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Discovery of an earliest Triassic, post-extinction foraminiferal assemblage above the Permian-Triassic boundary, Strandzha nappes, north-west Turkey

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A new foraminiferal fauna from Early Triassic (Induan) strata of the Çağlayık section on the "Strandzha Massif", north-west Turkey, comprises five species precisely determined and five species in open nomenclature belonging to ten genera. They belong to the post-extinction foraminiferal assemblage of the Permian-Triassic crisis, characterized by the presence of both disaster taxa (*Earlandia* and *Postcladella kalhori*) and Lazarus taxa (*Diplosphaerina inaequalis*, *?Rectostipulina quadrata*, *Arenovidalina* sp. and *Glomospira* sp.). The present study at Tütünlüktepe Formation identified for the first time the Permian foraminifers on the Strandzha Massif as relict members of a post-extinction foraminiferal assemblage.

Key words: Permian-Triassic boundary, post extinction, foraminifera, Strandzha, Turkey.

INTRODUCTION

The "Strandzha Massif" or the Istranca Composite Terrane (Hagdorn and Göncüoğlu, 2007) is one of the complex tectonic units or terranes in Bulgaria and Turkey that covers almost 1200 km^2 across the Turkish-Bulgarian border. The structural properties and geological settings of the Strandzha Terrane have been recently reviewed in some detail by Bulgarian (Gerdjikov, 2005a, b; Dabovski and Zagorchev, 2009) and Turkish (Okay et al., 2001) researchers. The first geological study on the Turkish part of the "Strandzha Massif" was carried out by Pamir and Baykal (1947). Later, some general geological studies were realized in the "massif" by Üşümezsoy (1982) and Aydın (1974, 1982). According to the recent classification of Okay and Yurtsever (2006) the "Strandzha Massif" which extends along the Black Sea coast is comprised of two main geological units, being metamorphic rocks of the "Strandzha Massif" and the Thrace Basin. The crystalline rocks of the "Strandzha Massif" have been classified in three main groups by previous researchers: a) low and high grade basal metamorphic rocks, b) plutonic rocks that belong to the basement and c) Triassic and Jurassic meta-sedimentary rocks which form the cover succession. Recent studies, carried out both in the Bulgarian and Turkish parts of the "Strandzha Massif", have shown the presence of nappe structures in the "massif" (Şengör et al., 1984; Okay et al., 2001; Gerdjikov, 2005a, b). Recently, Bedi et al. (2013) recognized different nappe structures in the Turkish part of the "Strandzha Massif".

We discovered Early Triassic foraminifera in recrystallised limestones to the south-east of Çağlayık village (Fig. 1) and found the evidence for a post-extinction foraminiferal assemblage above the Permian-Triassic boundary.

The Permian-Triassic mass extinction event was the most severe of the Phanerozoic mass extinctions (Erwin, 1993) with more than 90% of marine species eliminated because of the destruction of the marine ecosystem (Jin et al., 2000; Bambach et al., 2002). Potential causes and effects of the end-Permian mass extinction have been proposed remain in debate. Triggers such as a bolide impact, volcanic eruptions, oceanic anoxia, rapid climate change, catastrophic release of seafloor methane and so on (Baud et al., 1989; Erwin, 1993, 2006; Wignall and Twitchett, 1996; Hallam and Wignall, 1999; Becker et al., 2001; Kaiho et al., 2001; Weidlich et al., 2003; Knoll et al., 2007) have been suggested as the most likely causes for this crisis.

The foraminifers are one of the most important fossil groups through the P-Tr transition because they are very common and distributed in a variety of facies settings. They enable understanding of biotic extinction pattern *via* quantitative analysis and their evolutionary history across the P-Tr transition (Rampino and Adler, 1998; Jin et al., 2000; Groves et al., 2005; Song et al., 2009a, b, 2013)

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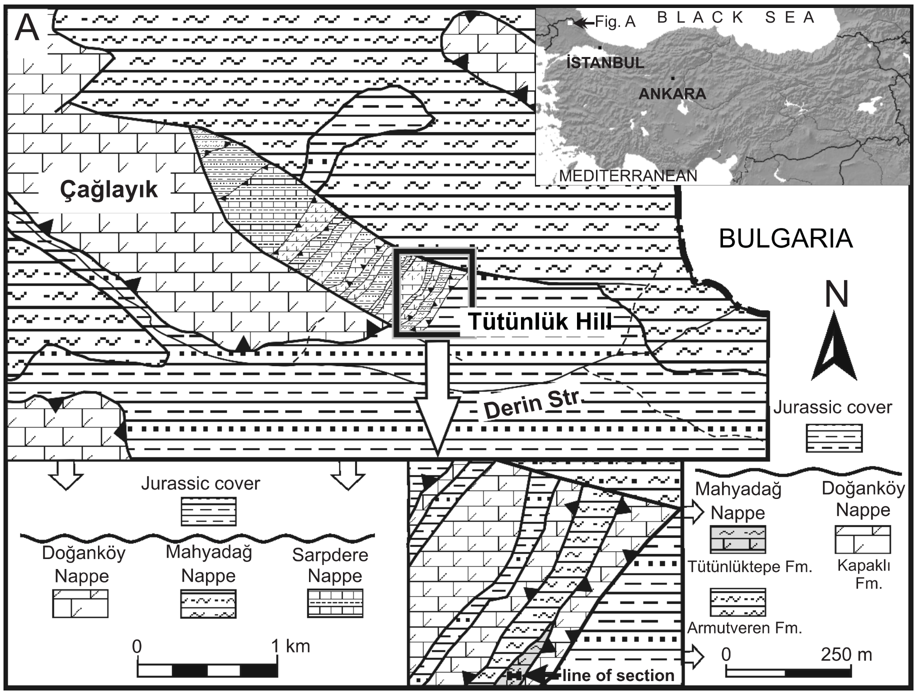

Fig. 1. Geographical and the geological map of the study area and location of the Çağlayık section (after Bedi, 2009)

A section of recrystallised limestones is well-exposed in the Turkish part of the "Strandzha Massif" and up until now has not been found in Bulgaria where Early Triassic foraminifera-bearing recrystallised limestones have only been documented by Trifonova (1978, 1984, 1992, 1993, 1994), Chatalov and Trifonova (1985) and Chatalov (1990) from the Peri-Tethyan (Subbalkanide) type (Sveti Ilija Ridge) and Tethyan (Strandzha) type Triassic of Strandzha Mountain (south-east Bulgaria). In the limestones belonging to the Omarcevo Formation (Sveti Ilija Ridge), the Lower Triassic *Meandrospira pusilla* acme-zone with a characteristic of the Spathian Stage foraminiferal association has been recognized. The species *Meandrospira pusilla* (Brönnimann), *Arenovidalina chialingchiangensis* (Ho), *Cyclogyra mahajeri* Broennimann, Zaninetti and Bozorgnia, *Kamurana chatalovi* Trifonova, *Ammodiscus multivolutus* (Reitlinger), and *Glomospira sinensis* Ho have been determined and figured. In the Tethyan (Strandzha) type Triassic the Lower Triassic corresponds to the lower and middle part of the Goljamo Bukovo Formation (Chatalov and Trifonova, 1985) where only few foraminifera species have been found, such as *Meandrospira pusilla* (Ho), *Nodosinella* cf. *rostrata* Trifonova, *Ammodiscus* sp., and *Nodosaria* sp. The aim of this study is to document the Early Triassic foraminifers (Induan) and to show the first post-extinction foraminiferal assemblage above the P-Tr transition in the Strandzha Nappes, north-west Turkey. Thus, the newly found foraminifers provide some insights into Early Triassic biostratigraphy and the foraminiferal extinction pattern across the P-Tr transition.

GEOLOGICAL SETTING

Recent studies along the Turkish-Bulgarian border have shown the presence of tectonic units which completely differ in stratigraphy, lithology and metamorphic features, and have revealed their thrust contacts between them (Bedi et al., 2013). These structural units in Turkey are called the Sarpdere Nappe (Subbalkanide type Triassic of Chatalov, 1980), the Mahyadağ Nappe (Strandzha type Triassic of Chatalov, 1980) and the Doğanköy Nappe (Sakar type Triassic of Chatalov, 1980) in ascending order. These three nappes are sealed by Lower Jurassic siliciclastic deposits.

The Early Triassic foraminifera in the recrystallised limestones were discovered in the Tütünlüktepe Formation of the Mahyadağ Nappe (Fig. 2) which is composed of Devonian (?)-Triassic successions. The lowermost Paleozoic succession of the Mahyadağ Nappe is Devonian (?)-Permian in age and is called the Armutveren Formation. The Armutveren Formation is composed of intercalations of reddish, yellowish, thin-bedded quartzite and calc-schist, dolomite and recrystallised limestone. The Tütünlüktepe Formation, which is 10-m-thick, displays discontinuous outcrops in the Turkish part of the "Strandzha Massif" and comprises intercalations of grey, dark grey, thin- to medium – and regularly-bedded recrystallised limestone and green, thinly foliated metasiltstone. This unit is observed around Tütünlüktepe Hill only on the road between Dereköy-Çağlayık in the Turkish portion of the "Strandzha Massif". The Tütünlüktepe Formation is underlain conformably by the Devonian (?)-Permian Armutveren Formation (Figs. 2 and 3). The Tütünlüktepe and the Armutveren formations are overlain with angular unconformity by the Early Triassic Çukurpınar Formation which is equivalent the the Struvnitsa Formation of Chatalov (1985) in Bulgaria and composed of metasiltstone, metaconglomerate with quartz schist interbeds, metamicroconglomerate and coarse-grained metasandstone. The Middle-Upper Triassic Adatepe, Tolpan, Kalina Chuka, Kaynakdere and Karlık formations are the succeeding units of Mahyadağ Nappe (Fig. 2).

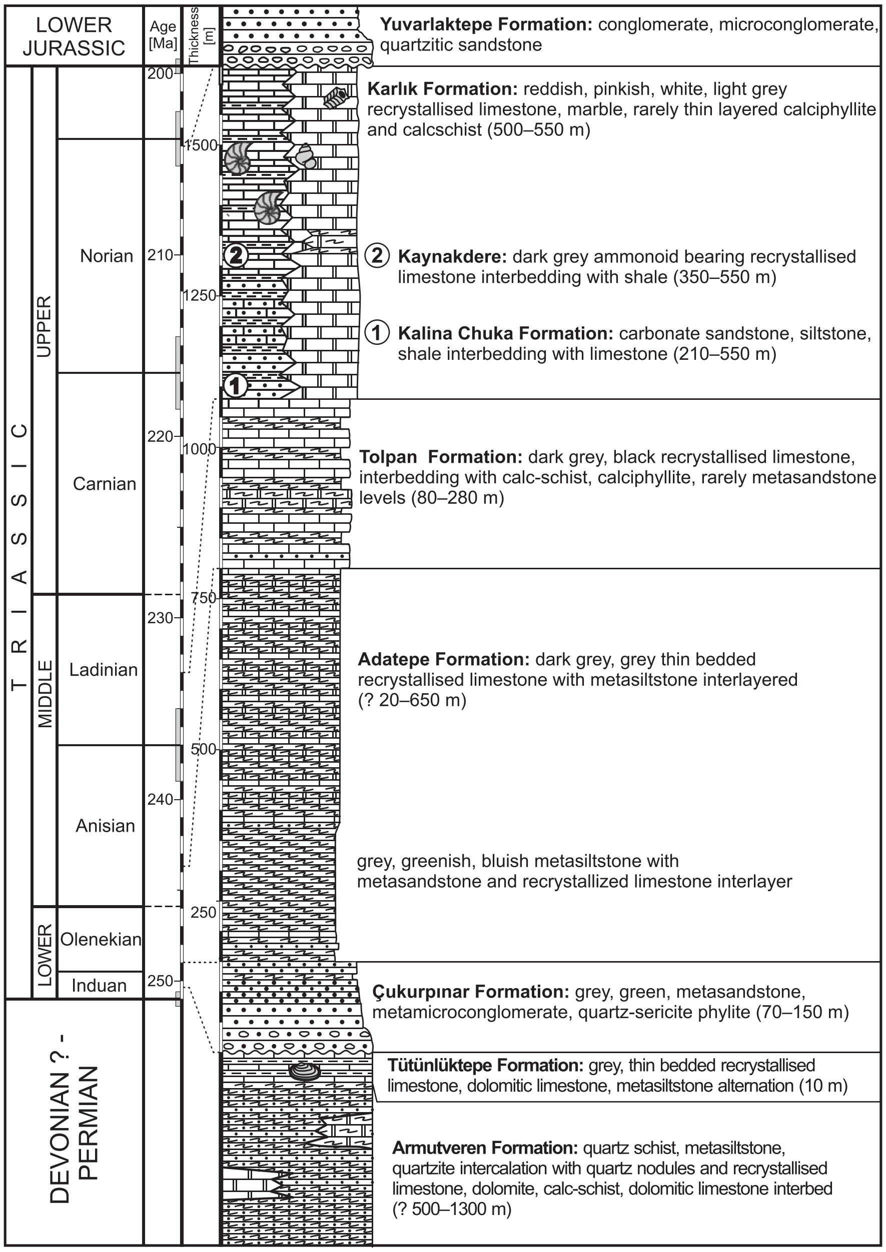

Fig. 2. Generalized stratigraphic columns of the Mahyadağ Nappe (Bedi et al., 2013)

MATERIAL

Twenty-five samples from the Çağlayık section (Kırklareli, south-east of Çağlayık village) were collected from the recrystallised limestones, dolomitic limestones and metasiltstones exposed there (Fig. 4). Dolomitic and recrystallised limestones levels are relatively rich in foraminiferal assemblages and represented by well-preserved specimens (Figs. 5 and 6). The collected samples have been processed for conodonts, but proved barren. Thin sections of the studied material are deposited in the MTA (General Directorate of Mineral Research and Exploration of Turkey) Paleontology Division.

RESULTS

Based on the relatively rich and well-preserved foraminiferal fauna, the rocks from the Çağlayık section have been effectively distinguished and classified (Figs. 5 and 6). The first sample (09-KK-214) from the base of the section was barren as regards foraminifera. The sample (09-KK-215) from the overlying bed contains very rare foraminifera represented by only *Ammodiscus* sp. and *Arenovidalina chialingchiangensis* (Ho). Sample 09-KK-216 is rich in foraminifera, including *Hemigordius* sp., *Ammodiscus* sp., *Arenovidalina chialingchiangensis* (Ho), *Globivalvulina bulloides* (Brady), *Glomospira* sp., ?*Rectostipulina quadrata* Jenny-Deshusses, *Diplosphaerina inaequalis* (Derville), *Earlandia* sp. and *Postcladella kalhori* (Brönnimann, Zaninetti and Bozorgnia). This part of the section is characterized by the presence of two Lazarus taxa, *Diplosphaerina inaequalis* (Derville) and ?*Rectostipulina quadrata* Jenny-Deshusses and two disaster species *Postcladella kalhori* (Brönnimann, Zaninetti and Bozorgnia) and *Earlandia* sp. This association characterizes the post-extinction foraminiferal assemblage after the Permian-Triassic mass extinction and is also present in the upper part of the section. The palaeobiogeographic distribution of these short-lived disaster forms is known from the western Tethyan area including Italy, Hungary, Yugoslavia, Bulgaria, Austria, Turkey and Iran (Trifonova, 1978; Rettori, 1995; Ünal et al., 2003; Groves and Altıner, 2005). Foraminifers recovered from samples 09-KK-218 and 09-KK-219 are very rare and they are assigned to only one species, *Ammodiscus* sp. Sample 09-KK-220 includes similar specimens to those described from 09-KK-216, with *Ammodiscus* sp., *Hemigordius* sp., *Earlandia* sp., *Arenovidalina chialingchiangensis* (Ho), *Postcladella kalhori* (Brönnimann, Zaninetti and Bozorgnia), *Glomospira* sp. After four barren samples ?*Rectostipulina quadrata* Jenny-Deshusses was found in sample 09-KK-225. The upper parts of the Çağlayık section yielded foraminifers, apart from sample 09-KK-226. The foraminiferal assemblages of sample 09-KK-227, 09-KK-228 and 09-KK-229 are *Ammodiscus* sp., *Hemigordius* sp., *Diplosphaerina inaequalis* (Derville) and *Endoteba*? sp. respectively. The foraminiferal abundance of the last samples from the recrystallised limestone level of the section is much smaller than in the underlying beds. Sample 10-KK-228 is the only sample that shows strongly recrystallised Lower Triassic ooids within all studied samples.

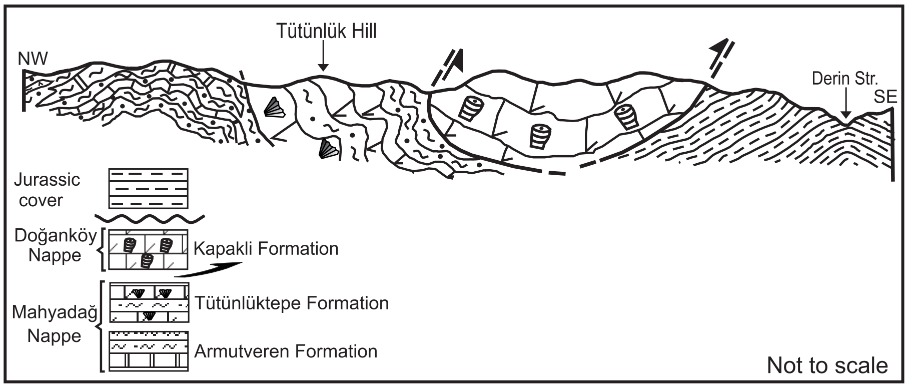

Fig. 3. Geological cross-sections showing the contact relationships between underlying and overlying successions of the Tütünlüktepe Formation

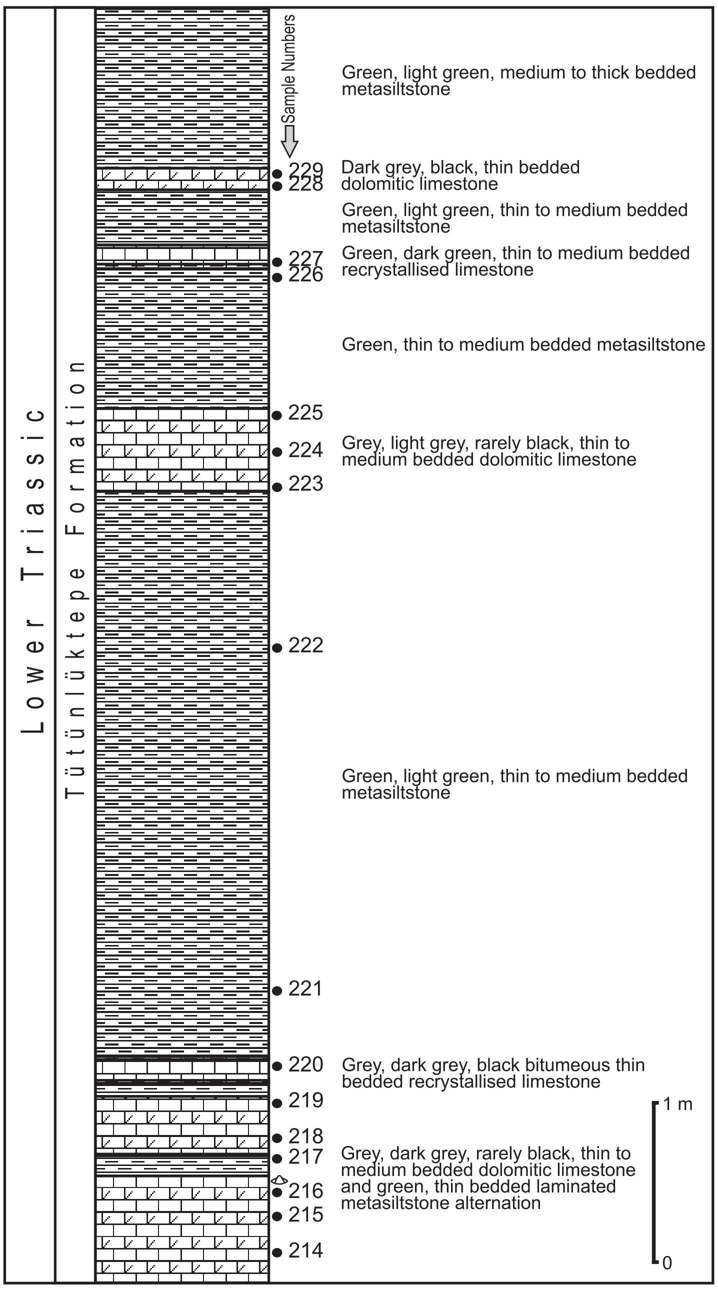

Fig. 4. Stratigraphical section of the Çağlayık section, showing the sampling levels and lithology

INTERPRETATION

The characteristic foraminiferal assemblage permits an exact chronostratigraphic determination for the recrystallised limestones, dolomitic limestones and metasiltstones of the section (Fig. 6). The foraminiferal assemblage of Çağlayık section from bottom to top (10-KK-214–10-KK-229) comprises only a post-extinction population characterized by disaster elements of the Early Triassic Epoch (Induan; Fig. 6).

Another argument supporting the Induan age of the studied rocks is the observation of the "Lilliput effect" (Urbanek, 1993), a pattern of size change through extinction events. Early Triassic animal body fossils and trace fossils are small relative to those in older and younger intervals. Size decreases sharply through the end-Permian extinction event and Permian-Triassic boundary and the smallest sizes are encountered in the earliest Induan (Song et al., 2011). According to the study of Twitchett (2007), all animal groups suffered a size reduction after the Late Permian extinction event and the body sizes of these animal groups remained low when compared to those of earlier Permian or later Triassic times. These smallest sizes of organisms are observed in *parvus* and *isarcisa* zones of the earliest Induan (Twitchett, 2006).

The lowest Triassic strata from the different Permian-Triassic sections of the world (e.g., Altıner et al., 2005; Groves et al., 2005, 2007; Shen et al., 2006; Haas et al., 2007) are characterized by mainly dolomitic limestone, recrystallised limestone with numerous tiny foraminifers and regular and planar millimetre-scale laminations with abundant pyrite crystals as in the Çağlayık section (Fig. 7). The occurrence of pyrite-rich lithofacies in Permian-Triassic boundary successions is evidence for widespread anoxia in shallow marine environments during the end-Permian mass extinction (Wignall and Hallam 1992, 1993; Wignall and Twitchett, 1996).

DISCUSSION

In the Çağlayık section, the recovered foraminiferal fauna is mainly represented by specimens of the genera *Diplosphaerina*, *Arenovidalina*, *Globivalvulina, Earlandia, Hemigordius, Rectostipulina* and *Postcladella.* The determined taxa include common elements of the Late Permian and the Early Triassic. The foraminiferal assemblage of both time intervals broadly indicates the

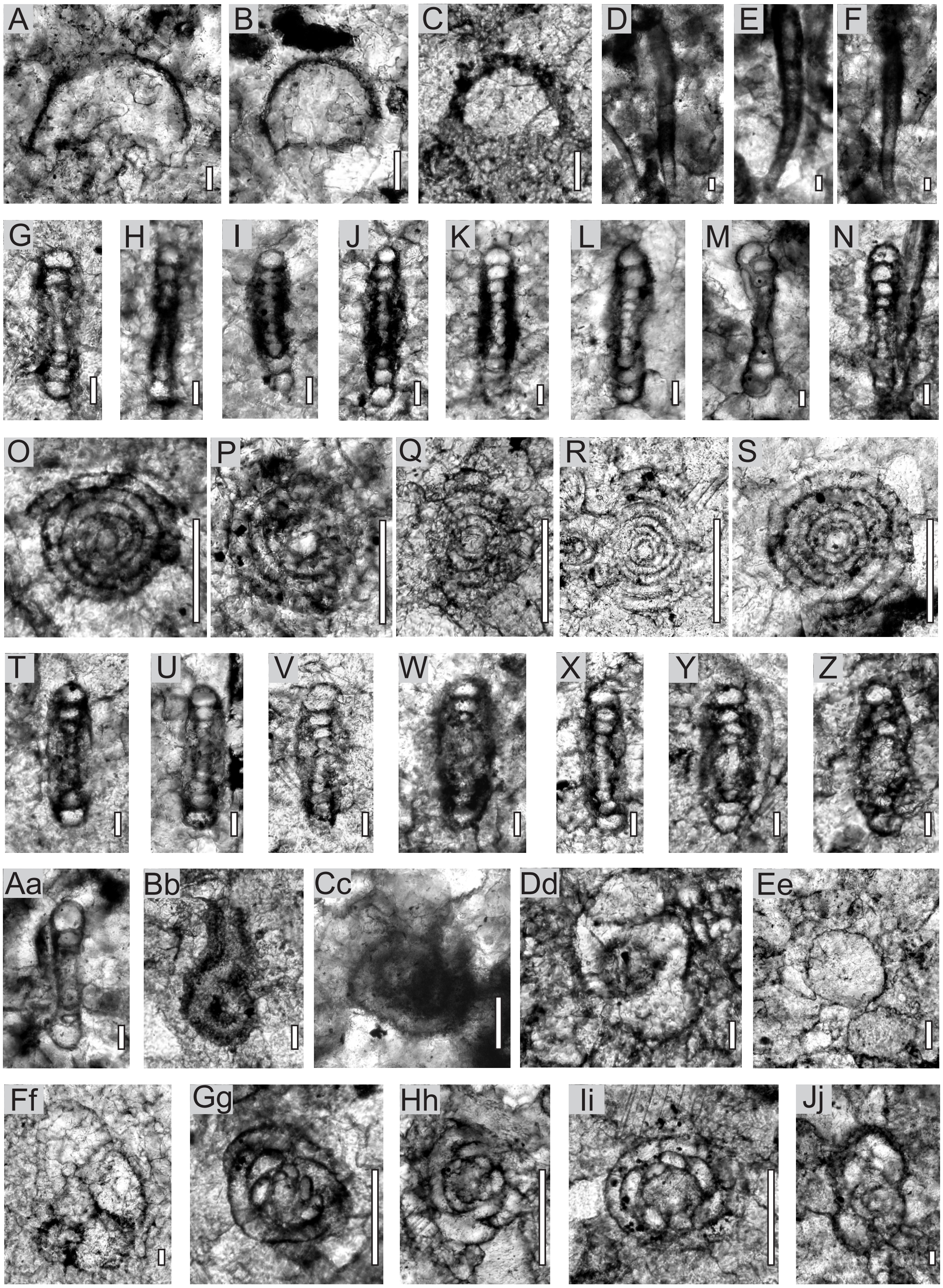

Fig. 5. Foraminifers of the Çağlayık section

A–C – *Diplosphaerina inaequalis* (Derville) (A, B – 09-KK-216, C – 09-KK-229); **D–F** – *Earlandia* sp. (09-KK-216); **G–N** – *Hemigordius* spp. (G–N – 09-KK-216, N – 09-KK-220); **O–S** – *Ammodiscus* spp. (O – 09-KK-227, P–S – 09-KK-216); **T–Z** – *Arenovidalina chialingchiangensis* (Ho) (T–X – 09-KK-216, Y – 09-KK-220, Z – 09-KK-215); **Aa–Cc** – *Postcladella kalhori* (Brönniman, Zaninetti and Bozorgnia) (Aa, Cc – 09-KK-216, Bb – 09-KK-220); **Dd, Ee** – ?*Rectostipulina quadrata* Jenny-Deshusses (Dd – 09-KK-225, Ee – 09-KK-216); **Ff** – *Globivalvulina bulloides* (Brady) (09-KK-216); **Gg–Ii** – *Glomospira* sp. (09-KK-220); **Jj** – *Endoteba* ? sp. (09-KK-228); scale bar is 20 μm end-Permian mass extinction and its disaster, survivor and aftermath components.

The Permian relict foraminifers consist of *Globivalvulina bulloides* (Brady), *Diplosphaerina inaequalis* (Derville), ?*Rectostipulina quadrata* Jenny-Deshusses and *Hemigordius* sp. *Globivalvulina bulloides* (Brady) is very common in Permian strata but also occur in lowermost Triassic successions as a survivor of the Permian-Triassic mass extinction (e.g., Bed 27, Meishan section from the southern China; Song et al., 2009a). These taxa show many similarities to those of the Meishan section "Survival Fauna Beds" (Bed 25–27; Chen et al., 2006) and compare with those of the second episode of extinction (Song et al., 2007). These Permian relict faunas have been described together with the earliest Triassic foraminifers such as *Postcladella kalhori* (Brönnimann, Zaninetti and Bozorgnia) and *Arenovidalina chialingchiangensis* (Ho). *Postcladella kalhori* (Brönnimann, Zaninetti and Bozorgnia) (with the type species *Rectocornuspira kalhori* Brönnimann, Zaninetti and Bozorgnia) is well-presented in the studied material. Krainer and Vachard (2011) recognized that *Cornuspira*? *mahajeri* and *Rectocornuspira kalhori* belong to the same genus and introduced the taxon as *Postcladella kalhori* n. comb. The known stratigraphic distribution of *Postcladella kalhori* is from latest Middle Permian to earliest Triassic strata; it is especially common and characteristic of Induan (earliest Triassic) strata globally, for instance, in South China (Ezaki et al., 2003; Song et al., 2007, 2009b; Galfetti et al., 2008), southern Turkey (Crasquin-Soleau et al., 2004; Altıner et al., 2005; Groves et al., 2005; Payne et al., 2007) and northern Italy (Groves et al., 2007). Some questionable occurrences of this taxon are indicated in the Olenekian (late Early Triassic; Krainer and Vachard, 2011). Representatives of the genus *Earlandia* are known from the level above the P-Tr mass extinction horizon in South China (Ezaki et al., 2003; Song et al., 2007, 2009a, b), southern Turkey (Altıner et al., 2005; Groves et al., 2005; Angiolini et al., 2007), Italy (Groves et al., 2007) and Hungary (Hips and Haas, 2006). *Postcladella kalhori* and *Earlandia* occur together with inferred disaster taxa foraminifer in the aftermath of the P-Tr crisis (Hallam and Wignall, 1997; Groves and Altıner, 2005; Groves et al., 2005, 2007; Song et al., 2007, 2009a, b).

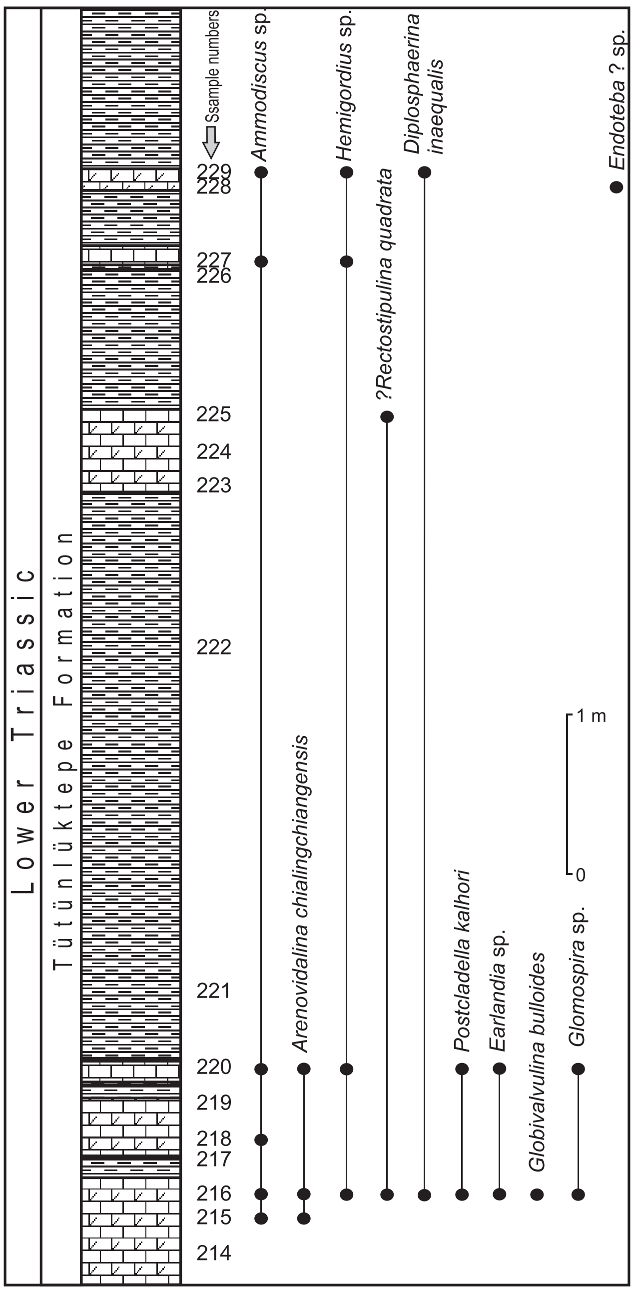

Fig. 6. Stratigraphic occurrences of foraminifers in the Çağlayık section

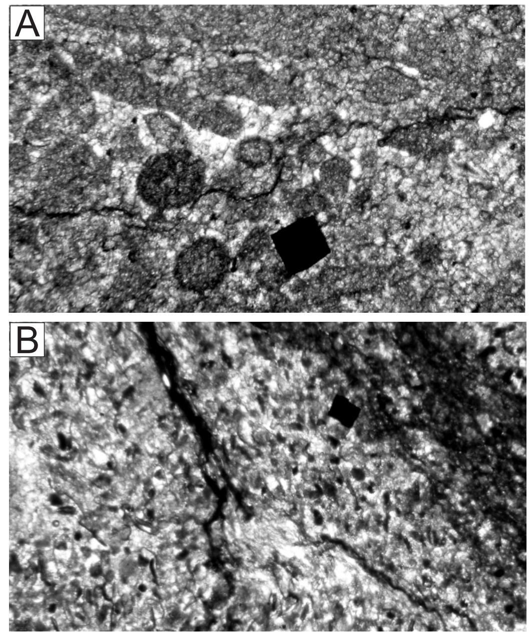

Fig. 7. Occurrences of pyrite cubes in the dolomitic limestone levels

A – sample 09-KK-216; **B** – sample 09-KK-228

The genus *Arenovidalina* is interpreted as a Lazarus taxon by Zaninetti et al. (1992), Rettori (1995), Altıner et al. (2005) and Groves and Altıner (2005) and its occurrence in Early Triassic (Induan?-Olenekian stages) probably represents a phyletic continuation of Permian forms assigned to *Neohemigordius* (Altıner et al., 2005). Based on published data (Altıner et al., 2005; Groves and Altıner, 2005; Song et al., 2011) the known stratigraphic range of *Arenovidalina chialingchiangensis* (Ho) is from the Olenekian (Early Triassic) to Anisian (Middle Triassic).

The successions from the Çağlayık section are thin overall because of the limited exposures of the Tütünlüktepe Formation which is 10-m-thick in the Turkish part of the "Strandzha Massif" and has no exposure in the Bulgarian part. The underlying and the overlying successions of the Tütünlüktepe Formation and their foraminiferal distribution could not be studied to see the contact with Permian units. We agree with previous studies that treated both *Earlandia* and *Postcladella* as disaster taxa (Hallam and Wignall, 1997; Groves and Altıner, 2005; Groves et al., 2005, 2007; Song et al., 2007, 2009a, b) and *Diplosphaerina inaequalis* (Derville), ?*Rectostipulina quadrata* Jenny-Deshusses, *Arenovidalina* and *Glomospira* sp. as Lazarus taxa (Song et al., 2011). Both disaster and Lazarus taxa described here characterize the post-extinction foraminiferal assemblage.

CONCLUSIONS

Five species and five species in open nomenclature belonging to ten genera of the calcareous foraminifers were discovered in recrystallised limestones to the south-east of Çağlayık village on the "Strandzha Massif". The foraminifera discovered represent a post-extinction population of Induan stage (Early Triassic) and comprise disaster and Lazarus taxa. The present study identified for the first time the presence of Permian foraminifers in the "Strandzha Massif" as relict in a post-extinction foraminiferal assemblage. The foraminifer associations are represented by widely distributed species and genera in association with Permian-Triassic boundary sections, allowing good correlation.

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