Biochronology of Jurassic and Early Cretaceous radiolarites from the Lycian Mélange (SW Turkey) and implications for the evolution of the Northern Neotethyan ocean

T. DANELIAN[1], A. H. F. ROBERTSON[2], A. S. COLLINS[3] & A. POISSON[4]

[1]*Micropaléontologie, Université P. & M. Curie (Paris VI), CNRS–UMR 5143, C. 104, 4 place Jussieu, 75005 Paris, France (e-mail: danelian@ccr.jussieu.fr)*

[2]*Grant Institute of Earth Science, School of GeoSciences, University of Edinburgh, West Mains Road, Edinburgh EH9 3JW, UK*

[3]*School of Earth and Environmental Sciences, University of Adelaide, Adelaide, SA 5005, Australia*

[4]*Département des Sciences de la Terre, Université de Paris-Sud, Orsay, France*

Abstract: New radiolarian ages for blocks of radiolarian cherts associated with other blocks of distal pelagic facies and ophiolitic lithologies within the Lycian Mélange, SW Turkey, indicate deposition during Mid-Jurassic to Early Cretaceous time. Radiolarites overlying pink pelagic limestones of an allochthonous carbonate unit accumulated during the Mid- to Late Jurassic. On the basis of structural evidence the Lycian Mélange is inferred to have been rooted within the Northern Neotethys, to the north of the Tauride–Anatolide microcontinent. The Lycian radiolarites can be compared with other dated radiolarites from the Izmir–Ankara suture, the root zone of the Northern Neotethyan ocean. Based on all the available radiolarian data it is inferred that radiolarites accumulated within the Northern Neotethys in western Turkey from Late Triassic (Mid-Carnian to Late Norian) to Mid-Cretaceous (Cenomanian) time. The radiolarites were later detached from their inferred oceanic basement and accreted within a subduction complex during the Late Cretaceous (Turonian–Maastrichtian) and emplaced over the northern margin of the Tauride–Anatolide continent together with slices of continental margin and ophiolitic lithologies.

Following the development of Mesozoic radiolarian biostratigraphical schemes during the last 25 years, radiolarian biochronology has become invaluable for reconstructing the palaeogeography, palaeoceanography and tectonic evolution of Tethyan oceanic basins and margins (De Wever 1989; Robertson *et al.* 1991; De Wever *et al.* 1994; Danelian & Robertson 1997, 2001). Radiolarites in the Tethyan realm commonly occur within mélanges that are interpreted as parts of accretionary prisms related to subduction of ocean crust (Robertson 2002, 2004). Radiolarian ages from such mélanges provide valuable age constraints on related geological processes, including spreading, intra-plate volcanism and tectonic accretion (e.g. Al Riyami *et al.* 2001; Beccaletto *et al.* 2005).

Here, we will present the first radiolarian evidence from the Lycian Mélange, an east–west-trending Late Mesozoic accretionary complex in SW Turkey (Collins & Robertson 1997; Fig. 1). This mélange forms part of the well-known Lycian Nappes in SW Turkey (De Graciancky 1972; Poisson 1977, 1984; Collins & Robertson 1998). The root zone of the mélange is considered to lie to the north of the regional 'basement' represented by the Tauride–Anatolide platform (Collins & Robertson 1998, 2003), and is inferred to lie within the Izmir–Ankara suture zone to the north of the Menderes Massif (Robertson & Pickett 2000; Robertson *et al.* 2004). We will also review the limited available data for radiolarites from comparable tectonic units within the Izmir–Ankara suture zone and the Bey Dağları. We conclude by considering the implications of the available radiolarian evidence for the evolution of the Mesozoic Tethyan ocean.

Geological setting

The Lycian Nappes occupy a large area to the NW of the Mesozoic Bey Dağları carbonate platform and to the SE of the Menderes Massif (De Graciansky 1972; Bernoulli *et al.* 1974; Collins & Robertson 1997, 1998, 1999; Poisson 1977; Fig. 2). Five major tectonostratigraphic units are recognized in ascending order, as follows.

From: ROBERTSON, A. H. F. & MOUNTRAKIS, D. (eds) 2006. *Tectonic Development of the Eastern Mediterranean Region*. Geological Society, London, Special Publications, **260**, 229–236.

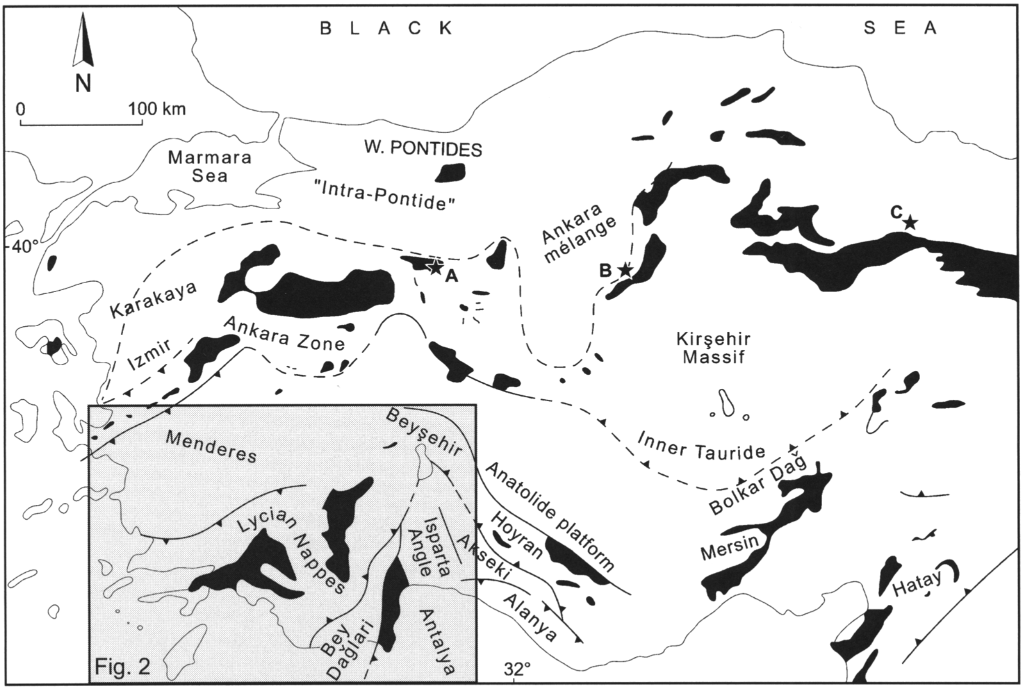

Fig. 1. Distribution of ophiolite and mélange outcrops (in black) in central and western Turkey. A, B, and C are previously dated radiolarite localities (see text for explanation).

(1) The relatively autochthonous Menderes Massif to the NW and the Bey Dağları platform to the SE, which represent the 'basement' onto which the Lycian Nappes were emplaced between the latest Cretaceous and Miocene times.

(2) The Lycian Thrust Sheets comprise Mesozoic–Early Tertiary platform, slope and basinal successions that are dominated by sedimentary rocks with subordinate amounts of extrusive igneous rocks. The Lycian Thrust Sheets are reconstructed as a passive continental margin that faced northwards into the northern branch of the Mesozoic Tethys, known as the Northern Neotethyan ocean (Şengör & Yılmaz 1981). However, the lowest thrust sheet, the Yavuz Thrust Sheet (Poisson 1977, 1984; Şenel 1981) is restored as an Early Tertiary foreland basin that was not finally incorporated into the Lycian Nappes until the latest stage of southward emplacement during Oligo-Miocene time (Collins & Robertson 1999, 2003).

(3) The Lycian Mélange tectonically overlies the Lycian Thrust Sheets and is interpreted as an accretionary prism related to the subduction of Mesozoic Tethyan (i.e. Neotethyan) oceanic crust (Collins & Robertson 1997). This is composed of two intergradational, but tectonically juxtaposed, subunits. First, there is the structurally lower Layered Tectonic Mélange (up to several hundred metres thick) that is mainly composed of dismembered thrust sheets and detached blocks of pelagic limestone of up to 10 m (sized units), together with thin sequences (<10 m) of highly disrupted ribbon radiolarites within a highly sheared shaly matrix. Second, above this, there is the Ophiolitic Mélange that comprises blocks and dismembered thrust sheets (up to 1 km in size) of ophiolitic lithologies including serpentinized harzburgite, gabbro, diabase and basalt. There are also generally smaller blocks of red–purple radiolarites and both neritic and pelagic limestone, all within a deformed matrix of terrigenous sediments, mainly turbidites and shales. In addition, there are large disrupted thrust sheets and detached blocks of Mesozoic shallow-water limestone, known as the Domuz Dağı unit (Poisson 1977, 1984). This typically forms dismembered units entrained within the Ophiolitic Mélange.

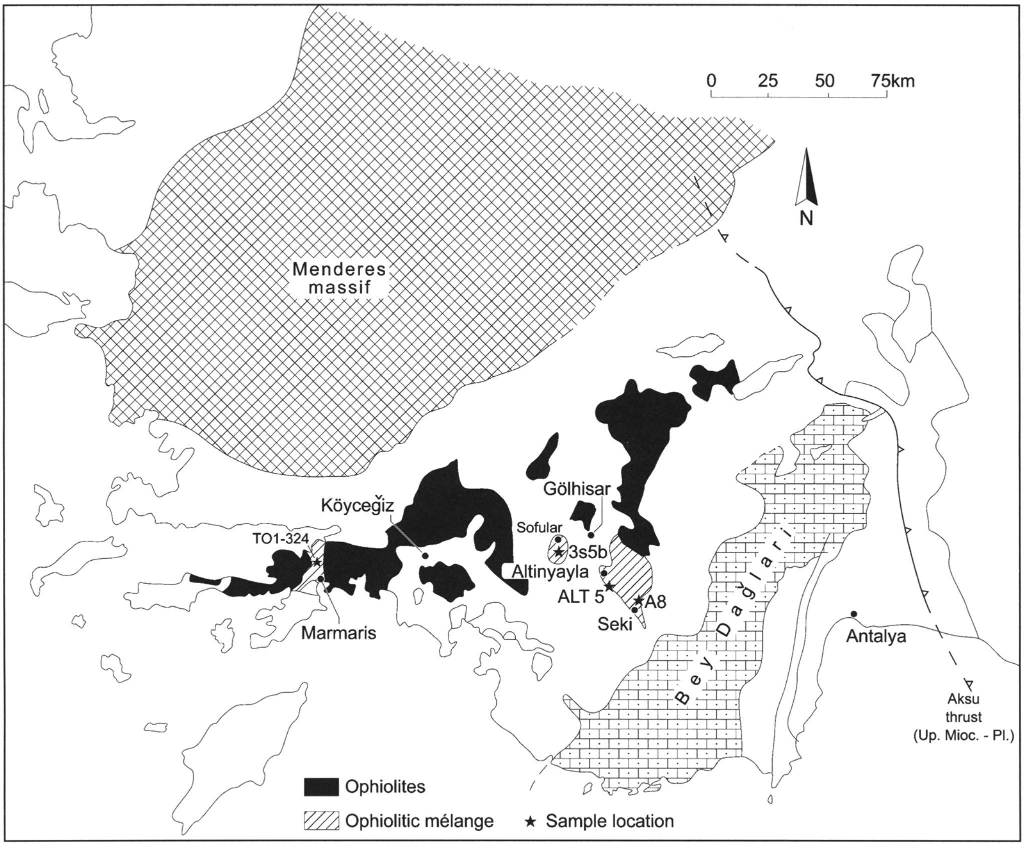

Fig. 2. Outcrops of the Menderes Massif, the Bey Dağları carbonate platform, the Lycian Ophiolite and the Ophiolitic Mélange. The locations of the radiolarite outcrops dated during this study are also shown.

(4) The Lycian Peridotite Thrust Sheet, situated at the top of the Lycian thrust stack, represents the mainly ultramafic portion of oceanic mantle. This is interpreted as Cretaceous Neotethyan oceanic lithosphere that formed above a subduction zone (Collins & Robertson 1998). The serpentinized harzburgites are underlain by a dismembered metamorphic sole that has been radiometrically dated as Early Cretaceous (101–88 Ma, but mainly 95–90 Ma; Thuizat *et al.* 1981; Dilek *et al.* 1999). Geochemical studies of the metamorphic sole suggest that the protoliths were potentially derived from a range of island arc, mid-ocean ridge and seamount settings (Çelik & Delaloye 2003).

Locality information and radiolarian ages

Over 30 chert samples from different localities associated with the Ophiolitic Mélange yielded Radiolaria; however, only four contained age-diagnostic taxa and are discussed here. The location of dated samples is indicated in Figure 2. Age-diagnostic radiolarian species are illustrated in Figure 3. Radiolarians were extracted by repetitive leaching of samples with low-concentration hydrofluoric acid (4% HF).

Sample 3s5b is from a roadside outcrop of radiolarite, 6 m thick, situated along a tarmac road *c.* 5 km south of the village of Sofular (29°20′N, 36°57′E). Red or purple chert is interbedded with siliceous red mudstones. Radiolarites are separated from adjacent neritic limestones by a fault. However, further SW, these radiolarites stratigraphically overlie similar limestones, and are overthrust by ophiolitic mélange. Elsewhere, on a mountainous ridge between Cameli and Sofular, the limestone–radiolarite lithologies form kilometre-scale blocks within the ophiolitic mélange. Sample 3s5b yielded a reasonably well-preserved radiolarian fauna

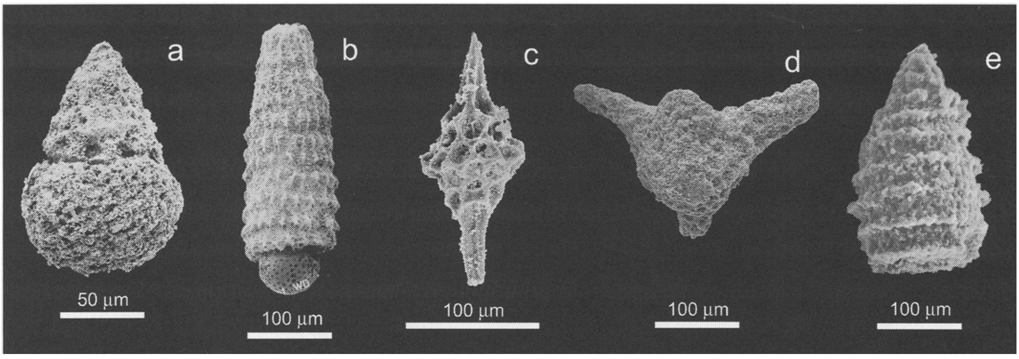

Fig. 3. Scanning electron micrographs of Mid-Jurassic to Early Cretaceous Radiolaria from radiolarite of the Lycian Ophiolitic Mélange. (**a**) *Sethocapsa (?) zweilli* Jud, sample 3s5b; (**b**) *Transhsuum* sp.cf. *T. brevicostatum* (Ozvoldova), sample A8; (**c**) *Zartus praejonesi* Pessagno & Blome, sample ALT 5; (**d**) *Tethysetta dhimenaensis* Baumgartner *s.l.*, sample TO1–324; (**e**) *Podocapsa amphitreptera* Foreman TO1–324.

including *Archaeodictyomitra apiarium* (Rüst), *A. mitra* Dumitrica, *Sethocapsa (?) zweillii* Jud, *S.* sp.cf. *S. uterculus* (Parona) *s.l.* and *Xitus* sp. The presence of species *S.(?) zweillii* indicates a Berriasian to Early Hauterivian (Early Cretaceous) age (Unitary Association Zones UAZ 14–19; Baumgartner *et al.* 1995).

Sample A8 comes from a bedded red chert, of 2 m thickness, located *c.* 2 km north of the village of Seki (29°41.5′N, 36°48′E). Individual chert beds reach 50 cm in thickness. These cherts depositionally overlie pink fine-grained limestones with nodular chert. The limestones form kilometre-sized blocks and are completely surrounded by mélange. Sample A8 yielded a poorly preserved fauna in which *Transhsuum* sp.cf. *T. brevicostatum* (Ozvoldova) and *Triactoma* sp.cf. *T. jonesi* (Pessagno) were identified, indicating a probable Mid- to Late Jurassic age (Baumgartner *et al.* 1995).

Sample ALT 5 comes from 3 km SE of Altinyayla, along a road leading from Altinyayla to Seki (29°35′N, 36°57.5′E). The sample is from a metre-scale, tightly folded, red–brown block of radiolarite, which occurs within the Ophiolitic Mélange, together with blocks of serpentinite, basalt, gabbro and red cherty limestone. This mélange is structurally overlain by a thick (hundreds of metres) thrust slice of serpentinized peridotite. A reasonably well-preserved radiolarian fauna was identified in Sample ALT 5, including *Eucyrtidiellum* sp., *Laxtorum (?) hichisoense* Isozaki & Matsuda, *Palinandromeda sognoensis* Baumgartner, *Parahsuum* sp., *Paronaella* sp., *Stichocapsa convexa* Yao and *Zartus praejonesi* Pessagno & Blome. The last species is known only from Bajocian strata (Pessagno & Blome 1980).

Sample TO1-324 was collected from radiolarite thrust sheets with lava intercalations just outside the town of Marmaris, along the road to Datça (28°15′N, 36°52′E). Although the relationship between the radiolarites and lavas appears to be stratigraphic, a tectonic contact cannot be excluded. The lavas predominate towards the top of the hill overlooking Marmaris, where they are more massive and contain tectonic inclusions of marble and phyllite. The radiolarite sample TO1-324 yielded a moderately well-preserved radiolarian fauna including *Archaeodictyomitra* sp.cf. *A. apiarium* (Rüst), *Emiluvia* sp.cf. *E. orea* Baumgartner *s.l.*, *Mirifusus dianae* ssp.cf. *M. d. dianae* (Karrer), *Obesacapsula* sp.cf. *O. morroensis* Pessagno, *Podocapsa amphitreptera* Foreman, *Protunuma* sp.cf. *P. japonicus* Matsuoka & Yao, *Tethysetta dhimenaensis* (Baumgartner) *s.l.* and *Tritrabs* (?) sp. The sample is Late Jurassic (Mid- to Late Oxfordian to Late Kimmeridgian–Early Tithonian) based on the co-occurrence of species *P. amphitreptera* and *T. dhimenaensis* (UAZ 9-11; Baumgartner *et al.* 1995).

Regional significance of the Lycian radiolarites

The radiolarites within the Lycian Ophiolitic Mélange are associated with other fine-grained sediments (e.g. pelagic carbonates) that also appear to have accumulated in an oceanic setting, far from a source of coarse-grained sediment (e.g. sandstone turbidites, neritic calciturbidites). In

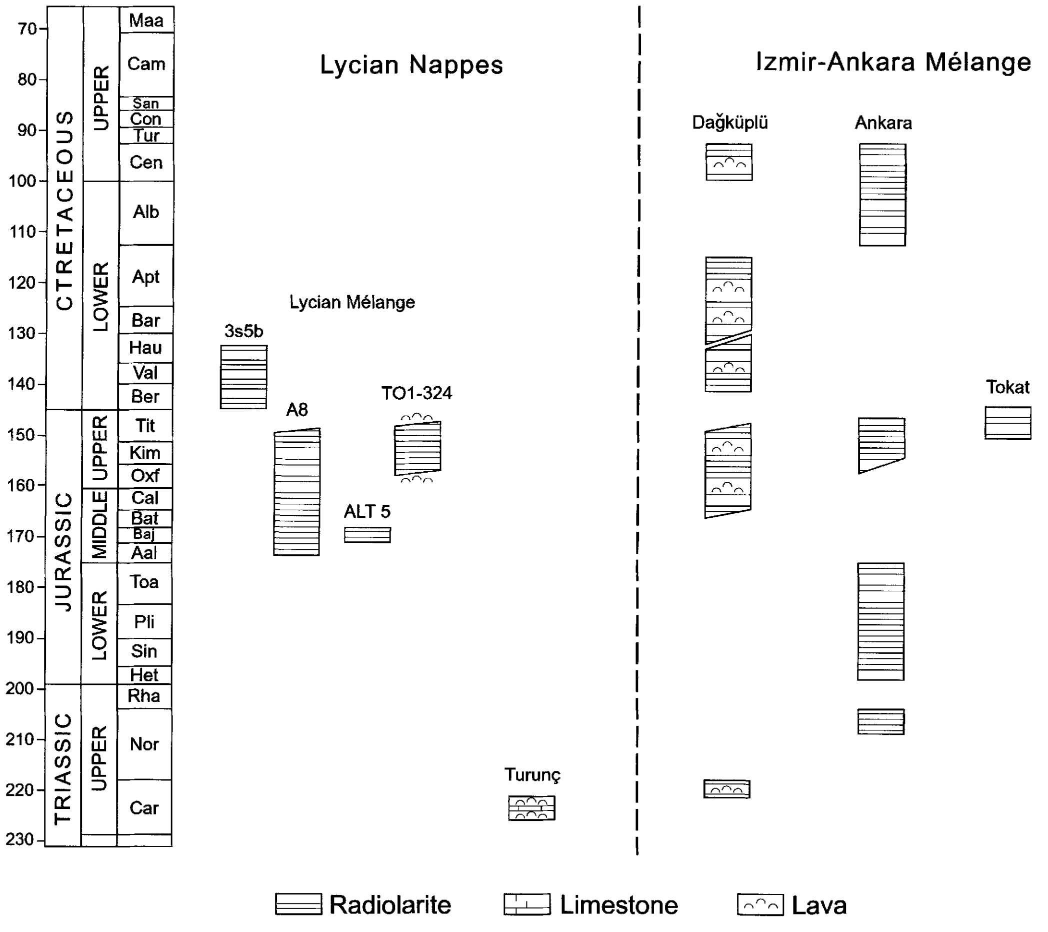

Fig. 4. Radiolarian ages determined from the Lycian Ophiolitic Mélange (this study) and the Turunç succession in the Marmaris area (Tekin & Göncüoğlu 2002), together with published ages from various other mélange outcrops within the Izmir–Ankara suture zone (Bragin & Tekin 1996; Bozkurt *et al.* 1997; Göncüoğlu *et al.* 2000, 2001; Tekin *et al.* 2002). Time scale after Gradstein *et al.* (2004).

contrast, more proximal successions, dominated by redeposited limestones, are associated with the structurally underlying Lycian Thrust Sheets, especially the Köyceğiz Thrust Sheet (Collins & Robertson 1999). The radiolarites are also associated with blocks of various ophiolitic rocks (e.g. serpentinite, gabbro, diabase, tholeiitic basalt). Geochemical study of the ophiolitic basalts is suggestive of eruption in a mid-ocean-ridge (MOR)-type setting (Collins & Robertson 1998). The radiolarites therefore provide clues to the age of the Neotethyan oceanic crust. Figure 4 synthesizes the ages determined during this study: i.e. from early Mid-Jurassic (ALT 5) to Early Cretaceous (3s5b).

The Lycian Ophiolitic Mélange, together with most of the Upper Palaeozoic–Mesozoic units of the Lycian Nappes, is widely considered to have been thrust southwards from the Izmir–Ankara suture zone (north of the Menderes Massif; Fig. 1; Robertson & Pickett 2000; Okay *et al.* 2001; Collins & Robertson 2003; Robertson *et al.* 2004), although emplacement from the south has also been suggested (Poisson 1984). The para-authochthonous Tavas–Boz Dağı Unit is the exception and is thought to represent a basin between the Menderes Massif and the Bey Dağları (Poisson 1984; Poisson & Sarp 1985; Collins & Robertson 1999, 2003). Radiolarites have also been dated by other workers from several units preserved within the Lycian Nappes and the Izmir–Ankara suture zone, as summarized below.

Within the Lycian Nappes, a Mesozoic deep-seawater succession exposed in the Marmaris area, near Turunç (Fig. 2; Ersoy 1993, 1997), begins with basalts and volcaniclastic turbidites. Radiolaria reported from limestones intercalated between MOR-type (or transitional-type) basalts (Collins & Robertson 1998, 2003) have yielded a microfauna of Mid-Carnian (Late Triassic) age (Tekin & Göncüoğlu 2002). The succession, as described by Ersoy (1993, 1997) and Collins & Robertson (1999), is overlain by Jurassic to Upper Cretaceous deep-water redeposited sedimentary rocks.

Radiolarites are associated with basic lavas within the Dağküplü Mélange, north of Eskişehir within the Izmir–Ankara suture zone (locality A in Fig. 1); these were recently reported to be Late Carnian in age (Tekin *et al.* 2002). The mélange crops out in the Central Sakarya Zone of the Northern Neotethyan suture, where it occurs beneath a regionally extensive ophiolite (Taştepe Ophiolite). The Dağküplü Mélange also includes several slices of mid-ocean ridge basalt (MORB)-type metabasalts that alternate with radiolarites dated as Mid–Late Jurassic (Bathonian–Tithonian), Early Cretaceous (Hauterivian–Aptian) and also as mid-Cretaceous (Cenomanian) (Göncüoğlu *et al.* 2000, 2001).

Further east, within an exposure of the Ankara Mélange on the outskirts of Ankara city (locality B in Fig. 1), blocks of radiolarite were reported to occur in a volcaniclastic matrix together with blocks of gabbro, lava and pink micritic limestone. The interbedded radiolarites were dated as Late Triassic (Late Norian), Early Jurassic, Late Jurassic and mid-Cretaceous (Albian–Cenomanian; Bragin & Tekin 1996). A long history of radiolarite accumulation is thus inferred within a single short succession.

Further north, a block of radiolarite associated with ophiolitic lithologies (e.g. serpentinite, gabbro, basalt) occurs within the Tokat Complex of the Central Pontides (locality C in Fig. 1) ; this was reported to be of Late Jurassic (Tithonian) age (Bozkurt *et al.* 1997).

In addition, basic–intermediate composition lavas, green volcaniclastic siltstone and pelagic carbonates are interbedded with greenish siliceous tuffs and tuffaceous radiolarian cherts, dated as Carnian in age (Tekin 1999), from within the Beyşehir–Hoyran Nappes in the Bozkir area, central Taurides. This succession was attributed to rifting to form the Inner Tauride oceanic basin to the south of the main, northerly Neotethyan ocean and is not considered further here (Andrew & Robertson 2002).

Discussion and conclusions: implication for Tethyan evolution

The radiolarian data shed light on the evolution of the Northern Neotethys ocean, especially if it is accepted that the Lycian Mélange formed within this ocean basin, together with the other radiolarites preserved within the Izmir–Ankara suture zone. In some cases the radiolarites are preserved only as detached blocks, commonly associated with ophiolitic rocks, thus limiting their interpretative potential. However, at some localities the dated radiolarites are interbedded with basalts for which the tectonic affinity is known based on geochemical analysis (e.g. MORB); these radiolarian ages are particularly useful for determining the timing and mode of ocean crust formation.

Accordingly, radiolarian ooze began to accumulate on the Neotethyan oceanic floor during the Late Triassic (Mid-Carnian) within units now forming parts of the Lycian Nappes (Tekin & Göncüoğlu 2002) and also during the Late Norian within the Ankara–Izmir suture (Bragin & Tekin 1996). Radiolarites of the former area are depositionally associated with MORB-type extrusive rocks, suggesting that the oldest oceanic lithosphere is Late Triassic (Collins & Robertson 1998, 1999). This is important as it supports initial genesis of oceanic crust within the Northern Neotethys by Late Triassic time (Robertson *et al.* 1996, 2004; Robertson & Pickett 2000; Tekin & Göncüoğlu 2002). This contrasts with an earlier view that Northern Neotethyan oceanic crust did not form until the Early Jurassic (Şengör & Yılmaz 1981; Görür *et al.* 1984).

The youngest confirmed radiolarites are of Mid-Cretaceous (Cenomanian) age associated with mélange units of the Izmir–Ankara suture zone (Bragin & Tekin 1996; Göncüoğlu *et al.* 2001). Taken together, these radiolarites appear to have accumulated within the Northern Neotethys during Late Triassic–Early Cretaceous time (*c.* 220–93.5 Ma). The radiometric ages of the metamorphic soles of the Lycian Peridotite, mainly dated at 95–90 Ma (Thuizat *et al.* 1981; Dilek *et al.* 1999), document the time of first tectonic disruption of young, still hot, oceanic lithosphere within the Northern Neotethys. This oceanic crust and mantle together with the distal deep-sea sediments of the Lycian Mélange, including the radiolarites dated here, were then accreted within a subduction complex during the Late Cretaceous (Turonian–Campanian; *c.* 90–75 Ma) (Collins & Robertson 1997; Okay *et al.* 2001).

Field and laboratory work was partly funded by the UK Natural Environmental Research Council and partly by CNRS-FR32 (Cepage). We thank J. Aitchison and K. Tekin for helpful reviews of the original manuscript. C. Abrial and A. Lethiers helped with the drawings.

References

AL-RIYAMI, K., DANELIAN, T. & ROBERTSON, A. H. F. 2001. Radiolarian biochronology of Mesozoic deep-water successions in NW Syria and Cyprus: implications for south-Tethyan evolution. *Terra Nova*, **14**, 271–280.

ANDREW, T. & ROBERTSON, A. H. F. 2002. The Beyşehir–Hoyran–Hadim (B–H–H) nappes: genesis and emplacement of Mesozoic marginal and oceanic units of the Northerly Neotethys in Southern Turkey. *Journal of the Geological Society, London*, **159**, 529–543.

BAUMGARTNER, P. O., BARTOLINI, A., CARTER, E. S., *et al.* 1995. Middle Jurassic to Early Cretaceous radiolarian biochronology of Tethys based on Unitary Associations. *In*: BAUMGARTNER, P. O., O'DOGHERTY, L., GORICAN, S., URQUHART, E., PILLEVUIT, A. & DE WEVER, P. (eds) *Middle Jurassic to Lower Cretaceous Radiolaria of Tethys: Occurrences, Systematics, Biochronology*. Mémoires de Géologie (Lausanne), **23**, 1013–1048.

BECCALETTO, L., BARTOLINI, A.-C., MARTINI, R., HOCHULI, P. A. & KOZUR, H. 2005. Biostratigraphic data from the Çetmi Mélange, northwest Turkey: palaeogeographic and tectonic implications. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **221**, 215–224.

BERNOULLI, D., DE GRACIANSKY, P. C. & MONOD, O. 1974. The extension of the Lycian nappes (SW Turkey) into the Southeastern Aegean islands. *Eclogae Geologicae Helvetiae*, **67**, 4–90.

BOZKURT, E., HOLDSWORTH, B. K. & KOÇYIĞIT, A. 1997. Implication of Jurassic chert identified in the Tokat Complex, northern Turkey. *Geological Magazine*, **134**, 91–97.

BRAGIN, N. Y. & TEKIN, U. K. 1996. Age of radiolarian-chert blocks from the Senonian Ophiolitic Mélange (Ankara, Turkey). *The Island Arc*, **5**, 114–122.

ÇELIK, Ö. F. & DELALOYE, M. 2003. Origin of metamorphic soles and their post-kinematic mafic dyke swarms in the Antalya and Lycian ophiolites. SW Turkey. *Geological Journal*, **38**, 235–256.

COLLINS, A. S. & ROBERTSON, A. H. F. 1997. Lycian mélange, southwestern Turkey: an emplaced Late Cretaceous accretionary complex. *Geology*, **25**, 255–258.

COLLINS, A. S. & ROBERTSON, A. H. F. 1998. Processes of Late Cretaceous to Late Miocene episodic thrust-sheet translation in the Lycian Taurides, SW Turkey. *Journal of the Geological Society, London*, **155**, 757–772.

COLLINS, A. S. & ROBERTSON, A. H. F. 1999. Evolution of the Lycian Allochthon, western Turkey as a north-facing Late Palaeozoic to Mesozoic rift and passive continental margin. *Geological Journal*, **34**, 107–138.

COLLINS, A. S. & ROBERTSON, A. H. F. 2003. Kinematic evidence for Late Mesozoic–Miocene emplacement of the Lycian Allochthon over the Western Anatolide Belt. *Geological Journal*, **38**, 295–310.

DANELIAN, T. & ROBERTSON, A. H. F. 1997. Radiolarian evidence for the stratigraphy and palaeo-oceanography of the deep-water northern passive margin of the Indian plate (Karamba Formation, Indus Suture Zone, Ladakh Himalaya). *Marine Micropaleontology*, **30**, 171–195.

DANELIAN, T. & ROBERTSON, A. H. F. 2001. Neotethyan evolution of eastern Greece (Pagondas Mélange, Evia island) inferred from radiolarian biostratigraphy and the geochemistry of associated extrusive rocks. *Geological Magazine*, **138**, 245–363.

DE GRACIANSKY, P. 1972. *Recherches géologiques dans le Taurus lycien*. Thèse Doctorat d'Etat, Université Paris-Sud (Orsay).

DE WEVER, P. 1989. Radiolarians, radiolarites and Mesozoic palaeogeography of the Circum-Mediterranean Alpine belts. *In:* HEIN, J. R. & OBRADOVIĆ, J. (eds) *Siliceous Deposits of the Tethys and Pacific Regions*. Springer, New York, 31–49.

DE WEVER, P., AZÉMA, J. & FOURCADE, E. 1994. Radiolarites et radiolarites: production primaire, diagenèse et paléogéographie. *Bulletin des Centres de Recherches Exploration–Production Elf-Aquitaine*, **18**, 315–379.

DILEK, Y., THY, P., HACKER, B. & GRUNDVIG, S. 1999. Structure and petrology of Tauride ophiolites and mafic dyke intrusions (Turkey): implications for the Neotethyan ocean. *Geological Society of America Bulletin*, **111**, 1192–1216.

ERSOY, S. 1993. The geological setting of the tectonic units situated in SW Anatolia (Turkey). *Bulletin of the Geological Society of Greece*, **28**, 617–628.

ERSOY, S. 1997. The syn-collisional deep-water sediments of the Marmaris Complex as a part of the Lycian Nappes, SW Turkey. *International Earth Sciences Colloquium of the Aegean Region, 9–14 October 1995, Izmir–Güllük, Turkey, Proceedings Volume, 1*, 95–111.

GÖNCÜOĞLU, M. C., TURHAN, N., ŞENTÜRK, K., ÖZCAN, A., UYSAL, S. & YALINIZ, K. 2000. A geotraverse across northwestern Turkey: tectonic units of the Central Sakarya region and their tectonic evolution. *In*: BOZKURT, E., WINCHESTER, J. A. & PIPER, J. D. A. (eds) *Tectonics and Magmatism in Turkey and the Surrounding Area*. Geological Society, London, Special Publications, **173**, 139–161.

GÖNCÜOĞLU, M. C., YALINIZ, M. K., TEKIN, U. K. & TURHAN, N. 2001. Petrology of Late Berriasian–Late Hauterivian and Cenomanian oceanic basalts within the Central Sakarya ophiolitic complex, NW Turkey: constraints for the evolution of the Izmir–Ankara oceanic branch of Neotethys. *Fourth International Turkish Geology Symposium (ITGS IV)*, Cükürova University Adana (Turkey), 93.

GÖRÜR, N., OKTAY, F. Y., SEYMEN, I. & ŞENGÖR, A. M. C. 1984. Paleotectonic evolution of Tuz Gölü Basin complex, central Turkey. *In*: DIXON, J. E. & ROBERTSON, A. H. F. (eds) *The Geological Evolution of the Eastern Mediterranean*. Geological Society, London, Special Publications, **17**, 81–96.

GRADSTEIN, F. M., OGG, J. G., SMITH, A. G., BLEEKER, W. & LOURENS, L. J. 2004. A new Geologic Time Scale, with special reference to Precambrian and Neogene. *Episodes*, **27/2**, 83–100.

OKAY, A. I., TANSEL, I. & TÜYSÜZ, O. 2001. Obduction, subduction and collision as reflected in the Upper Cretaceous–Lower Eocene sedimentary record of western Turkey. *Geological* Magazine, **138**, 117–142.

PESSAGNO, E. A., JR. & BLOME, C. D. 1980. Upper Triassic and Jurassic Pantanelliinae from California, Oregon and British Columbia. *Micropaleontology*, **26**, 225–273.

POISSON, A. 1977. *Recherches géologiques dans les Taurides occidentales (Turquie)*. Thesis Doctorat d'Etat, Université Paris-Sud, Orsay.

POISSON, A. 1984. The extension of the Ionian trough into southwestern Turkey. *In*: DIXON, J. E. & ROBERTSON, A. H. F (eds) *The Geological Evolution of the Eastern Mediterranean*. Geological Society, London, Special Publications, **17**, 235–241.

POISSON, A. & SARP, H. 1985. La zone de Kızılça–Çoragöl. Un example de sillon intra plate-forme à la marge externe du Massif du Menderes. *In*: IZDAR, E. & NAKOMAN, E. (eds) Proceedings of the VI Colloquium on the Geology of the Aegean Region, 19 September — 4 October 1977, Izmir, Turkey. Dokuz Eylül University, Bornova, Izmir, 555–564.

ROBERTSON, A. H. F. 2002. Overview of the genesis and emplacement of Mesozoic ophiolites in the Eastern Mediterranean Tethyan region. *Lithos*, **65**, 1–67.

ROBERTSON, A. H. F. 2004. Development of concepts concerning the genesis and emplacement of Tethyan ophiolites in the Eastern Mediterranean and Oman regions. *Earth-Science Reviews*, **66**, 331–387.

ROBERTSON, A. H. F. & PICKETT, E. A. 2000. Palaeozoic–Early Tertiary Tethyan evolution of mélanges, rift and passive margin units in the Karaburun Peninsula (western Turkey) and Chios Island (Greece). *In*: BOZKURT, E., WINCHESTER, J. A. & PIPER, J. D. (eds) *Geological Evolution of Turkey and the Surrounding Area*. Geological Society, London, Special Publications, **173**, 25–42.

ROBERTSON, A. H. F., CLIFT, P. D., DEGNAN, P. J. & JONES, G. 1991. Palaeogeographic and palaeotectonic evolution of the Eastern Mediterranean Neotethys. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **87**, 289–343.

ROBERTSON, A. H. F., DIXON, J. E., BROWN, S., *et al.* 1996. Alternative tectonic models for the Late Palaeozoic–Early Cenozoic development of Tethys in the Eastern Mediterranean region, *In*: MORRIS, A. & TARLING, D. H. (eds) *Palaeomagnetism and Tectonics of the Mediterranean Region*. Geological Society, London, Special Publications, **105**, 239–263.

ROBERTSON, A. H. F., USTAÖMER, T., PICKETT, E. A., COLLINS, A. S., ANDREW, T. & DIXON, J. E. 2004. Testing models of Late Palaeozoic–Early Mesozoic orogeny in Western Turkey: support for an open-Tethys model. *Journal of the Geological Society, London*, **161**, 201–511.

ŞENEL, Y. M. 1981. Palaeocene–Eocene sediments interbedded with volcanics within the Lycian Nappes: Faralya Formation. *General Directorate of Mineral Research and Exploration (MTA) Bulletin*, **113**, 1–14.

ŞENGÖR, A. M. C. & YILMAZ, Y. 1981. Tethyan evolution of Turkey: a plate tectonic approach. *Tectonophysics*, **75**, 81–241.

TEKIN, U. K. 1999. *Biostratigraphy and Systematics of Late Middle to Late Triassic Radiolarians from the Taurus Mountains and Ankara Region, Turkey*. Geologisch–Paläontologische Mitteilungen Innsbruck, Sonderband, **5**.

TEKIN, U. K. & GÖNCÜOĞLU, M. C. 2002. Middle Carnian radiolarians from the intra-pillow limestones of the Turunç Unit within the Gülmahar Nappe (Lycian Nappes, Marmaris, southern Turkey): geodynamic implications. *First International Symposium of the Faculty of Mines (ITU) on Earth Science and Engineering, 16–18 May 2002, Technical University, Istanbul* **84**.

TEKIN, U. K., GÖNCÜOĞLU, M. C. & TURHAN, N. 2002. First evidence of Late Carnian radiolarians from the Izmir–Ankara suture complex, central Sakarya, Turkey: implications for the opening age of the Izmir–Ankara branch of Neo-Tethys. *Geobios*, **35**, 127–135.

THUIZAT, R., WHITECHURCH, H., MONTIGNY, R. & JUTEAU, T. 1981. K–Ar dating of some intra-ophiolite metamorphic soles from the East Mediterranean: new evidence for oceanic thrusting before obduction. *Earth and Planetary Science Letters*, **52**, 302–310.