigraphy and hence in depositional as well as palaeogeographical environments. These differences were for the most part attributed to lateral facies changes by Aydın *et al.* (1987) and Derman (1997). The alternative view is that these tectonic units represent parts of two different terranes (e.g. Göncüoğlu and Kozur 1998, 1999); the Istanbul Terrane around Bosphorus and the Kocaeli Peninsula and Zonguldak Terrane to the east. The Çamdağ area in between could has not previously been attributed to either of these main tectonic entities. The new stratigraphic data obtained by this study clearly indicate that both terranes may be represented in the Çamdağ area, the Southern Çamdağ Unit representing the Istanbul Terran and the Northern Çamdağ Unit the Zonguldak terrane. They are in contact along the Çamdağ Thrust Fault, previously mapped by Gedik and Önalan (2001). The new fossil data from the Northern Unit enabled its correlation with the Karadere and Catak sections of the Zonguldak Terrane. However, in these latter localities, Middle Devonian unconformably overlies Silurian black shales, whereas in the Northern Çamdağ the Upper Silurian and Lower Devonian are still preserved and characterizes a regressive series trough the Silurian-Devonian boundary-interval.

The Silurian acritarchs found in the Northern Çamdağ Unit are similar to those in northern Africa and southern Europe, supporting the Peri-Gondwanan origin of the Zonguldak Terrane, as suggested by Göncüoğlu (2001) and Yanev *et al*. (2006).

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