Int J Earth Sci (Geol Rundsch)
DOI 10.1007/s00531-010-0628-9

ORIGINAL PAPER

New radiolarian biostratigraphic age constraints on Middle Triassic basalts and radiolarites from the Inner Hellenides (Northern Pindos and Othris Mountains, Northern Greece) and their implications for the geodynamic evolution of the early Mesozoic Neotethys

Péter Ozsvárt · Lajos Dosztály · Georgios Migiros · Vassilis Tselepidis · Sándor Kovács

Received: 29 July 2010 / Accepted: 13 November 2010

Abstract The Avdella Mélange in the northern Pindos Mountains and its equivalent formation, the Loggitsion Unit in the Othris Mountains expose early Mesozoic (Mid-Late Triassic) oceanic fragments beneath the Western Greek Ophiolite Belt of the Inner Hellenides, Northern Greece. The mélange consists of locally interfingering blocks and slices of ribbon radiolarite, radiolarian chert and pillow basalt and is usually overthrust by Jurassic ophiolites. New Middle and Upper Triassic radiolarian biostratigraphic data are presented from radiolarites and basalt-radiolarite sequences within mélange blocks. Pillow basalts associated with the radiolarites provide clues to the opening of the Neotethyan ocean basin. The radiolarians indicate a Middle Triassic age (latest Anisian, probably early Illyrian), which is documented for the first time in the northern Pindos Mountains. The new radiolarian biostratigraphic data suggest that rift-type basalt volcanism already began in pre-Ladinian time (late Scythian?—Anisian). These basalts were then overlain by Upper Anisian to Carnian (?Norian) radiolarites.

Keywords Triassic · Hellenides · Greece · Radiolarians · Basalts · Radiolarites

L. Dosztály and S. Kovács: Deceased.

P. Ozsvárt (✉)
Hungarian Academy of Sciences–Hungarian Natural History Museum, Research Group for Paleontology, P.O. Box 137, 1431 Budapest, Hungary
e-mail: ozsi@nhmus.hu

G. Migiros
Laboratory of Mineralogy-Geology, Agricultural University, Iera Odos 75, 11855 Athens, Greece

V. Tselepidis
Institute of Geology and Mineral Exploration, Messoghion 70, 11855 Athens, Greece

L. Dosztály
Hungarian Geological Institute, Stefánia u. 14, 1143 Budapest, Hungary

S. Kovács
Geological, Geophysical and Space Science Research Group, Hungarian Academy of Sciences–Eötvös Loránd University, Pázmány P. sétány 1/C, 1117 Budapest, Hungary

Introduction

Early rift-related submarine volcanics and related deep-sea sedimentary units, including radiolarites of the Western Tethys orogenic belt, provide important clues to the geodynamic evolution of the early Mesozoic Neotethys. Dating of intercalated radiolarites and basalts can help to constrain the initial opening of Neotethys. Most geodynamic reconstructions suggest onset of ocean seafloor spreading during Middle–Late Triassic time (e.g. Jones and Robertson 1991; Jones et al. 1992; Danelian et al. 2000; Danelian and Robertson 2001; Bortolotti et al. 2001, 2006; Robertson 2007). Previously, the oldest biostratigraphic ages (upper Illyrian, Anisian) came from similar mélanges that extend from the Inner Dinarides to the Inner Hellenides. An upper Illyrian (Anisian) age was specifically reported from the Mirdita Zone in Albania (Chiari et al. 1994, 1996; Kellici et al. 1994; Marcucci et al. 1994; Bortolotti et al. 2006; Gawlick et al. 2008), where radiolarian cherts are associated with MOR-type basalts and also from basalt-radiolarian chert sequences in the Othris Mountains (Bortolotti et al. 2008).

The aim of this study is to present new radiolarian biostratigraphical age data from several localities in the northern Pindos Mountains, where radiolarites are intercalated with and directly overlie basalts. In addition, we

Published online: 05 January 2011

give results from one locality in the Othris Mountains, where the contact relations are less well defined but where the oldest known radiolarian fauna also occur. We also compare our new data with similar Neotethyan units in southeast Slovakia and northeast Hungary and more widely throughout the Inner Dinarides and Inner Hellenides as a whole. The results allow an improved reconstruction of the early evolution of the Mesozoic Tethys.

Geological setting

The Pindos and Othris Mountains, where the radiolarian data come from, form parts of the Western Greek Ophiolite Belt (Fig. 1). Both areas consist of thrust sheets and mélange (Jones and Robertson 1991) and are assigned to the Maliak Zone (Ferrière 1976, 1982) or to the Pindos-Othris zone (Jones and Robertson 1991; Rassios and Smith 2000). The regional tectono-stratigraphy comprises the following units: 1. Triassic rift-related basalts and sediments within tectonic-sedimentary mélange (Avdella Mélange in the northern Pindos Mountains: Jones and Robertson 1991; Kemp and McCaig 1984; Pe-Piper 1998; Saccani et al. 2003; Loggitsion Unit in Othris Mountains: Ferrière 1982), 2. Middle Jurassic MORB-type and ophiolitic sequences (Dramala Complex in the northern Pindos Mountains: e. g. Capedri et al. 1980; Jones and Robertson 1991; Metallion, Fourka and also some other units in the Othris Mountains: Ferrière 1982), 3. Mesozoic pelagic, platform-related sedimentary sequences, and turbiditic slope sediments (Dio Dendra Group: in the northern Pindos Mountains: Kemp and McCaig 1984; Jones and Robertson 1991; but no equivalent formation exists in the Othris Mountains), 4. Upper Cretaceous platform carbonates (Orliakas group in Northern Pindos Mountains: Jones and Robertson 1991); 5. Uppermost Cretaceous—Eocene flysch (Pindos Flysch in Northern Pindos Mountains: Richter 1976 (the latter two are not distinguished on the geological map of Othris by Ferrière (1982).

Northern Pindos Mountains

Avdella Mélange

Traditionally, the Avdella Mélange is considered as a tectono-stratigraphic complex, which includes massive extrusive rocks (e. g. pillow basalts), various pelagic sediments and metamorphic blocks (Jones and Robertson 1991; Jones et al. 1992). This lower "volcanosedimentary" unit (e.g. ophiolitic olistostrome/mélange) was assigned a Triassic age using radiolarian biostratigraphic data (De Wever et al. 1979). Samples that yielded Triassic radiolarians were collected from Kandila Hill, northwest Liagkouna Mountain, close to Armata and near to Alatopetra (Fig. 2). Poorly preserved radiolarian assemblages was assigned a Carnian–Norian age, based on the occurrence of *Capnuchosphaera* spp. and *Xiphothecaella* spp. This age is supported by a detailed revision of the family Capnuchosphaeridae (Kozur et al. 2009) and the family Xiphothecaellidae (Kozur et al. 2007). The mélange is overthrusted by Jurassic ophiolitic complex (Fig. 2), which is unconformably overlain by Upper Cretaceous rudist limestone in some areas. Thrust sheets and blocks of sedimentary rock within the mélange include pelagic carbonates, cherty limestones and radiolarian cherts. The matrix of these blocks and dismembered thrust sheets is mainly shale, marl and sandstone (Jones and Robertson 1991).

Section NE of Avdella, radiolarite overlying pillow basalt

The basalt/radiolarite section is a block within the mélange with a sheared black shale matrix and is exposed on the northern side of a small stream gorge where it crosses the road (Fig. 3.1–5). Green pillow lava is overlain by a 6–7 m thick, steep to subvertical succession of red, ribbon radiolarite (Fig. 3.4). Eight samples (I/7/1–I/9/3) were collected from this section.

Section on the southeastern ridge of Mt. Straggopetra (including Mt. Lekani)

It includes green, amygdaloidal basalt lava ~300 m in thick with upper Scythian to lower Anisian-aged slide blocks as "olistoliths" (Migiros and Tselepidis 1990, Fig. 2) of Hallstatt-type pelagic limestone. Overlying red radiolarites, several tens of meters thick form the summit of Mt. Lekani (Fig. 5). Apparently, the contact between basalts and red radiolarites is continuos, but mostly covered by grass. A close intermixing between reddish to pinkish micrite and amygdaloidal pillow basalt of the same color provides evidence that the lime mud was unlithified during extrusion of the lava (Fig. 6.3–5). Hallstatt-type limestone blocks ranging in size from <10 cm in across tens of meters in size (to 10–12 m in height and 40–50 m in length) appear to have been emplaced together in one gravitational emplacement event. The overlying red radiolarite outcrop beneath the summit of Lekani Mt. and southeastwards toward the road connecting Lavda to Avdella. Three samples (Av-3,4,6) were collected from this section.

Section NW of Avdella village

The outcrop comprises large blocks with intercalations of slightly chloritized basalt, pillow basalt with red limestone, mudstone, chert and radiolarite (Fig. 6.1). Four samples

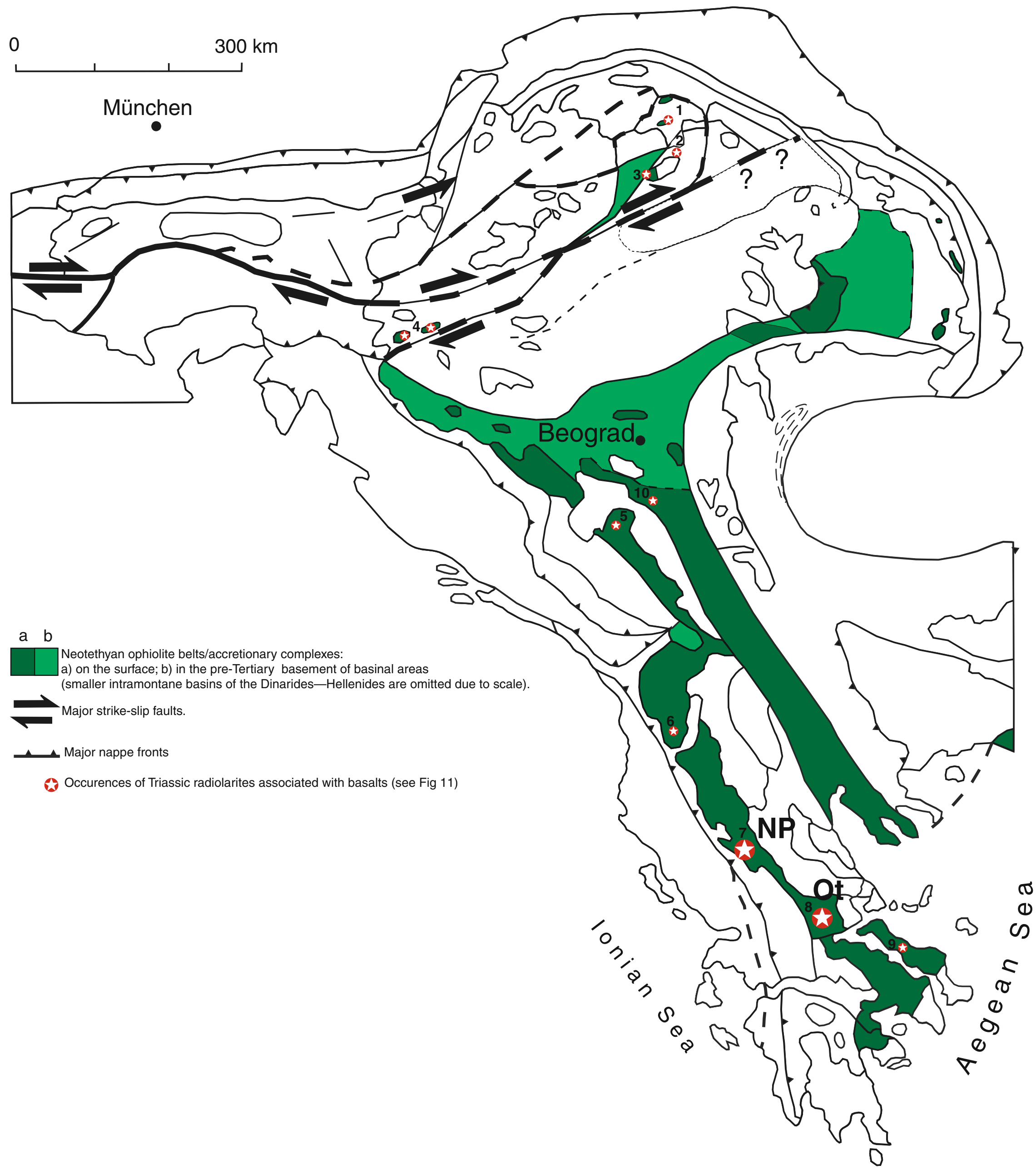


Fig. 1 Neotethyan ophiolite belts in the Alps, Carpathians, Dinarides and Hellenides and their dispersed fragments (= small-sized "*disrupted terranes*" of Neotethyan oceanic origin) in the Circum-Pannonian region. (*Base map* simplified after Kovács et al. 2000). *NP* North Pindos, *Ot* Othris

(G.4, G.4/1-3) were taken from the limestone and radiolarite sequence.

Othris Mountains area

Loggitsion unit

In the central part of Othris Mountain area (Fig. 7), thrust sheets and blocks of pillow basalts are overlain by (or locally interfinger with) ribbon radiolarites and cherts (Ferrière 1976, 1982; Bortolotti et al. 2008). The blocks usually occur in a strongly sheared black shale matrix. The radiolarites are dated as Middle to Upper Triassic (upper Anisian–lower Ladinian to Norian) in age (Bortolotti et al. 2008).

Section S of Metallion

In its lower part of the section dark green, basalt whit sheeted dykes is exposed (up to a few meters above the

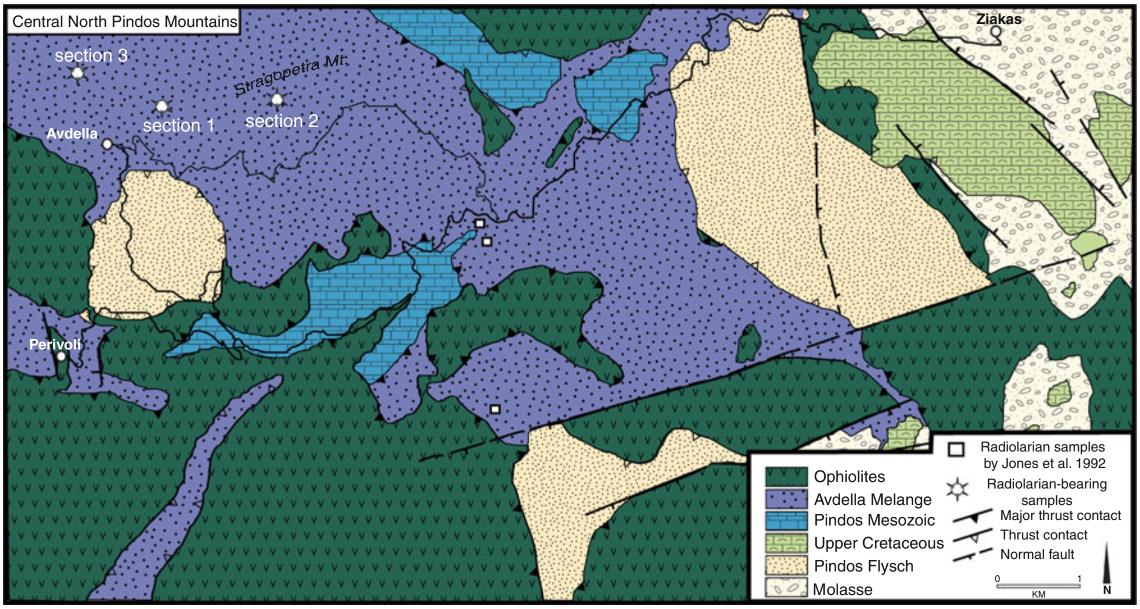


Fig. 2 Geological sketch map of the central part of Northern Pindos Mountains (area between Avdella–Perivoli–Ziakas villages, W of Grevena town), after Jones and Robertson (1991), slightly modified. Section 1 (N:40°00′44.30; E:21°08′02.48) = Section NE of Avdella, radiolarite overlying pillow basalt; Sect. 2 (N:40°00′52.31; E:21°09′48.07) = Section on the southeastern ridge of Mt. Straggopetra (incl. Mt. Lekani); Sect. 3 (N:40°01′24.5; E:21°05′34.8) = Section NW of Avdella village

Fig. 3 Avdella Mélange, Northern Pindos Mountains. Gorge of a small creek NE of Avdella village, opening to the forestry road encircling the head of the Avdella Valley. *1*: The section is exposed ∼1.5 km to the NE of Avdella village (Fig. 2), along a forestry road paralleling the valley. Opening of the gorge to the forestry road, with the small creek in the middle, exposing the sheared *black* shale matrix of the mélange in the *back* part. *2*: Typical mélange exposed in the *back* part of the gorge, with sheared *black* shale matrix and *pinkish* micritic limestone, *greenish* basalt blocks. *3*: *Lower* part of the investigated *red* radiolarite section. *4*: The investigated radiolarite section. *5*: The *upper* part of the investigated section, with a fault cutting across. *6*: Contact between the uppermost part of the underlying *green* basalt and the base of the overlying *red* radiolarite

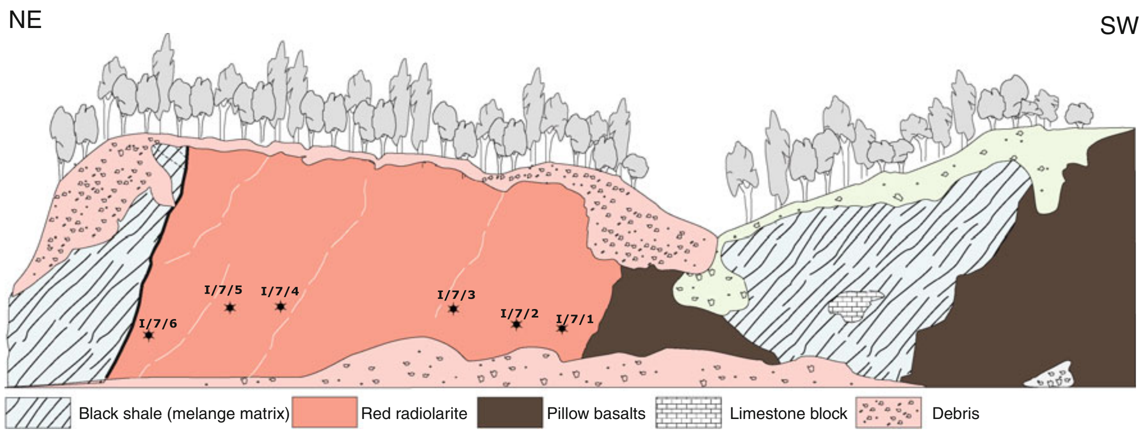
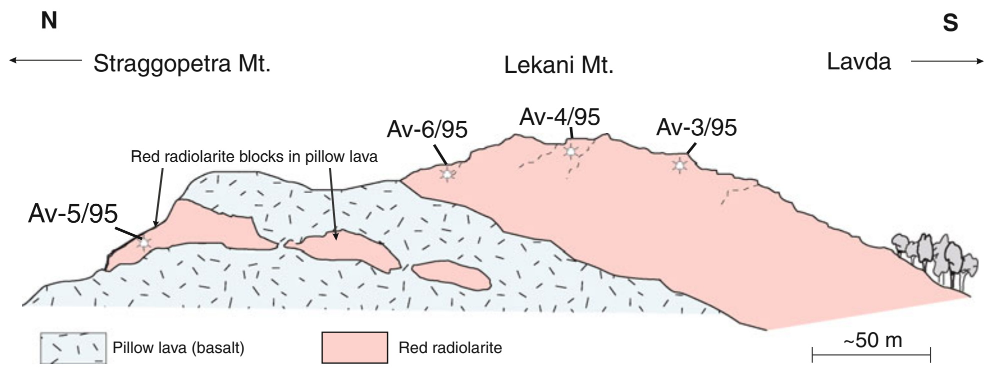


Fig. 4 Section NE of Avdella, exposing radiolarite overlying pillow basalts in Avdella Mélange, Northern Pindos Mountains

Fig. 5 This section is located on the southeastern ridge of Mt. Straggopetra (1,656 m), at an altitude of ~1,400 m above sea level



road), overlain by poorly exposed black shale (1–2 m) and red radiolarite (2–3 m) (Figs. 6.2; 8).

Radiolarian fauna and biostratigraphy

Radiolarians were extracted from the cherts and red radiolarites using hydrofluoric acid and standard laboratory techniques (De Wever et al. 2001). Preservation is generally poor, sometimes very poor, but a few identifiable taxa have been found suitable for biostratigraphic dating (Figs. 9, 10). Table 1 summarizes the taxa identified in samples from the sections.

Preliminary results of our investigations (Ladinian-Carnian age of radiolarites) are mentioned in Skourtsis-Coroneou et al. 1995. The first sample (I/7/1) of the section NE of Avdella, which was taken just a few centimeters above a basaltic block (Fig 3.6), yielded numerous unidentifiable spongy shells and a few slightly curved, apical polar spines of an Oertlispongidae species. Presumably belonging to the genus *Paroertlispongus* Kozur and Mostler, 1981. Several genus of the family Oertlispongidae Kozur and Mostler (in Dumitrică et al. 1980) were the stratigraphically most important radiolarian genus in the Tethyan realm during the Middle Triassic (Kozur and Mostler 1996). The stratigraphic range of the genus *Paroertlispongus* extended from the Middle Anisian (Bithynian) to the Early Carnian. We have identified *Paroertlispongus multispinosus* Kozur and Mostler in the *Tetraspinocyrtis leavis* radiolarian zone (correspond with *Paraceratites trinodosus* Ammonoid Subzone—lower Illyrian, Anisian) in the Felsőörs section of the Balaton Highland in Hungary (Ozsvárt and Dosztály 2007). The recently accepted GSSP (Global Boundary Stratotype Section and Point) of the Anisian–Ladinian stage boundary (Brack et al. 2003, 2005) places the base of the Ladinian at the base of the *Curioni* Ammonoid Zone. Consequently, based on the presence of the species *Paroertlispongus multispinosus* Kozur and Mostler, this sample could be assigned to the upper Anisian (lower Illyrian) to the lower Ladinian (upper Fassanian). In addition, based on the presence of *Eptingium manfredi* Dumitrică, sample I/7/2 can be assigned to the upper Anisian (lower Illyrian) to lowermost Ladinian (lower Fassanian). However, the presence of *Muelleritortis firmum* (Goričan) introduces some ambiguity in the age assignment. Originally, *M. firmum* (Goričan) was reported from the Longobardian of the Vršič and Mokronog sections in Slovenia (Goričan and

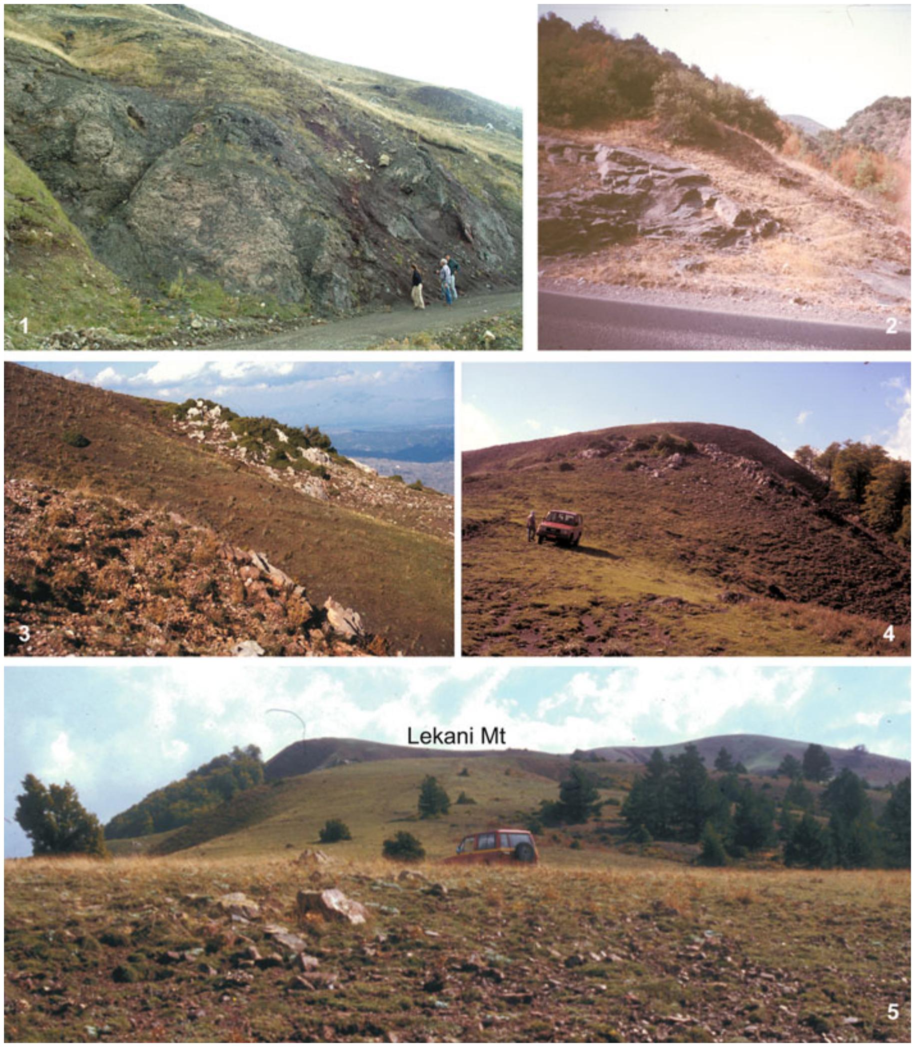


Fig. 6 Avdella Mélange, Northern Pindos Mts. and Loggitsion Unit, western part of Othris Mts. *1*: This section is located 3.5 km northwest of Avdella village. *Dark, purplish red* radiolarite (locality of sample G.4) and *red*, micritic limestone wedged between a *reddish* and *greenish*, amygdaloidal basalt block (*left*) and a serpentinite block (*right*). The latter also includes red micritic limestone fragments, tectonically reworked along a shear zones. NNE of Avdella village, along the forestry road encircling the head of the Avdella valley. *2*: Loggitsion Unit, western part of Othris Mts.: *Green* basalt, with some black shale, than *red* radiolarite (*behind the bush*) above it, yielding Ladinian radiolarians (described in Ozsvárt et al. 2006). Along the western side of the road leading from Domokos to Lamia, 5 km S of Metallion village. *3–4*: Slide blocks of reddish, micritic Hallstatt-type limestone in amygdaloidal basalt "matrix" on the southeastern extension of Straggopetra Mt. From the *lower* part of the limestone block shown on Fig. 4, Migiros and Tselepidis (1990) published an *Upper* Scythian ammonoid fauna. *5*: *Red* radiolarite succession of Lekani Mt. overlying the amygdaloidal basalt sequence of the SE extension of Straggopetra Mt

Buser 1990). This species co-occurs with *Triassocampe scalaris* Dumitrică, Kozur and Mostler, which is known from the upper Anisian (lower Illyrian) to the lowermost Ladinian (lower Fassanian) beds within the entire Eurasiatic Tethyan realm (Kozur and Mostler 1994). The most probable stratigraphic age range of *M. firmum* (Goričan) is therefore upper Anisian (lower Illyrian) to lowermost Ladinian (lower Fassanian), rather than Longobardian. In summary, sample I/7/2 is regarded as being upper Anisian (lower Illyrian) to lowermost Ladinian (Lower Fassanian).

Sample I/7/3 yielded poorly preserved radiolarians. The presence of the species *Annulotriassocampe* cf. *sulovensis* Kozur and Mock and *Capnuchosphaera* sp. suggests a younger age than lower Carnian for this bed, because the range of the genus *Annulotriassocampe* is Middle Anisian–Middle Norian, while the genus *Capnuchosphaera* first appears in the early Carnian in the Tethyan realm and disappears in the Middle Norian.

Samples I/7/4–6 were collected a few meters above basalt. The poorly preserved radiolarian assemblage of this samples

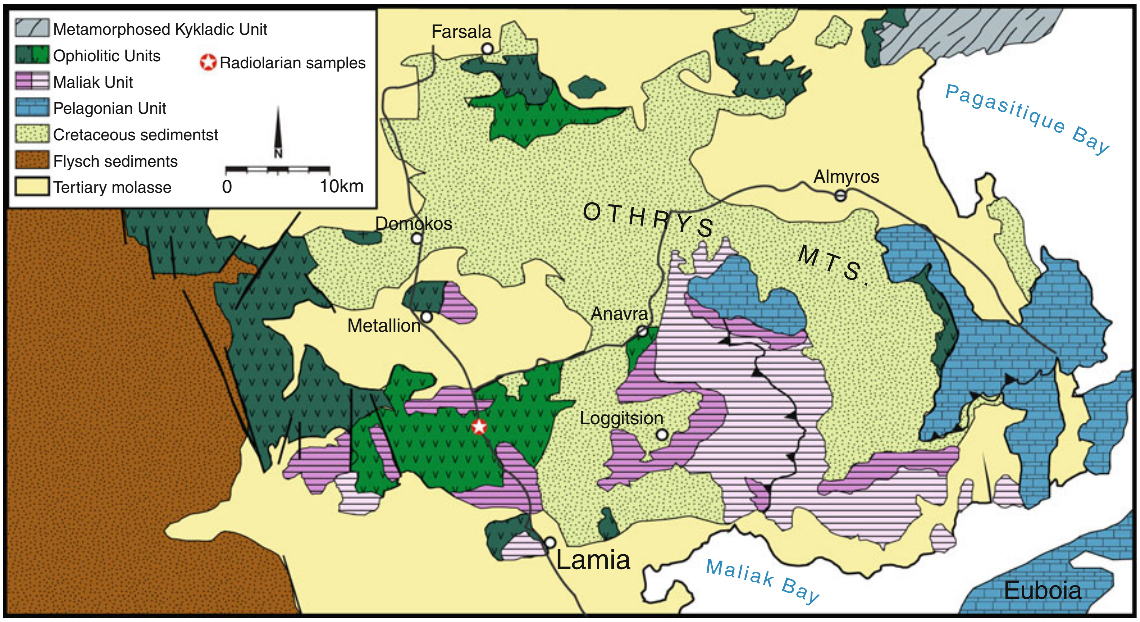


Fig. 7 Geological sketch map of the Othris Mts. (modified after Ferriére 1982), with location of the outcrop studied with radiolarite above basalt, shown on Fig. 3.2 (along the road between Metallion and Lamia)

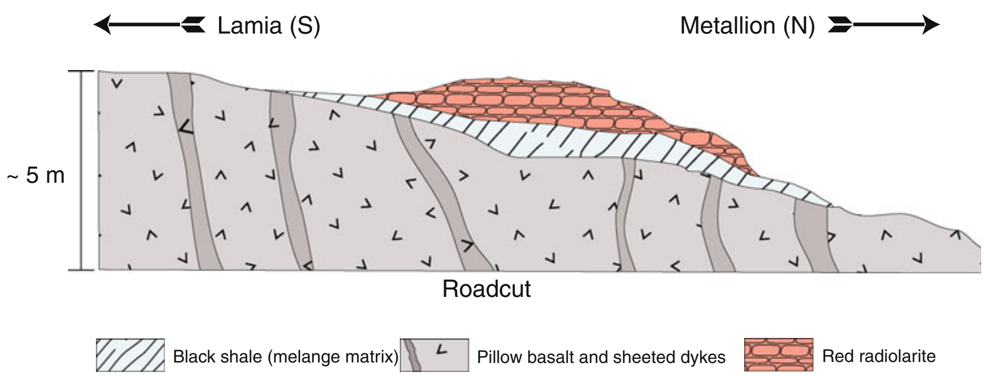


Fig. 8 The outcrop is located along the western side of a road leading from Domokos to Lamia, 10 km S of Metallion (Fig. 7), near the boundary with the dykes of the Loggitsion and ophiolite units

suggests a Norian age on the basis of the co-occurrence of *Capnuchosphaera crassa* Yeh, which first appears in the Carnian, and of *Capnodoce anapetes* De Wever which is known from the lower Norian beds in the Antalya Nappes (De Wever et al. 1979; De Wever 1982).

In summary, the lower part (sample I/7/1-2) of the red radiolarite succession exposed 1.5 km to the NE of Avdella village is certainly of Upper Anisian (Lower Illyrian) to lowermost Ladinian (Lower Fassanian) age. The middle part of the succession (Sample 1/7/3) is probably Upper Ladinian, and the upper part (Sample 1/7/4-6) Upper Triassic (probably Carnian to Lower Norian).

Poorly preserved radiolarian assemblages were also extracted from the three samples (Av-6/95, Av-4/95, Av-3/95) from the section on the southeastern ridge of Mt. Straggopetra (Table I). The probable age for the lower part of this section (Av-6/95) is Ladinian (see above for a discussion of *Oertlispongidae*). Based on the presence of some poorly preserved *Capnuchosphaeridae,* an Upper Triassic age (probably Carnian to Norian) is assumed for the upper part of the section (Av-4/95, Av- 3/95), because the common occurrence of the genus *Capnuchosphaera* is characteristic of the Carnian (Tuvalian) and is also very frequent in the Norian. Our data, in agreement with Migiros and Tselepidis (1990), show that the age of the amygdaloidal pillow basalt is between upper Scythian (base of Ammonite fauna; Migiros and Tselepidis 1990) and upper Anisian (or lowermost Ladinian).

Samples G.4, G.4/1–G.4/3 were collected from the section northwest of Avdella village where altered basalt is intercalated with red limestone, mudstone-chert and radiolarite. The co-occurrence of *Astrocentrus latispinosus*

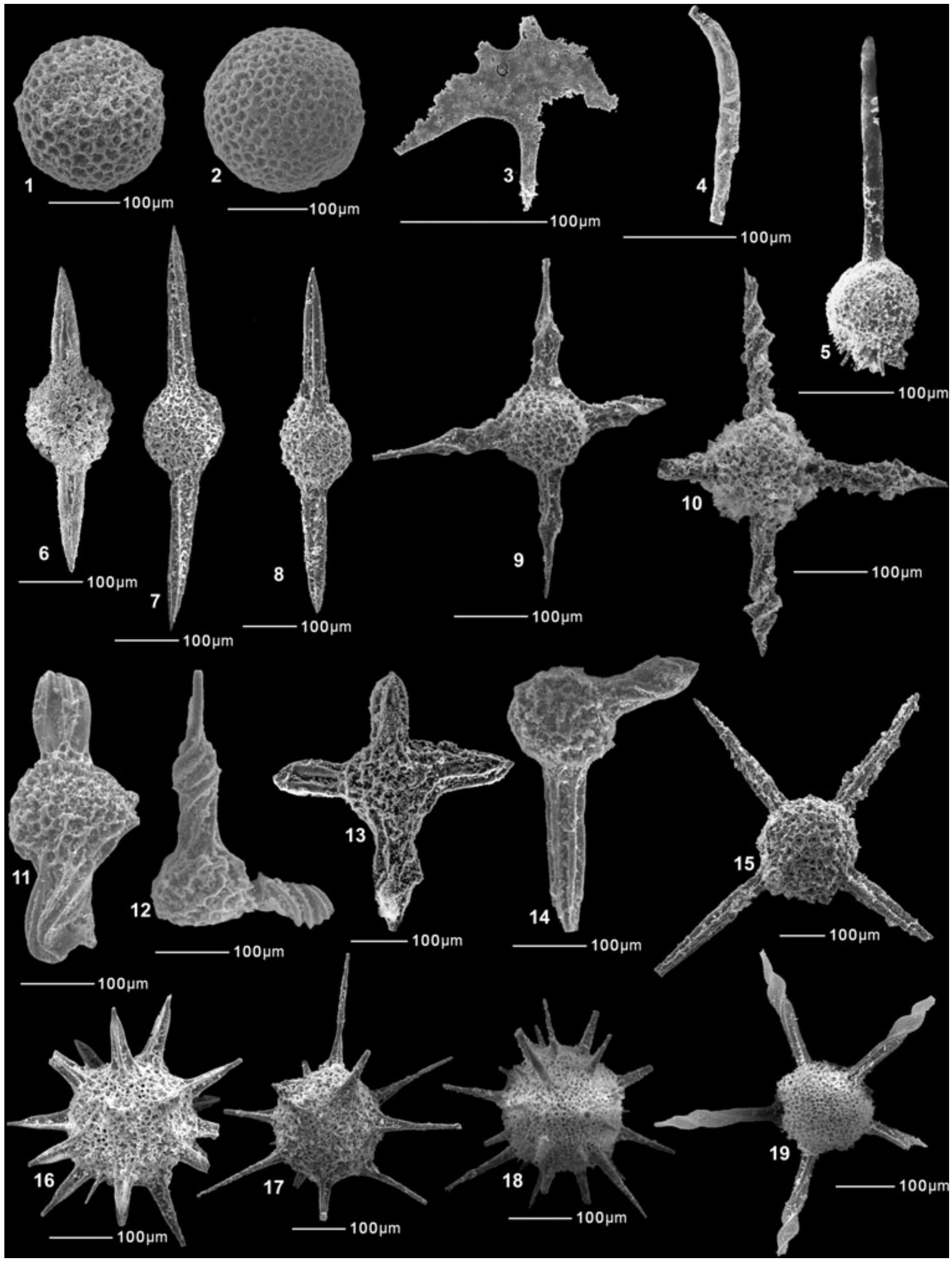


Fig. 9 Illustration of selected radiolarian taxa from the Pindos Mts. *1—Cenosphaera* sp. 1, G.4; *2—Cenosphaera* sp. 2, G.4; *3—Steigerispongus* sp., G.4/1; *4—Paroertlispongus* cf. *weddigei* (Lahm), I/7/1; *5—Paroertlispongus multispinosus* Kozur and Mostler, I/7/2; *6—Pseudostylosphaera coccostyla acrior* (Bragin), I/7/2; *7—Pseudostylosphaera longispinosa* Kozur and Mostler, G.4; *8—Pseudostylosphaera longobardica* Kozur and Mostler, G.4/1; *9—Plafkerium? muelleri* Dumitrică, Kozur and Mostler, G.4; *10—Plafkerium? nazarovi* Kozur and Mostler, I/7/2; *11—Muelleritortis* sp. 1, G.4; *12—Muelleritortis* sp. 2, G.4; *13—Muelleritortis firmum* (Goričan and Buser), I/7/2; *14—Tritortis* sp. G.4/2; *15—Parasepsagon asymmetricus* Kozur and Mostler, I/7/1; *16—Astrocentrus latispinosus* (Kozur and Mostler), G.4/3; *17—Astrocentrus pulcher* Kozur and Mostler, G.4/1; *18—Triassospongosphaera multispinosa* (Kozur and Mostler), G.4/3; *19—Pentaspongodiscus ladinicus* Dumitrică, Kozur and Mostler, G.4/1

(Kozur and Mostler), *Holzmadia reticulata* Dumitrică, Kozur and Mostler, *Plafkerium muelleri* Dumitrică, Kozur and Mostler, *Stauracontium trispinosum* (Kozur and Mostler), *Pseudostylosphaera longispinosa* Kozur and Mostler (see Table 1) suggests a Middle Triassic age (Illyrian–Longobardian) for the lower part of the section. The taxa identified from samples G.4/1–G.4/3: *Astrocentrus pulcher* Kozur and Mostler, *Pseudostylosphaera longobardica* Kozur and Mostler, *Steigerispongus* sp., *Triassospongosphaera multispinosa* (Kozur and Mostler), see Table 1, suggest a Longobardian age.

Sample II/3/1 was collected in the Othris Mountain section (Fig. 8), and a Middle Triassic (probably Illyrian) age is proposed based on the presence of moderately preserved radiolarians (see Table 1).

Discussion

Using radiolarians, we have dated four radiolarite outcrops within tectono-stratigraphic mélanges of the Northern Pindos and Othris Mountains beneath the Jurassic

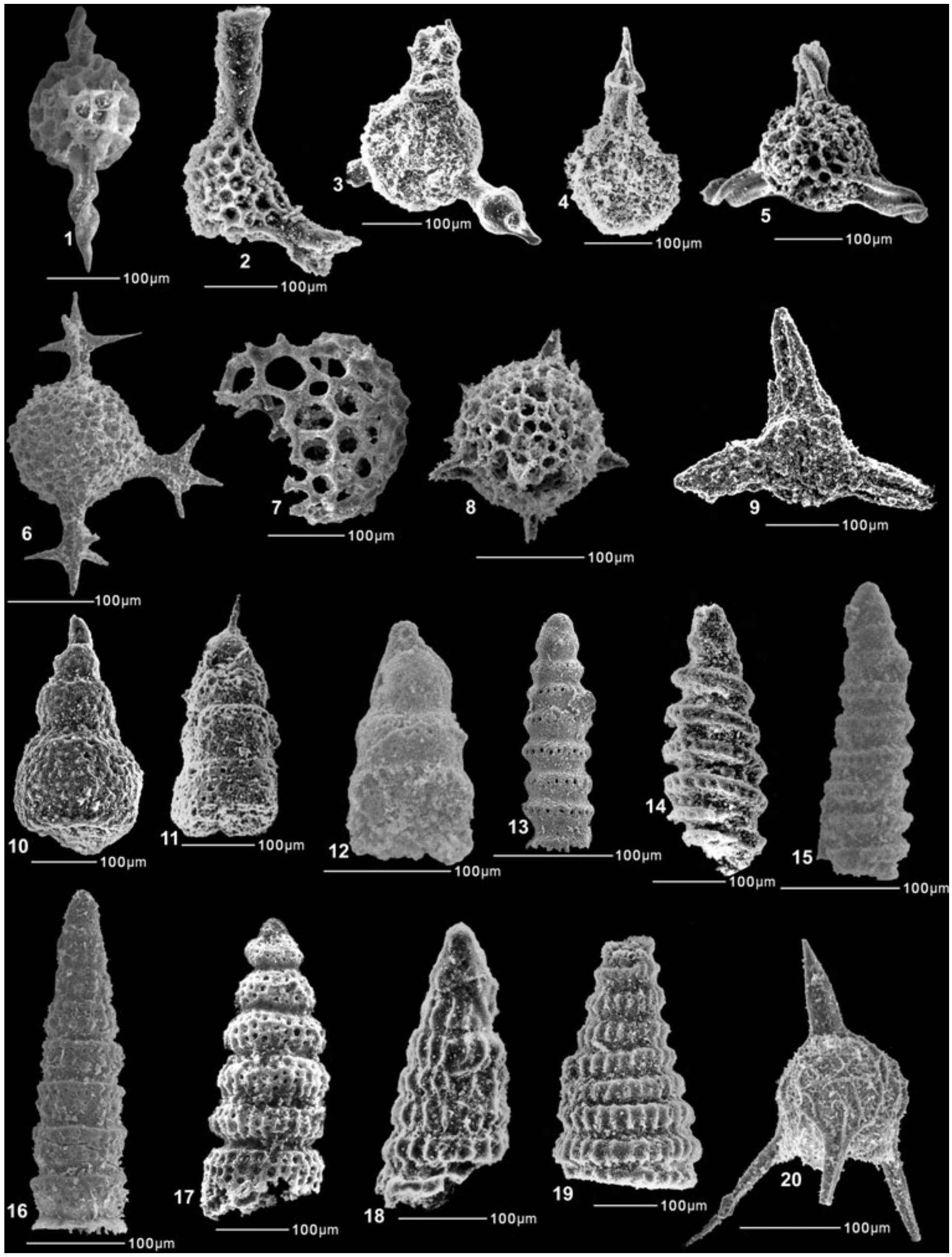


Fig. 10 Illustration of selected radiolarian taxa from the Pindos and Othris Mts. *1—Pantanellium* sp., Av-4; *2—Capnodoce cf. anapetes* De Wever, I/7/5; *3—Capnuchosphaera* sp. 1, II/4/5; *4—Capnuchosphaera* sp. 2, II/4/5; *5—Sarla* sp., II/7/3; *6—Stauracontium trispinosum* (Kozur and Mostler), G.4/1; *7—?Pentactinocarpus* sp., G.4/1; *8—Welirella* sp., G.4/3; *9—Eptingium manfredi* Dumitrică, I/7/2; *10—?Nakasekoellus* sp., Av-3; *11—Anisicyrtis* sp., I/7/1; *12—Anisicyrtis* sp., I/7/1; *13—Annulotriassocampe campanilis* Kozur and Mostler, I/7/1; *14—Annulotriassocampe* cf. *sulovensis* (Kozur and Mock), I/7/3 slightly deformed; *15—Annulotriassocampe* cf. *sulovensis* (Kozur and Mock), I/7/3; *16—Triassocampe* cf. *scalaris* Dumitrică, Kozur and Mostler, II/3/1; *17—Pararuesticyrtium* sp., I/7/3; *18—Corum kraineri* Tekin, I/7/6; *19—Whalenella* sp., II/4/5; *20—Holzmadia reticulata* Dumitrică, Kozur and Mostler, G.4/1

ophiolites in Northern Greece, two of them directly overlying basalts. The latter two near Avdella village in Northern Pindos Mts. provide evidence that begin already before the earliest Ladinian time. In particular, the Straggopetra—Lekani Mt. section shows that an $\sim$300 m thick amygdaloidal basalt succession had already erupted during the Anisian. The geochemical study on a single sample from this section shows that the within-plate (WP) origin is the most probable for these basaltic rocks (Kiss et al.). In addition, detailed geochemically analysis indicated the WP and MOR-type basalts from several localities in Avdella Mélange (Jones and Robertson 1991), and WPB and N-MORB from Othris Mountains (Bortolotti et al. 2008). Field evidence suggests that basaltic volcanism started on deep water environment (e. g. basalts intensively mixed with pelagic lime mud resulting in a characteristic peperitic facies) which might concerned to the initial stage of rifting of the Neotethys in the Hellenide sector or might connected to a seamount on the oceanic floor, although we do not know any characteristic slope or terrigenous sediments in this area, temporarily. The latter geodynamic model seems unlikely, as it is not probable, that in the initial stage of rifting there was enough space away from the rift zone for larger seamounts to have formed. Upper Scythian

Table 1 Middle and Upper Triassic radiolarian occurrences in Northern Pindos Mts. and in Othris Mts

	Northern Pindos Mountains															Othrys Mountains		
	Section NE of Avdella								Straggopetra Mt.			Section NW of Avdella village				Roadcut (S of Metallion)		
	Illyrian–Fassanian		?Carnian		?Carnian–Norian				Anisian-Ladinian	?Carnian			Longobardian					
	I/7/1	I/7/2	I/7/3	I/7/4	I/7/5	I/7/6	I/8/3	I/9/3	Av-6	Av-4	Av-3	G.4	G.4/1	G.4/2	G.4/3	II/3/1	II/4/5	II/7/3
Anisicyrtis sp.	+																	
Annulotriassocampe campanilis Kozur and Mostler	+																	
Annulotriassocampe cf. *sulovensis* (Kozur and Mock)			+															
Archaeospongoprunum mesotriassicum Kozur and Mostler																+		
Astrocentrus latispinosus (Kozur and Mostler)												+	+		+			
Astrocentrus pulcher Kozur and Mostler													+					
Capnodoce cf. *anapetes* De Wever					+													
Capnodoce sp.					+												+	
Capnuchosphaera crassa Yeh					+													
Capnuchosphaera sp. 1			+	+	+		+			+							+	
Capnuchosphaera sp. 2																	+	
Cenosphaera sp. 1												+						
Cenosphaera sp. 2												+						
Corum kraineri Tekin						+												
?Corum sp.		+																
Cryptostephandium sp.		+																
Eptingium manfredi Dumitrică		+														+		
Hozmadia reticulata Dumitrică, Kozur and Mostler												+	+					
Hozmadia sp.		+	+									+		+		+		
?Monocapnuchosphaera sp.										+								
Muelleritortis firmum (Goričan and Buser)		+																
Muelleritortis sp. 1												+						
Muelleritortis sp. 2												+						
?Nakasekoellus sp.					+						+						+	
Oertlispongus sp. 1	+								+							+		
Oertlispongus sp. 2	+	+							+									
Pantanellium sp.										+								
Pararuesticyrtium sp.			+															
Parasepsagon asymmetricus Kozur and Mostler	+																	
Paroertlispongus cf. *weddigei* (Lahm)	+	+														+		

Table 1 continued

	Northern Pindos Mountains															Othrys Mountains		
	Section NE of Avdella								Straggopetra Mt.			Section NW of Avdella village				Roadcut (S of Metallion)		
	Illyrian–Fassanian		?Carnian		?Carnian–Norian				Anisian-Ladinian	?Carnian			Longobardian					
	I/7/1	I/7/2	I/7/3	I/7/4	I/7/5	I/7/6	I/8/3	I/9/3	Av-6	Av-4	Av-3	G.4	G.4/1	G.4/2	G.4/3	II/3/1	II/4/5	II/7/3
Paroertlispongus multispinosus Kozur and Mostler		+																
Paroertlispongus sp.		+																
?Pentactinocarpus sp.													+					
Pentaspongodiscus ladinicus Dumitrică, Kozur and Mostler													+					
Plafkerium ? muelleri Dumitrică, Kozur and Mostler												+						
Plafkerium ? nazarovi Kozur and Mostler		+																
Pseudostylosphaera coccostyla acrior (Bragin)		+																
Pseudostylosphaera longispinosa Kozur and Mostler												+						
Pseudostylosphaera longobardica Kozur and Mostler													+					
Pseudostylosphaera sp.		+				+						+						
Sarla sp.									+								+	+
Spongopallium sp.												+				+		
Stauracontium trispinosum (Kozur and Mostler)												+	+					
Steigerispongus sp.													+					
Stichocapsa cf. *robusta* Matsuoka								+										
Tiborella magnidentata Dumitrică, Kozur and Mostler																+		
Triassocampe cf. *scalaris* Dumitrică, Kozur and Mostler																+		
Triassocampe sp.		+	+	+													+	
Triassospongosphaera multispinosa (Kozur and Mostler)															+			
Tritortis sp. 1													+	+				
Tritortis sp. 2													+					
Welirella sp.															+			
Whalenella sp.				+						+							+	

ammonoids and lowermost Anisian conodonts from a Hallstatt-type limestone block in the basal part of this Straggopetra—Lekani Mt. section (Migiros and Tselepidis 1990) suggest a lower age limit of the characteristic peperitic basaltic volcanism (Kovács et al. in press).

Having compared other areas, upper Illyrian (Anisian) to upper Ladinian radiolarians have been reported (partly from outcrops, where radiolarites are associated with basalts) from several localities in SE Slovakia (Meliaticum *sensu stricto*, Jaklovce subunit) (Mello et al. 1995) and the Tornakápolna unit of NE part of Hungary (Kozur and Réti 1986; Dosztály and Józsa 1992, Fig. 11). Upper Illyrian to lower Carnian radiolarian assemblages are also recorded in the Darnó and Mónosbél units (De Wever 1984; Dosztály and Józsa 1992) of NE Hungary. In addition, upper Ladinian to Middle Norian radiolarian assemblages were dated from Zagorje region (NW Croatia) where radiolarites directly overlie basaltic volcanics (Halamić and Goričan 1995; Halamić et al. 2001; Goričan et al. 2005) (Fig. 11). Within the Dinaric Ophiolite Belt (DOB) of Serbia (for references see Hein and Obradović 1988; Kovács et al. in press), several localities (Zlatibor and Zlatar Mts.) include Ladinian to lower Norian radiolarites associated with basalts (Obradović and Goričan 1988; Vishnevskaya et al. 2009). Further localities were reported from the Vardar Zone Western Belt (Ovčar-Kablar gorge, west of Čačak)

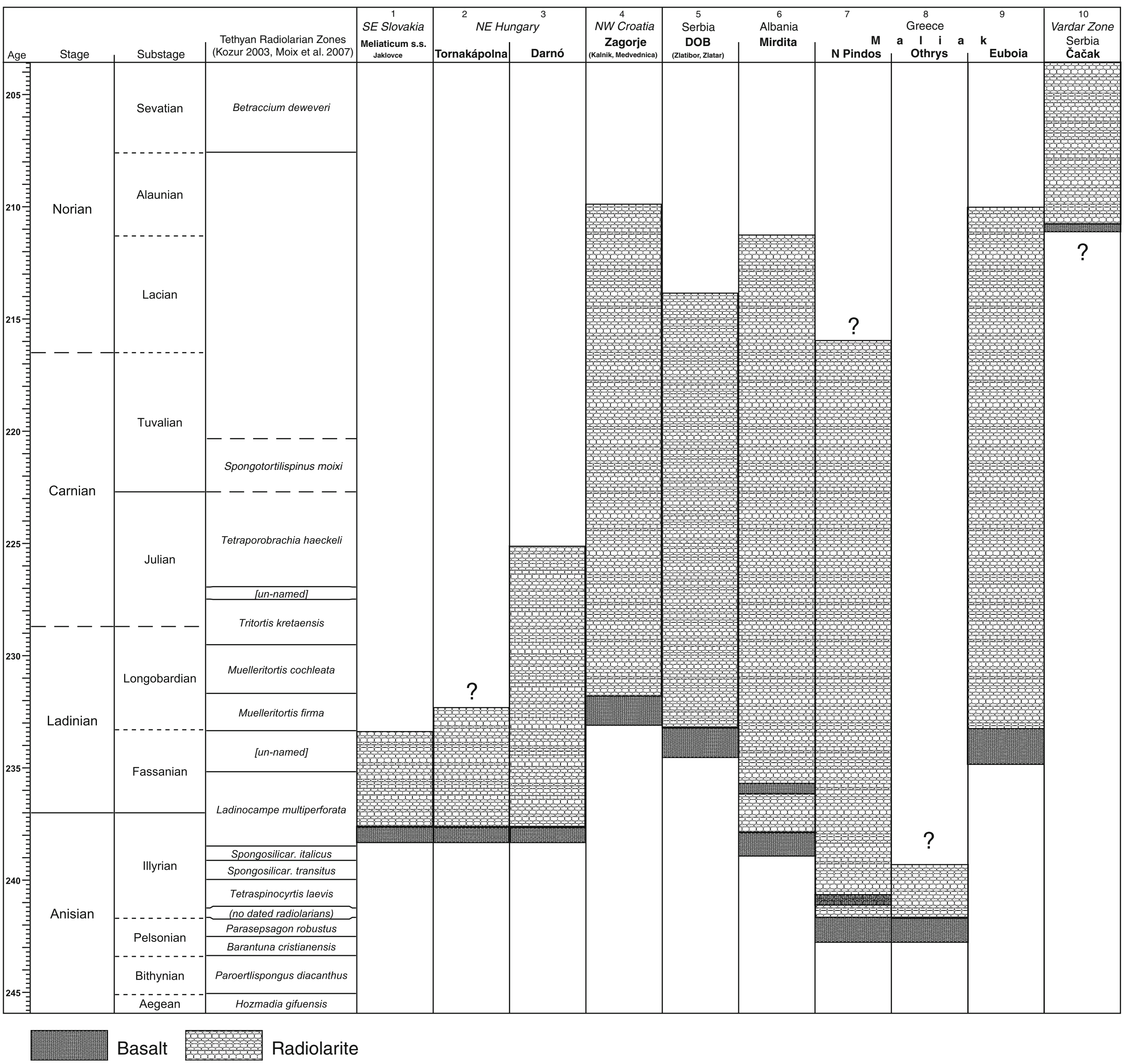


Fig. 11 Published age ranges of radiolarites with associated pillow basalts in the Western part of Mesozoic Neotethys. See text for References

and from DOB (Katusnica creek, near Gostilje, Zlatibor Mountains) where radiolarian-bearing rocks are associated with basalts, dated as Ladinian to Norian in age (Obradović and Goričan 1988; Vishnevskaya et al. 2009) (Fig. 11). Farther south, several localities in the Mirdita Zone in Albania have been shown to be of Anisian age (Fig. 11). Alkaline basalts within the mélange are directly overlain by upper Anisian (Illyrian) radiolarites (Chiari et al. 1994, 1996; Kellici et al. 1994; Marcucci et al. 1994; Bortolotti et al. 2006; Gawlick et al. 2008).

Conodont data from other parts of the Inner Hellenides are also relevant. Kaufmann (1976) has reported Upper Scythian red, Hallstatt-type limestones associated with basalts from Euboia Island. Upper Ladinian to ?Middle Norian radiolarian age data (Fig. 11) have also been reported from the Pagondas Mélange of Euboia Island (Danelian and Robertson 2001). As concerns conodonts, here we can add an own data from the Avdella Mélange: at the road branching W of Ziakas toward Avdella, we found Pelsonian (Middle Anisian) conodonts (*Gondolella hanbulogi*) in a ca. 2-m long, lens-like red limestone block within amygdaloidal basalt.

In the former area pelagic sedimentation began in the Late Scythian followed by basalt volcanism in the Late Scythian?—Anisian time. On the other hand, in the latter region, where remnants of the northwestern termination of the Neotethys ocean have been preserved, pelagic sedimentation began only in the Middle–Late Anisian time, followed by sporadically recorded basalt volcanism only in the Ladinian (Kovács 1984; Réti 1985; Lein 1987; Kozur 1991; Haas et al. 1995; Mello et al. 1995). Toward the northwest end of the Neotethys ocean, pelagic sedimentation began in the Middle–Late Anisian, followed by new oceanic crust forming in the Ladinian. Moreover, pelagic sedimentation (Hallstatt-type limestones, radiolarites) associated with basalt volcanism commenced in Oman already in the Middle–Late Permian (e. g. Maury et al. 2003). These age data clearly demonstrate the westwards propagation of Neotethyan rifting.

Conclusions

1. Radiolarites overlaying or intercalating with basalts from Northern Pindos Mountains and Othris Mountains, Inner Hellenides are dated as upper Anisian to lower Norian age.
2. The oldest radiolarians indicate Middle Triassic age (upper Anisian, probably lower Illyrian), which has been documented for the first time in Northern Pindos Mountains. This is the oldest radiolarian age data from this area.
3. The new data presented here constrain the beginning of basaltic volcanism in Western Greek Ophiolites Belt as pre-Ladinian (Late Scythian?–Anisian).
4. These biostratigraphic constraints suggest that Neotethyan rifting started earlier in the Hellenidic domain, than in the Eastern Alps-West Carpathian region, but significantly later than in Oman. This indicates a considerable time shift of the onset of Neothethyan rifting from east toward west.

Acknowledgments The authors thank A. H. F. Robertson for discussion in the field concerning the Avdella Mélange. J. Pálfy corrected on an earlier draft of the manuscript. Two anonymous reviewers and editorial comments by A. H. F. Robertson helped improve the clarity and presentation. Péter Ozsvárt acknowledges a grant of the Hungarian Scientific Foundation (OTKA F048341) in support of his studies on Triassic and Jurassic radiolarians. This work was also supported by OTKA (K61872 and K81298).

References

Bortolotti V, Chiari M, Marcucci M, Photiades A, Principi G (2001) Triassic radiolarian assemblages from the cherts associated with pillow lavas in Argolis Peninsula (Greece). Ofioliti 26:75

Bortolotti V, Chiari M, Kodra A, Marcucci M, Marroni M, Mustafa F, Prela M, Pandolfi L, Principi G, Saccani E (2006) Triassic MORB magmatism in the Southern Mirdita Zone (Albania). Ofioliti 31:1–9

Bortolotti V, Chiari M, Marcucci M, Photiades A, Principi G, Saccani E (2008) New geochemical and age data on the ophiolites from the Othris area (Greece): implication for the Triassic evolution ov the Vardar ocean. Ofioliti 33:135–171

Brack P, Rieber H, Nicora A (2003) A proposal for the GSSP at the base of the Curionii Zone in the Bagolino section (Southern Alps, Northern Italy). Albertiana 28:13–25

Brack P, Rieber H, Nicora A, Mundil R (2005) The Global boundary Stratotype Section and Point(GSSP) of the Ladinian Stage (Middle Triassic) at Bagolino (Southern Alps, Northern Italy) and its implications for the Triassic time scale. Episodes 28:233–244

Capedri S, Venturelli G, Bocchi G, Dostal J, Garuti G, Rossi A (1980) The geochemistry and petrogenesis of an ophiolite sequence from Pindos, Greece. Contr Mineral Petrol 74:189–200

Chiari M, Marcucci M, Cortese G, Ondrejickova A, Kodra A (1996) Triassic radiolarian assemblages in the Rubik area, and Cukali zone, Albania. Ofioliti 21:77–84

Chiari M, Marcucci M, Prela M (1994) Mirdita Ophiolites Project: 2 Radiolarian assemblages in the cherts at Fushe Arrez and Shebaj (Mirdita area, Albania). Ofioliti 19:313–318

Danelian T, Lekkas S, Alexopoulos A (2000) Découverte de radiolarites triasiques dans un complexe ophiolitique à l'extrême–sud du Péloponnèse (Agelona, Lakonie, Grèce). Comp Ren Acad Sci (Paris) 330:639–644

Danelian T, Robertson AHF (2001) Neotethyan evolution of eastern Greece (Pagondas Mélange, Evia Island) inferred from radiolarian biostratigraphy and the geochemistry of associated extrusive rocks. Geol Mag 138:345–363

De Wever P (1982) Radiolaries du Trias et du Lias de la Tethys (Systématique, Stratigraphie). Soc Géol Nord 7:1–599

De Wever P (1984) Triassic radiolarians from the Darnó area (Hungary). Acta Geol Hung 27:295–306

De Wever P, Dumitrica P, Caulet JP, Nigrini CA, Caridroit M (2001) Radiolarians in the sedimentary record. Gordon & Breach; Marston, Amsterdam

De Wever P, Sanfilippo A, Riedel WR, Gruber B (1979) Triassic radiolarians from Greece, Sicily and Turkey. Micropaleontology 25:75–110

Dosztály L, Józsa S (1992) Geochronological evaluation of Mesozoic formations of Darnó Hill at Recsk on the basis of Radiolarians and K-Ar age data. Acta Geol Hung 35:371–393

Dumitrică P, Kozur H, Mostler H (1980) Contribution to the radiolarian fauna of the Middle Triassic of the Southern Alps. Geol Pal Mitt Innsbruck 10:1–46

Ferrière J (1976) Sur la signification des séries du massif de l'Othris (Grèce continentale): la zone isopique maliaque. Ann Soc Geol Nord 96:121–134

Ferrière J (1982) Paléogéographie et tectoniques superposées dans les Hellenides internes: le massifs de l'Othrys et du Pelion (Grèce continentale). Publ Soc Géol Nord 8:1–493

Gawlick HJ, Frisch W, Hoxha L, Dumitrică P, Krystyn L, Lein R, Missoni S, Schlagintweit F (2008) Mirdita Zone ophiolites and associated sediments in Albania reveal Neotethys Ocean origin. Int J Earth Sci 97:865–881

Goričan S, Buser S (1990) Middle Triassic radiolarians from Slovenia (Yugoslavia). Geologija 31–32:133–197

Goričan S, Halamić J, Grgasovic T, Kolar-Jurkovsek T (2005) Stratigraphic evolution of Triassic arc-backarc system in northwestern Croatia. Bull Soc Geol France 176:3–22

Halamić J, Goričan S (1995) Triassic Radiolarites from Mts. Kalnik and Medvednica (Northwestern Croatia). Geol Croat 48:129–146

Haas J, Kovács S, Krystyn L, Lein R (1995) Significance of Late Permian—Triassic facies zones in terrane reconstructions in the Alpine-North Pannonian domain. Tectonophysics 242:19–40

Halamić J, Marchig V, Goričan S (2001) Geochemistry of Triassic radiolarian cherts in north-western Croatia. Geol Carpath 52:327–342

Hein J, Obradović J (1988) Siliceous Deposits of the Tethys and Pacific Regions. Springer-Verlag, New York

Jones G, De Wever P, Robertson AHF (1992) Significance of radiolarian age data to the Mesozoic tectonic and sedimentary evolution of the northern Pindos Mountains, Greece. Geol Mag 129:358–400

Jones G, Robertson AHF (1991) Tectono-stratigraphy and evolution of the Mesozoic Pindos Ophiolite and related units, northwestern Greece. J Geol Soc London 148:267–288

Kaufmann G (1976) Perm und Trias im östlichen Mittelgriechenland und auf einigen Aegeischen Inseln. Zeitschr Deutsch Geol Ges 127:387–398

Kellici I, De Wever P, Kodra A (1994) Radiolaires mésozoïques du massif ophiolitique de Mirdita, Albanie. Paléontologie et stratigraphie. Revue Micropal 37:209–222

Kemp AES, McCaig A (1984) Origins and significance of rocks in an imbricate thrust zone beneath the Pindos ophiolite, northwestern Greece. In: Robertson AHF and Dixon JE (eds) The Geological Evolution of the Eastern Mediterranean. Geol Soc London, Spec Publ 17:569–580

Kiss G, Molnár F, Palinkaš LA, Kovács S, Hrvatović H (in press) Correlation of Triassic advanced rifting related Neotethyan submarine basaltic volcanism of the Darnó Unit (NE Hungary) with some Dinaridic and Hellenidic occurrences on the basis of volcanological, fluid-rock interaction and geochemical characteristics. (this volume)

Kovács S (1984) North Hungarian Triassic facies types: A review. Acta Geol Hung 27(3–4):251–264

Kovács S, Haas J, Ozsvárt P, Palinkaš L, Kiss G, Molnár F, Józsa S, Kövér Sz (in press) Re-evaluation of the Mesozoic complexes of Darnó Hill (NE Hungary) and comparisons with Neotethyan accretionary complexes of the Dinarides and Hellenides—preliminary data. Cent Eur Geol (Acta Geol Hung)

Kovács S, Szederkényi T, Haas J, Buda G, Császár G, Nagymarosi A (2000) tectonostratigraphic terranes in the pre-Neogene basement of the Hungarian part of the Pannonian Area. Acta Geol Hung 43:225–328

Kozur H (1991) The Evolution of the Meliata-Hallstatt Ocean and Its Significance for the Early Evolution of the Eastern Alps and Western Carpathians. Palaeogeogr Palaeoclimatol Palaeoecol 87:109–135

Kozur H. (2003) Recovery of the Radiolarians after the Permian-Triassic biotic crisis and integrated Radiolarian zonation of the Middle Triassic. 10th meeting of the Int Ass of Radiolarian Paleontologist, Lausanne:73–74

Kozur H, Moix P, Ozsvárt P (2007) Characteristic Nasselaria of the lower Tuvalian Spongotortilispinus moixi Zone of the Huğlu Unit in the Mersin Mélange. Bull Géol Soc Vaudoise Sci Nat 90:151–173

Kozur H, Moix P, Ozsvárt P (2009) Additional new Spumellaria (Radiolaria) from the Spongotortilispinus moixi Zone of the Huğlu Unit in the Mersin Mélange (southeastern Turkey), with some remarks on the age of this fauna. Jahrb Geol Bund, Vienna 149:25–59

Kozur H, Mostler H (1981) Beitraege zur Erforschung der mesozoischen Radiolarien; Teil IV; Thalassosphaeracea Haeckel, 1862, Hexastylacea Haeckel, 1882 emend. Petrusevskaja, 1979, Sponguracea Haeckel, 1862 emend. und weitere triassische Lithocycliacea, Trematodiscacea, Actinommacea und Nassellaria. Geol Pal Mitt Innsbruck S1:1–208

Kozur H, Mostler H (1994) Anisian to Middle Carnian radiolarian zonation and description of some stratigraphically important radiolarians. Geol Pal Mitt Innsbruck S3:39–246

Kozur H, Mostler H (1996) Longobardian (Late Ladinian) Muelleritortiidae (Radiolaria) from the Republic of Bosnia-Hercegovina. Geol Pal Mitt Innsbruck S4:83–103

Kozur H, Réti Z (1986) The first paleontological evidence of Triassic ophiolites in Hungary. N Jahrb Geol Pal Mh 5:284–292

Lein R (1987) Evolution of the Northern Calcareous Alps during Triassic Times. In: Flügel HW, Faupl P (eds) Geodynamics of the Eastern Alps. Deuticke, Wien, pp 85–102

Maury RC, Béchennec F, Cotten J, Caroff M, Cordey F, Marcoux J (2003) Middle Permian plume-related magmatism of the Hawasina Nappes and the Arabian Platform: implications on the evolution of the Neotethyan margin in Oman. Tectonics 22:1073–1086

Mello J, Polak M, Ondrejickova A (1995) Mesozoic radiolarites of central and inner part of the West Carpathians. Spec Publ Geol Soc Greece 4:232–236

Marcucci M, Kodra A, Pirdeni A, Th Gjata (1994) Radiolarian assemblages in the Triassic and Jurassic cherts of Albania. Ofioliti 191:105–114

Migiros G, Tselepidis V (1990) Der erste Nachweis von Hallstatter Kalken in der Nord- Pindos-Decke (Nordwest-Griechenland). N J Geol Pal Mh 4:248–256

Moix P, Kozur HW, Stampfli GM, Mostler H (2007) New palaeontological, biostratigraphical and palaeogeographical results from the Triassic of the Mersin mélange, SE Turkey. In: Lucas SG, Spielmann JA (eds) The Global Triassic. New Mexico Mus of Nat Hist and Sci Bull 41:282–311

Obradović J, Goričan Š (1988) Siliceous Deposits in Yugoslavia: Occurrences, Types and Ages. In: Hein JR, Obradović J (eds) Siliceous Deposits of the Tethys and Pacific Regions. Springer-Verlag, New York, pp 51–64

Ozsvárt P, Dosztály L (2007) Middle Triassic radiolarian fauna from Balaton Highland: quantitative biochronology and biodiversity. 10th Hungarian Symposium on Paleontology: Program, Abstracts and Field Guide:30

Ozsvárt P, Dosztály L, Migiros G, Kovács S (2006) Triassic and Jurassic radiolarians from the northern and southern edge of Vardar Zone: geodynamic implications for mesozoic paleogeography. InterRad 11 and Triassic Stratigraphy Symposium, Wellington, New Zealand:110

Pe-Piper G (1998) The nature of Triassic extension related magmatism in Greece: evidence from Nd and Pb isotope geochemistry. Geol Mag 135:331–348

Rassios A, Smith AG (2000) Constraints on the formation and emplacement of western Greek ophiolites (Vourinos, Pindos, and Othris) inferred from deformation structures in peridotites. In: Dilek Y, Moores EM, Elthon DA, Nicolas A (eds) Ophiolites and Oceanic Crust: New Insights from Field Studies and Oceanic Drilling Program. GSA, Spec Publ 349:473–483

Réti Zs (1985) Triassic ophiolite fragments in an evaporitic melange, Northern Hungary. Ofioliti 10:411–422

Richter D (1976) Das Flysch-Stadium der Helleniden—Ein überblick. Zeitschr Geol Gesellsch 127:467–483

Robertson AHF (2007) Overview of tectonic settings related to the rifting and opening of Mesozoic ocean basins in the Eastern Tethys: Oman, Himalayas and Eastern Mediterranean regions. Imaging, Mapping and Modelling Continental Lithosphere Extension and Breakup. Geol Soc London, Spec Pub 282:325–388

Saccani E, Padoa E, Photiades A (2003) Triassic mid-ocean ridge basalts from the Argolis Peninsula (Greece): new constraints for the early oceanization phases of the Neo-Tethyan Pindos basin. Geol Soc London, Spec Pub 218:109–127

Skourtsis-Coroneou V, Tselepidis V, Kovács S, Dosztály L (1995) Triassic pelagic sedimentary evolution in some geotectonic unit sin Greece and Hungary: a comparison. Geol Soc Greece, Sp Publ 4:275–281

Vishnevskaya VS, Djeric N, Zakariadze GS (2009) New data on Mesozoic Radiolaria of Serbia and Bosnia, and implications for the age and evolution of oceanic volcanic rocks in the Central and Northern Balkans. Lithos 108:72–105