ELSEVIER

Lithos 65 (2002) 1–67

LITHOS

www.elsevier.com/locate/lithos

# Overview of the genesis and emplacement of Mesozoic ophiolites in the Eastern Mediterranean Tethyan region

Alastair H.F. Robertson*

*Department of Geology and Geophysics, University of Edinburgh, West Mains Road, Edinburgh EH9 3JW, UK*

Received 17 July 2000; received in revised form 30 October 2001; accepted 30 November 2001

**Abstract**

The Eastern Mediterranean region exhibits a fascinating diversity of ophiolites and related oceanic magmatic units of mainly Triassic, Jurassic and Cretaceous age. Comparisons with the settings of modern oceanic lithosphere indicate that the various Eastern Mediterranean ophiolites have different origins and formed in a variety of tectonic settings. Some have argued that the largest ophiolites, of Jurassic and Cretaceous age (e.g. Troodos), formed at mid-ocean ridges. However, the widespread occurrence of andesitic extrusives, chemically "depleted" basalts and highly magnesian lavas (boninites), favour formation of most of the large, relatively intact ophiolites in the Eastern Mediterranean region above subduction zones rather than at mid-ocean ridges (MORs). Such ophiolites probably formed by spreading during the initial stages of intra-oceanic subduction, prior to the emergence of any major related oceanic arc. Supra-subduction-type ophiolites typically formed during short-lived periods ( < 5 Ma) of regional plate re-organisation. By contrast, most MOR-type oceanic crust was subducted, or is preserved only as dismembered thrust sheets or blocks in ophiolitic melange, commonly metamorphosed under high-pressure/low-temperature (HP/LT) conditions. However, MOR-type ophiolites are locally preserved (e.g. Jurassic Western-type Albanian ophiolite). Seamounts were preferentially accreted into melanges and record subduction of large areas of oceanic crust. Volcanic–sedimentary units of mainly Triassic age, including alkaline to MOR-type extrusives and radiolarites record rifting, transitional to spreading of Neotethyan ocean basins. Back-arc, intra-continental marginal basins of Triassic and Late Jurassic age developed within the northerly (Eurasian) continental margin (e.g. Jurassic Guevgueli ophiolite, N Greece). Ophiolites formed in these basins were exposed by uplift, without significant transport. Transform-influenced ophiolites are occasionally preserved (e.g. Late Cretaceous Tekirova ophiolite, SW Turkey). Metamorphic soles reflect tectonic displacement of oceanic lithosphere while still hot, near a spreading centre (whether of mid-ocean ridge or supra-subduction type). The Eastern Mediterranean subduction-type ophiolites, of both Jurassic and Cretaceous age, were rooted in several coeval Neotethyan oceanic basins, separated by microcontinents and cannot be interpreted as vast, far traveled thrust sheets derived (at different times) from a single, palaeogeographically simple Tethyan oceanic basin.


*Keywords:* Ophiolites; Oceanic crust; Tethys; Eastern Mediterranean

## 1. Introduction

The aim of this paper is to present an overview of the tectonic settings of formation and emplacement of

* Fax: +44-31-668-3184.
*E-mail address:* alastair.robertson@glg.ed.ac.uk (A.H.F. Robertson).

0024-4937/02/$ - see front matter © 2002 Elsevier Science B.V. All rights reserved.
PII: S0024-4937(02)00160-3

ophiolites and related oceanic rocks within the Tethyan orogenic belt in the Eastern Mediterranean region (Figs. 1 and 2). Comparisons will be made with magmatic units in the modern oceans, elsewhere in the Tethyan region (e.g. Oman) and in other orogenic belts (e.g. Caledonides). Although the main focus is on ophiolites, it is also essential to take account of other fragments of oceanic lithosphere (e.g. seamounts, rift volcanics) that help to document former oceans. The approach here is to identify "tectonic facies", whereby lithological assemblages in orogenic belts, where possible, can be related to known modern tectonic environments, allowing recognition of various types of ophiolites formed in different tectonic settings (Robertson, 1994). The paper begins with a summary of the current alternative models of ophiolite genesis. Examples of Eastern Mediterranean ophiolites and related magmatic units formed in different tectonic settings are then discussed. Emphasis is placed on ophiolites and related units formed in rift, marginal basin, open-ocean, transform and accretionary prism settings. The assembled data are then used to test alternative, ocean ridge versus subduction-related models of ophiolite genesis. The regional geology of the ophiolites sheds light on the question of ophiolite root zones, whether in a single wide Tethyan ocean, or smaller oceanic basins separated by continental fragments. However, no attempt is made here to discuss all the known ophiolites in the region.

The area covered comprises, from west to east, the countries of Croatia, Serbia, Bosnia–Herzegovina, (including Kosovo and Montenegro), Albania, Macedonia (Skopje), Greece, Turkey, Cyprus and Syria. The Alpine-Mountain chain runs through these countries as orogenic segments known as the Dinarides (former Yugoslavia), Albanides (Albania), Hellenides (Greece), Anatolides/Taurides (central and southern Turkey, Cyprus), Pontides (northern Turkey) and the northern margin of the Arabian plate (southern Turkey, Syria). The Carpathians are mentioned, but the Caucasus region is excluded.

### 1.1. Definitions

According to the well-known Penrose Conference definition (Anonymous, 1972), a complete ophiolite exhibits, from the base upwards: (1) ultramafic rocks, with variable amounts of harzburgite, lherzolite and dunite (variably serpentinised); (2) a gabbro complex with cumulates and isotropic gabbros; (3) a mafic sheeted dyke complex; (4) mafic volcanics, commonly pillowed. Associated units, not formally part of the definition, include ribbon cherts, podiform chromites and felsic intrusives, or extrusives. Today, this definition is increasingly open to criticism. First, associated sediments, that commonly form one of the best guides to the tectonic setting of ophiolite formation (e.g. the presence of radiolarian cherts, or terrigenous sediments) were excluded from the Penrose Conference definition. Secondly, it is now clear that many ophiolites originally lacked complete successions and, in particular, sheeted dykes may be absent. Extrusives may rest directly on plutonic rocks (e.g. gabbros or ultramafic), as observed in the Jurassic ophiolites of the Western Mediterranean region (i.e. Apennines and Alps; Lagabrielle and Cannat, 1990; Desmurs et al., 2001).

A more modern definition of an ophiolite is "an oceanic magmatic complex comprising ultramafic rocks at the base, with variable amounts of harzburgite, lherzolite and dunite (commonly serpentinised), overlain by layered/non-layered gabbroic rocks, then by mainly basaltic extrusive rocks, with, or without, a sheeted dyke complex, and including a cover of pelagic deep-sea sediments". This modified definition excludes, e.g. intrusive layered igneous complexes, but could still run into difficulties, e.g. where extension has exposed ultramafic lower crust or subcontinental mantle (Müntner and Hermann, 2001), as seen along the rifted margin of Iberia (Whitmarsh et al., 1996, 2001), and in some Mesozoic Apennine and Alpine bodies (Lagabrielle and Cannat, 1990; Lagabrielle, 1994). In some cases, it may be necessary to resort to isotopic analysis to determine if an ophiolite-like body (e.g. I-type peridotite) is truly ophiolitic.

Many ophiolites are preserved in a highly dismembered state and may be termed *dismembered ophiolites*, assuming that the essential components of an ophiolite are present, as in the modified definition above. Where preserved in a highly mixed state, the term *ophiolitic melange* may be used, although care must be taken to ensure that the component blocks originally formed an ophiolite, and not, e.g. a rift or seamount assemblage.

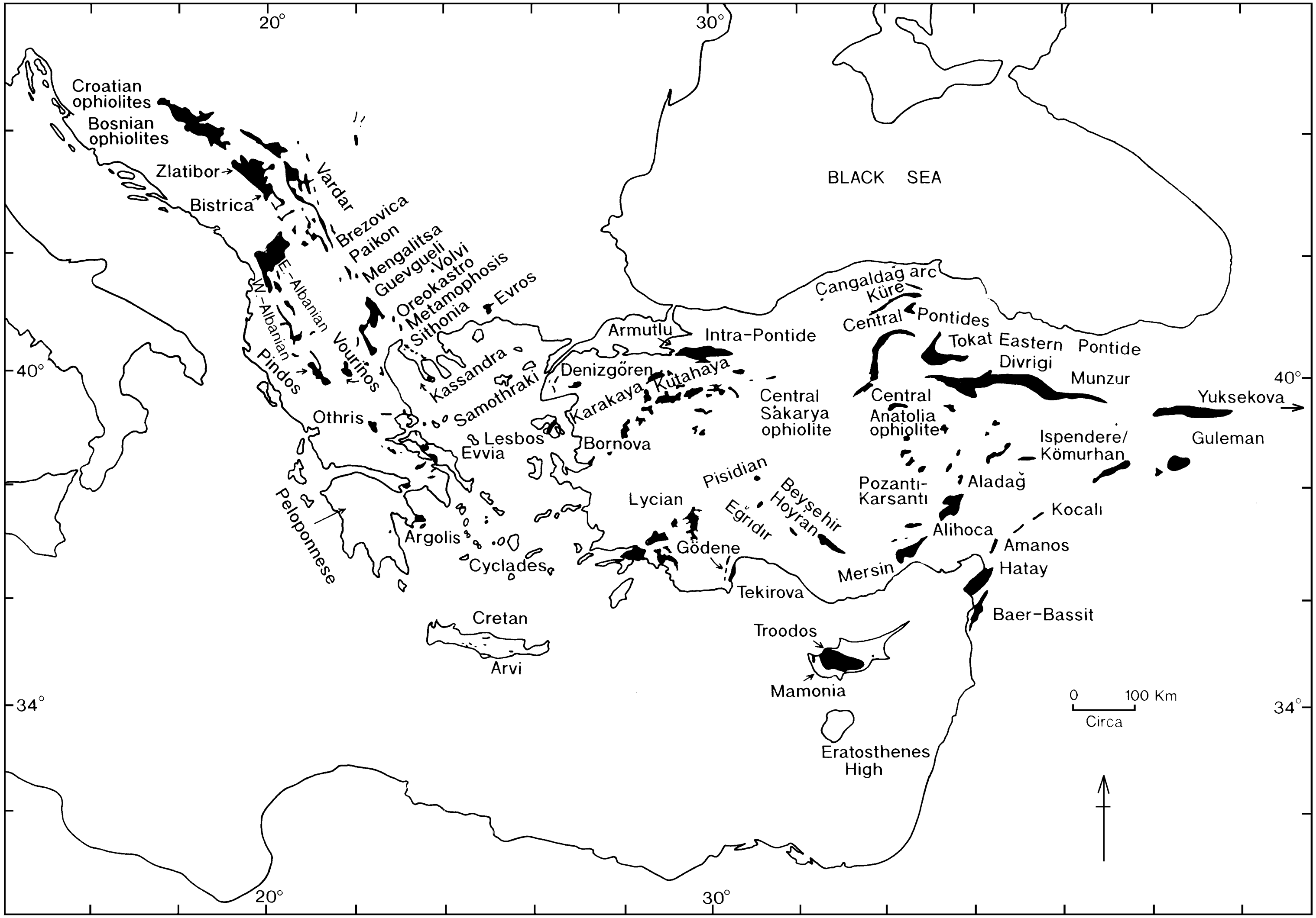


Fig. 1. Outline map of the Eastern Mediterranean region showing the main occurrences of ophiolites.

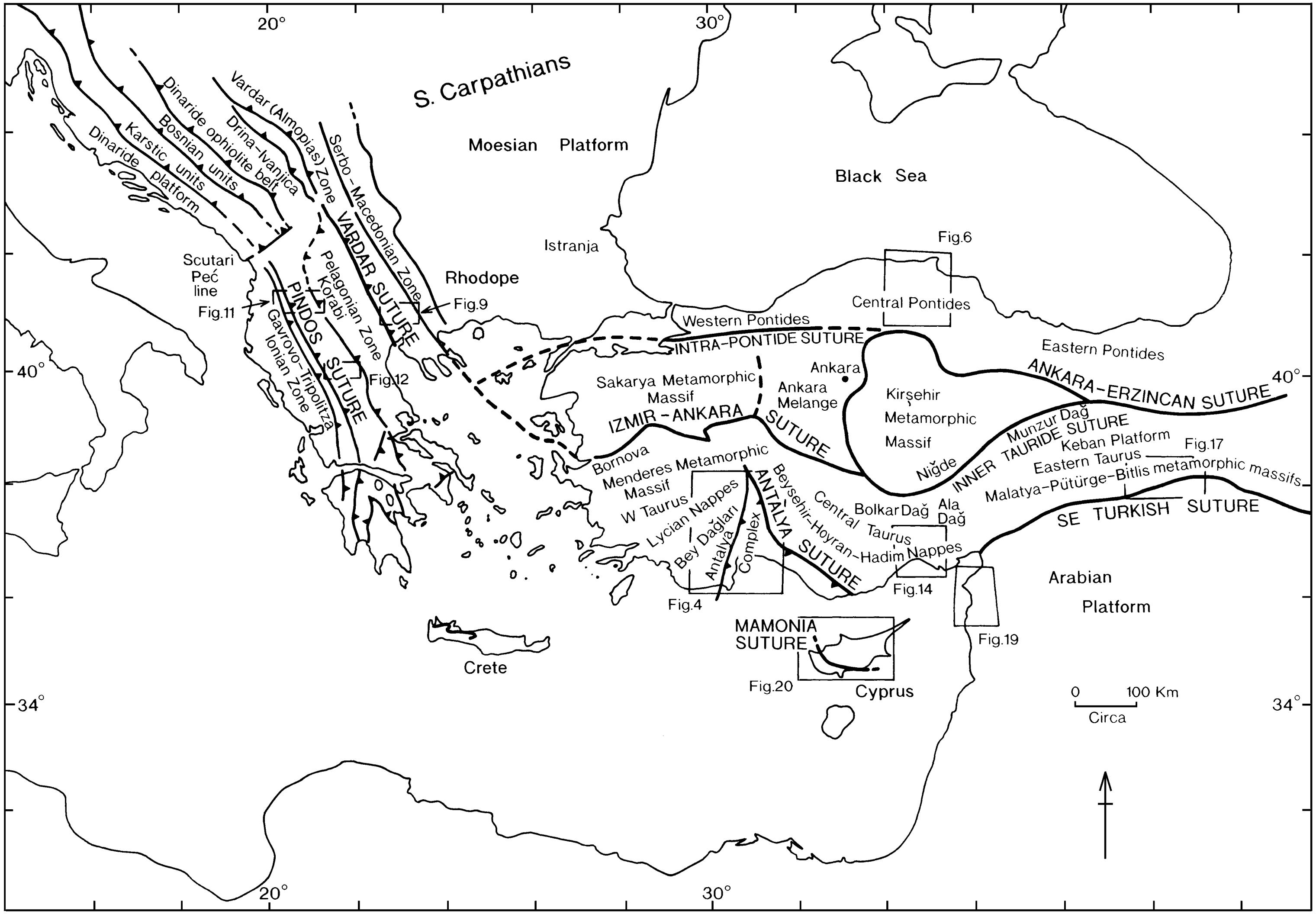


Fig. 2. Outline tectonic map showing the main sutures in the Eastern Mediterranean region, as discussed in the text.

### 1.2. Regional geology, dating and geochronology

In this paper, the scene is set for the regional geology of the ophiolites by first considering rift-related units. These commonly tectonically underlie ophiolites and are juxtaposed with continental units. An on-going debate concerning ophiolite root zones is retained until the end of the paper. The tectonic setting of formation of many of the basaltic units associated with the ophiolites and other volcanic units can be interpreted based on the composition of "immobile" elements (e.g. Pearce, 1980); however, original chemical data will not be presented here. Very few of the ophiolites are directly dated by radiometric means, the Troodos ophiolite being one exception (Mukasa and Ludden, 1987). Most of the ophiolites are indirectly dated from one, or another of the following. (1) Metamorphic soles that are assumed to have formed near the spreading axis where the crust was still extremely hot (and thus young), capable of metamorphosing underplated units up to amphibolite facies conditions (Woodcock and Robertson, 1977; Jones et al., 1991; Searle and Cox, 1999). A recent compilation of metamorphic sole ages, with errors of determination (Parlak and Delaloye, 1999), is shown in Fig. 3. Only age ranges are given in the text, for brevity. (2) The pelagic sedimentary cover where preserved, commonly using radiolarians. (3) Cross-cutting dykes or other intrusive rocks that give minimum age of ophiolite genesis. (4) The regional geological setting, e.g.

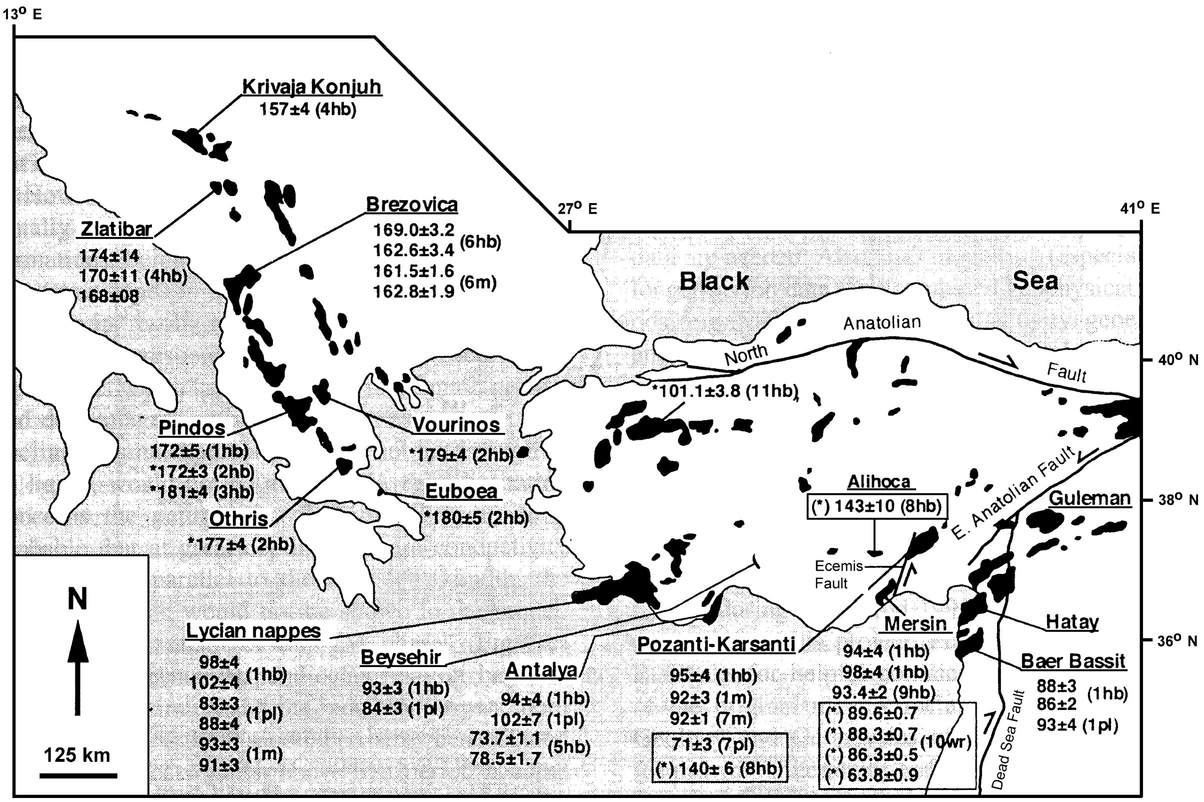


Fig. 3. Regional map of the Easten Mediterranean region summarising K–Ar and $^{40}Ar/^{39}Ar$ (*) geochronological data from the metamorphic soles of ophiolites (after Parlak and Delaloye, 1999). hb = hornblende; pl = plagioclase; m = mica; wr = whole rock. Boxes indicate post-tectonic dyke injection in the Pozantı–Karsantı, Alihoca and Mersin ophiolites. Numbers indicate references: 1 Thuizat et al. (1981); 2 = Spray and Roddick (1980); 3 = Roddick et al. (1979); 4 = Lanphere et al. (1975); 5 = Yılmaz and Maxwell (1982); 6 = Okrusch et al. (1978); 7 = Thuizat et al. (1978); 8 = Dilek et al. (1999); 9 = Parlak et al. (1995); 10 = Parlak and Delaloye (1999); 11 = Harris et al. (1994). Additional $^{40}Ar/^{39}Ar$ data are given for the Albanian ophiolites by Vergély et al. (1998) (not shown).

timing of emplacement and dating of post-emplacement cover units, mainly dated palaeontologically. This paper uses the Harland et al. (1989) time scale.

### 1.3. Tectonic framework of Tethyan ocean crust genesis

Regional tectonic reconstructions currently differ strongly and the reader is referred for alternatives to Şengör et al. (1984), Robertson and Dixon (1984), Dercourt et al. (1986, 1992) and Stampfli, 2000, Stampfli et al., 1998, 2000. Most models have some features in common. From the Late Palaeozoic onwards, the Tethys ocean widened eastwards from an oceanic gulf into a wider ocean (Panthalassa). Recent studies (Stampfli et al., 1998, 2000) have found no evidence to support an alternative Pangea reconstruction (Irving, 1982) that would eliminate any need for a pre-Jurassic ocean (i.e. Palaeotethys) in the Eastern Mediterranean region. The well-dated ophiolites in the Eastern Mediterranean are restricted to three well-defined, relatively brief time intervals: Triassic, Mid-Late Jurassic and Late Cretaceous.

Definitions of "Palaeotethys" (older) versus "Neotethys" (younger) differ in the alternative models cited above. As used in this paper, Palaeotethys refers to an older oceanic area from which ophiolites were emplaced prior to Late Jurassic time. Palaeotethyan units in the south (e.g. Karakaya Complex) are widely transgressed by Early Jurassic sediments, but in the north (e.g. Central Pontides), transgression did not occur until Late Triassic rime. Neotethys refers to oceans that rifted in the Early Mesozoic i.e. Triassic–Early Jurassic (mainly in the south of the region). Tethys in the Eastern Mediterranean region as a whole was closed by the Early Tertiary (Eocene–Oligocene), but oceanic remnants in the Eastern Mediterranean Sea and Black Sea still survive. However, no sharp distinction exists between Palaeotethys and Neotethys and the two ocean systems evolved from one to the other.

Pre-Triassic oceanic remnants remain poorly known, because of scarcity, common metamorphism and inadequate dating and will not be discussed in detail here. Throughout the region, metamorphic basement units include meta-basic/ultrabasic units many of which represent dismembered ophiolites. Examples include the Alpine Variscides (Neubauer et al., 1989; Stampfli, 1996), the SerboMacedonian–Rhodope metamorphic massifs of Bulgaria and northern Greece (Haydoutov and Yanev, 1997), the Sakarya and Kirşehir/Niğde metamorphic massifs in Anatolia (Şengör et al., 1984; Okay, 1986, 1989; Göncüoğlü et al., 1996–1997). A few of the meta-ophiolites highlighted here can be correlated with unmetamorphosed counterparts emplaced onto neighbouring platforms (e.g. related to the Izmir–Ankara suture; Fig. 2).

## 2. Ophiolite models

In this section the main alternative models of ophiolite genesis are summarised. One important conclusion from this is that the regional geological settings of individual ophiolites are critical to their interpretation, especially rift-related units that are outlined in the following section.

### 2.1. Ocean ridge versus subduction-related origin

The settings of formation of ophiolites and other oceanic magmatic units (e.g. seamounts) can be interpreted using knowledge of the modern oceans, especially as obtained by scientific drilling (DSDP, IPOD and ODP). However, there are some problems with this approach. (i) Ocean crust has very limited potential for preservation on land, as shown by the scarcity of ophiolites in some orogenic belts (e.g. Franciscan complex, western USA). Mid-ocean ridge (MOR)-type oceanic crust is typically subducted rather than emplaced, whereas, e.g. seamounts, oceanic plateaus, transform faults, forearc and rift-related units have a higher chance of preservation. (ii) Often, only deeper, plutonic parts of ophiolites are preserved in orogenic belts (e.g as harzburgite thrust sheets), yet the deeper parts of the oceanic lithosphere and upper mantle remain poorly documented in the modern oceans (i.e. the cumulates and upper mantle). (iii) There is no general agreement concerning the origin of ophiolites that show geochemical evidence of hydrous melting in their formation (supra-subduction zone ophiolites). The possible formation of many large ophiolites in subduction-related settings is one of the most contentious issues in tectonics today.

Acceptance of the seafloor-spreading hypothesis during the mid-1960s opened the way to classical Alpine-type peridotites, commonly exhibiting the Steinmann Trinity (see Amstutz, 1980) of serpentinite, mafic extrusives and radiolarian cherts to be re-interpreted as mid-ocean ridges emplaced in orogenic belts. In the Eastern Mediterranean, it was argued that the Troodos ophiolite, Cyprus formed at a mid-ocean ridge within a Tethyan ocean between Africa and Eurasia (Gass and Masson-Smith, 1963; Gass, 1968, 1990; Moores and Vine, 1971). However, following the development of geochemical discrimination techniques that allow the extrusive rocks of ophiolites to be compared with oceanic volcanics in a range of modern tectonic settings (e.g. Pearce, 1980), it soon became clear that the Troodos and many other ophiolites (e.g. Bay of Islands, Newfoundland; Jenner et al., 1991) exhibit extrusive sequences that are different from mid-ocean ridge extrusives, but similar to those found in modern subduction-influenced settings, notably volcanic arcs. The ophiolitic magmas underwent relatively high degrees of partial melting in the presence of water introduced by subduction. Upper mantle residues after hydrous melting are represented by thick depleted mantle harzburgite sequences of supra-subduction zone (SSZ)-type ophiolites (e.g. Troodos). Ophiolites of the Tethyan region, and elsewhere, could thus be divided into subduction influenced (many in the Eastern Tethys area) and non-subduction influenced (e.g. many in the western Tethys area) (Pearce et al., 1984). However, many geologists continued to interpret most of the large ophiolites as having formed at mid-ocean ridges (Coleman, 1981; Nicolas, 1989), including the large Late Cretaceous Tauride ophiolites of southern Turkey (Whitechurch et al., 1984; Dilek et al., 1999).

Much debate has centered on the Semail ophiolite, Oman (Hopson et al., 1981), for which an ocean ridge model was developed based on outcrops in the south (near Muscat), where extrusive rocks are not preserved (Coleman, 1981). Further north, where the succession is complete, the lower lavas are of near MORB (mid-ocean ridge) composition, whereas the upper lavas are strongly subduction influenced (Pearce et al., 1981). Different authors, therefore, favoured either a spreading ridge model (Nicolas, 1989; Nicolas et al., 1994; Boudier and Nicolas, 1995; Boudier et al., 1996), or a subduction-influenced model (Lippard et al., 1986; Searle and Cox, 1999).

Proponents of the mid-ocean ridge model argued that compositionally different ophiolites can be divided into: (1) mainly lherzolitic ophiolites formed at slow spreading ridges (Lherzolite Ophiolite Type, LOT; Fig. 4Ai) and (2) harzburgitic ophiolites (Harzburgite Ophiolite Type, HOT) formed at fast-spreading ridges (Nicolas, 1989; Fig. 4Aii). Where high-temperature amphibolitic metamorphic soles are present beneath ophiolites (Woodcock and Robertson, 1977; Spray et al., 1984); these formed at, or near, a spreading ridge in this model (Nicolas and Le Pichon, 1980; Robertson and Dixon, 1984; Boudier et al., 1985). More recently, ODP drilling within the Hess Deep, a young fast-spreading segment in the Eastern Pacific has revealed an upper plutonic sequence similar that of the Oman ophiolite (Natland and Dick, 1996; Dilek, 1998; MacLeod et al., 1996). However, the lower plutonic sequence (cumulates) remains unsampled, limiting detailed comparison with Oman. Although the tectonic setting of the Oman ophiolite is debatable, many of the Eastern Mediterranean ophiolites show much more definitive evidence of a subduction-related origin.

There are a number of pros and cons of the mid-ocean ridge interpretation, as follows:

Pros:

(1) a mid-ocean ridge setting is the simplest hypothesis, and has appealed to many land- and marine-based earth scientists seeking to make comparisons between ophiolites and modern oceanic lithosphere;
(2) as noted above, the Hess Deep upper plutonic sequence matches an equivalent interval in the Semail ophiolite, Oman;
(3) many of the “depleted” SSZ-type ophiolites exhibit pelagic sedimentary covers that lack arc-derived tuffaceous sediments, unexpected if these ophiolites formed in an arc-related setting.

Cons:

(1) no case is known in the modern oceans where large volumes of “depleted” oceanic extrusives (e.g. as in the Troodos) occur unrelated to subduction;

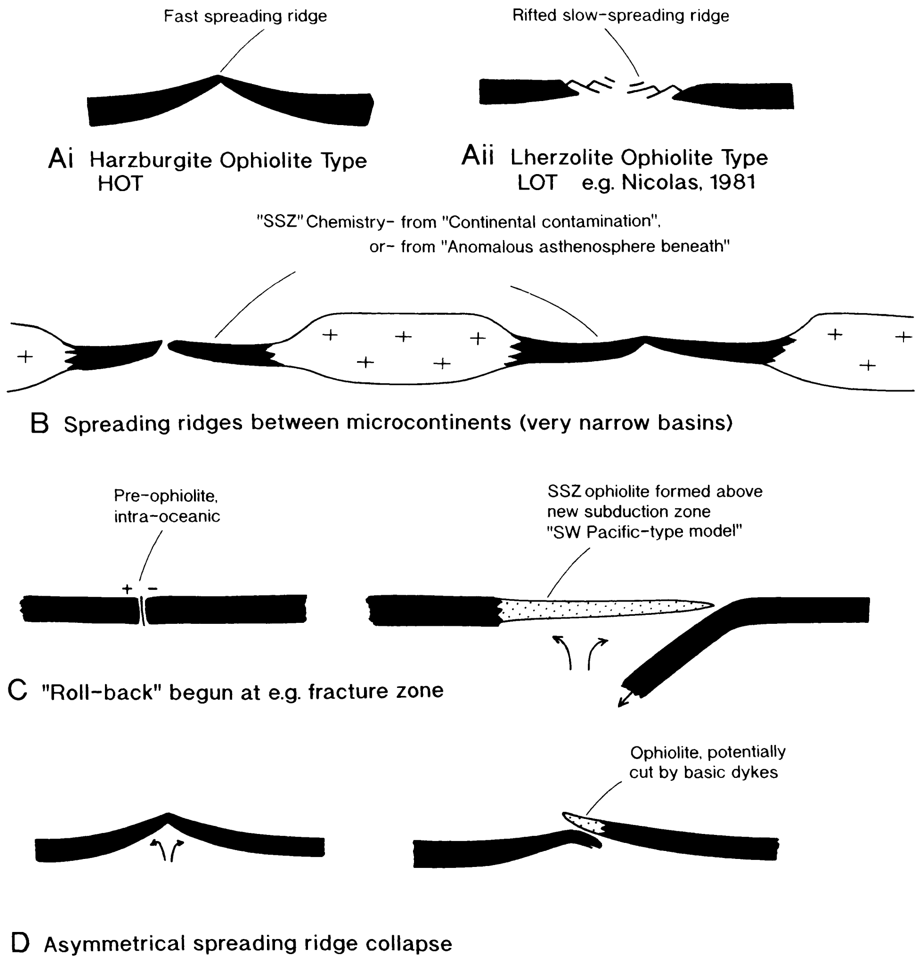


Fig. 4. Alternative models for ophiolite genesis in the Eastern Mediterranean region; see text for explanation.

(2) fresh volcanic glasses of the Troodos ophiolite, collected from the base of the extrusives upwards, are typical of subduction-related orogenic andesites (Robinson et al., 1983).
(3) mid-ocean ridges may not be emplaced onto continental margins without activating a major intra-oceanic thrust zone; in many cases, this can be equated with a subduction zone.

In addition there are a number of pros and cons of the SSZ-ophiolite model:

Pros:
(1) subduction-influenced volcanics, especially high-magnesian andesites (boninites; Crawford et al., 1989), as seen in the Troodos ophiolite, commonly occur in modern forearc settings (e.g. Tonga, Mariana forearcs; see later), but are unknown in oceanic MOR settings;
(2) genesis of ophiolites above an intra-oceanic subduction zone provides a mechanism of both formation and emplacement;
(3) the high-temperature basal metamorphic soles and overlying large ophiolites commonly overlap in age (dated radiometrically or palaeontologically), consistent with simultaneous underplating of subducted material and SSZ-spreading above (e.g. in Oman; Searle and Cox, 1999).

Cons:

(1) No exact modern analogue of SSZ-type spreading has been found in the oceans, and thus, the mechanism of formation remains largely hypothetical.

A number of authors have attempted to explain the SSZ-like chemistry of many ophiolites as follows.

(1) The asthenosphere varies compositionally over large regions of the earth, such that resulting melts are more or less depleted in different regions, explaining different ophiolite compositions in different areas. Ophiolite-producing melts may arise from previously subducted mantle, in the case of the Eastern Mediterranean, surviving from the Hercynian or Pan-African orogenesis (Moores and Kellog, 1999).

(2) "SSZ-type" ophiolites formed in narrow rifted basins where melts were contaminated by partial melting of neighbouring lower crust (Hall, 1984; Dilek et al., 1999; Fig. 4B).

(3) Seawater involved in SSZ-type magma genesis was introduced from above, e.g. by hydrothermal circulation, or stoping of magma into water-rich oceanic country rocks.

## 2.2. Ridge collapse model

Oceanic crust initially formed at a mid-ocean spreading ridge. In response to regional convergence, the spreading ridge then collapsed (Fig. 4D). The leading edge of the downgoing slab was underplated to produce an amphibolite facies metamorphic sole. Melt generated by the pre-existing, but later, underplated spreading centre was injected upwards through the sole and intruded into the upper plate (Whitechurch et al., 1984). Asymmetrical spreading continued (Dixon and Robertson, 1985), giving rise to subduction-influenced extrusives and plutonic rocks. Asymmetrical spreading then ceased followed by passive subduction/accretion until a volcanic arc formed or the ophiolite was emplaced onto a continental margin. Initiation of obduction tectonics close to the spreading ridge was specifically inferred for the Oman Ophiolite (Nicolas and Le Pichon, 1980; Boudier et al., 1985).

## 2.3. Pre-arc spreading model

The model for SSZ-spreading (Pearce et al., 1984) explains the formation of forearcs in the SW Pacific (e.g. Mariana, Tonga), where an almost identical suite of lithologies to a SSZ-type ophiolite occurs (Bloomer, 1987; Bloomer et al., 1995). SSZ-type ophiolites possibly nucleated along a pre-existing oceanic fracture zone (Casey and Dewey, 1984; Fig. 4C). Relatively old, dense oceanic crust "rolled-back" allowing subduction-modified asthenosphere to well up, creating a spreading fabric (i.e. sheeted dykes). Linear zones of SSZ-type crust, up to several hundred kilometres wide and several thousand kilometres long, formed in < 10 Ma years. In the open ocean, this SSZ-type spreading was followed by construction of volcanic arcs unless the subduction trench collided with, e.g. a continental margin or oceanic plateau first, in which case spreading stopped and SSZ-type ophiolites were obducted.

Both of the above, "ridge-collapse" and "pre-arc spreading" models, involve subduction and will be tested using data for the Eastern Mediterranean ophiolites in this paper.

## 2.4. Metamorphic soles

Many, but not all, ophiolites include metamorphic soles that exhibit inverted metamorphic gradients, with amphibolite (locally to granulite) facies metamorphics (formed at up to 1000 °C; Nicolas and Le Pichon, 1980), of oceanic origin, passing structurally downwards into greenschist facies rocks that typically show lithological affinities with underlying continental margin units. Pressure conditions range considerably (Searle and Cox, 1999) and in many cases remain poorly constrained. Where present, well-dated amphibolitic metamorphic soles tend to be near to, or overlap with, the age of the overlying ophiolite, as in Oman (Searle and Malpas, 1980; Searle and Cox, 1999; Gnos and Peters, 1993). This has been taken to support formation at, or near, a collapsed spreading ridge by some (Boudier et al., 1985). However, metamorphic soles are also explicable in SSZ models (see above) as oceanic crust that was underplated during "pre-arc spreading" (see above). The overlap of formation and sole ages for a number of ophiolites, including the Albanian ophiolites (see below), supports coeval spreading and sole formation at depth in the hanging wall of a subduction zone.

## 3. Tectonic setting of rifting and initial oceanic crust genesis

In the following section, specific modern tectonic settings of rifting to form oceanic lithosphere in the modern oceans will be outlined and compared with preserved remnants in Eastern Mediterranean Tethyan region. This is critical to understanding ophiolites, as the nature and timing of rifting needs to be compared with that of ophiolite genesis. Also, the chemical composition of the rift-related extrusives needs to be compared with each ophiolite in the same region to shed light on any regional variations of lithosphere/asthenosphere composition, that could, in turn, influence ophiolite chemistry. Recent work on rifted continental margins in the modern oceans, largely based on ocean drilling, allows identification of three main categories of rifted margin.

*Volcanic-rifted margins* are characterised by voluminous outpourings of basaltic extrusives, showing a distinctive plume-related signature (e.g. E Greenland margin; conjugate Vøring Plateau). Overlying deep-sea sediments are terrigenous influenced. Any underlying plutonic rocks remain undocumented, although related dyke swarms are known on land in Greenland.

*Non-volcanic margins* are marked by extreme thinning of the lithosphere, with little associated magmatism. Asthenosphere is exhumed onto the seafloor as serpentinite ridges, exemplified by the Iberia margin (Whitmarsh et al., 1996, 2001). Ancient, tectonically emplaced examples include the Jurassic rifted margins of the Alpine and Apennine regions (Lagabrielle and Cannat, 1990). Rift-related units underwent strong extension, and include serpentinised peridotite breccia beneath a terrigenous deep-sea sedimentary succession, including radiolarian cherts and manganiferous hydrothermal deposits.

*Transform-rifted margins* are marked by steep continental slopes, basement ridges, regional-scale shearing, minimal volcanism and reduced subsidence rates relative to orthogonally rifted margins, as demonstrated by ODP drilling of the Ivory Coast margin (Mascle et al., 1996). However, small-scale structures preserved in cores are mainly dip-slip faults, with limited evidence of strike-slip faulting (Pickett and Allerton, 1998). Recognition of transform-rifted passive margin segments in orogenic belts may not always be able to rely on obvious field evidence of strike-slip faulting.

### *3.1. Eastern Mediterranean examples*

The field and geochemical evidence support rifting and initial spreading in Mid–Late Triassic time throughout the southern part of the Eastern Mediterranean region (Figs. 1 and 2). Typical rift-related units are characterised by thick successions (hundred of metres) of alkaline, to transitional, to locally MOR-type basic extrusives, interbedded with and overlain by sediments that include terrigenous, carbonate and pelagic deposits. However, basement rocks (continental or oceanic) are not exposed.

Rift/early spreading related rocks are commonly dismembered related to much later ophiolite emplacement. Exceptionally, an excellent example of a Triassic rift/ocean transition is preserved within the Antalya Suture (Antalya Complex), SW Turkey (Figs. 2 and 5). Later emplacement was dominated by high-angle strike-slip tectonics, preserving thick rift-early spreading units. As a result, there are relatively intact Late Triassic (Carnian) extrusive successions, up to 750 m thick (Juteau, 1970; Marcoux, 1995; Robertson and Woodcock, 1979), that contain local interbeds of terrigenous turbiditic sandstones, hemi-pelagic limestones and rare shallow-water-derived limestone blocks (Gödene zone). The volcanics are overlain by Fe–Mn crusts, and in places, by terrigenous conglomerates and turbiditic sandstones, passing up into Halobia limestones, interpreted as fine-grained carbonate sediments shed from a neighbouring carbonate platform. Above come Jurassic–Lower Cretaceous ribbon radiolarites that include minor terrigenous turbidites, neritic-derived calciturbidites and rare manganiferous hydrothermal deposits (Robertson and Woodcock, 1982). Geochemical analysis shows that the Triassic extrusives range from within-plate-type (WPB) to transitional MORB (Robertson and Waldron, 1990). Locally, additional MORB-type tholeiitic basalts are associated with radiolarites of Late Jurassic–Early Cretaceous age (Yılmaz, 1984). Elsewhere, in the NE segment the Antalya Complex (SE of Lake Eğrıdır; Fig. 5) MOR-type volcanics are again associated with radiolarian cherts of Late Jurassic–Early Cretaceous age (Waldron, 1984; Robertson and Waldron, 1990).

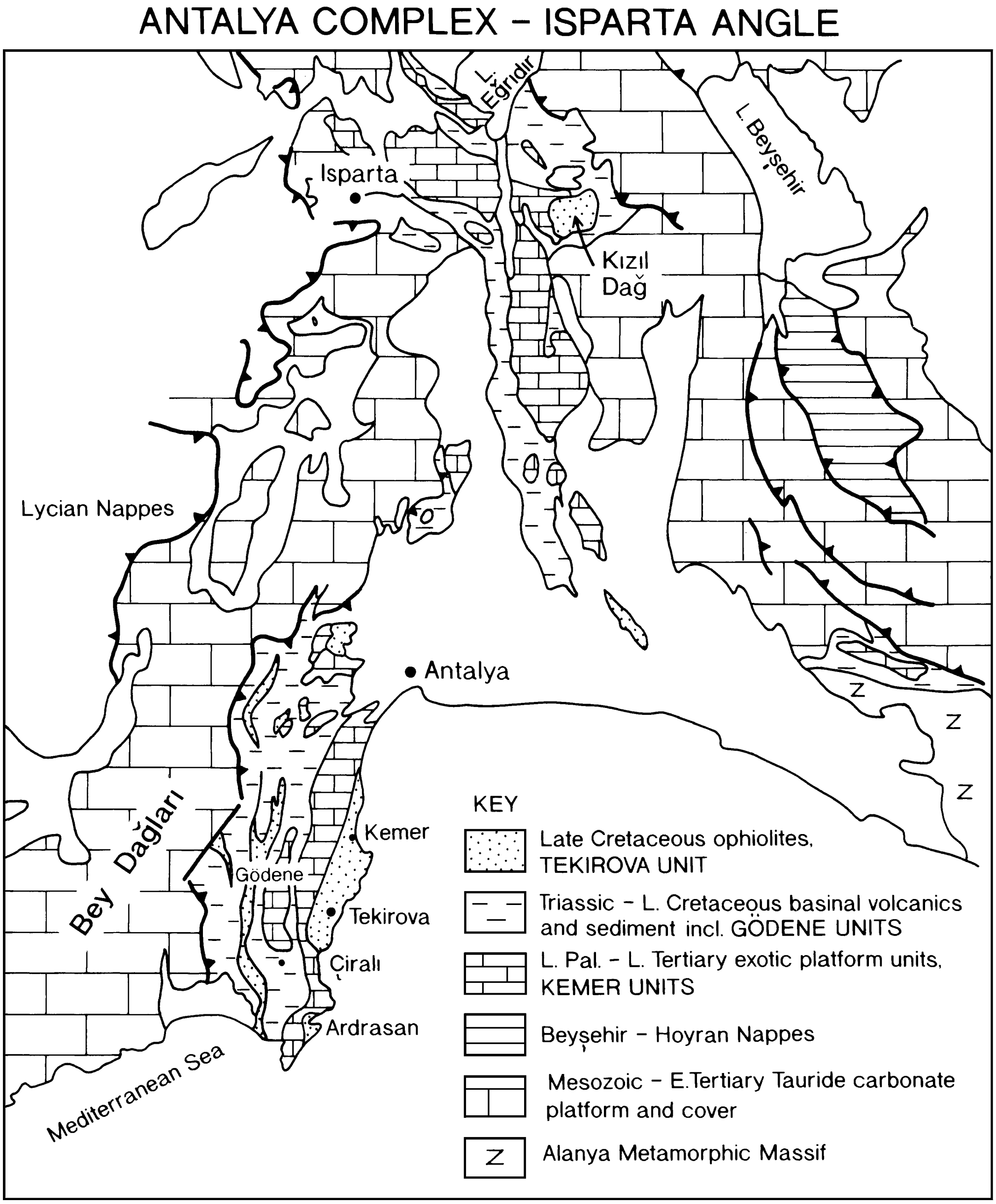


Fig. 5. Setting of Triassic rift—early spreading-related volcanics and sediments in the Antalya Complex, SW Turkey; see text for explanation.

In the Antalya Complex, SW Turkey, initial rifting took place in the Late Permian, marked by normal faulting and syn-tectonic deposition. A second phase of rifting took place in Mid-Triassic (Late Anisian–mid-Ladinian) time, marked by gravity collapse, reworking and initial deep-water pelagic sedimentation (radiolarite and shale). Large-scale volcanism began in the Late Ladinian and reached a maximum in Carnian time (Marcoux, 1995). This is taken to mark the time of initial seafloor spreading in the region (Robertson, 1993).

Elsewhere in the easternmost Mediterranean region, within the Mamonia Suture (Mamonia Complex) of SW Cyprus (Fig. 2), some 80% of the Triassic volcanic rocks are tholeiites that show MORB-type signatures and are overlain by radiolarian cherts, shales and minor fine-grained limestone (Malpas et al., 1992, 1993; Swarbrick and Robertson, 1980). Subordinate WPB-type alkaline basalts and volcaniclastic sediments are associated with Triassic reef carbonates, interpreted as seamounts within the Late Triassic Neotethys (Swarbrick and Robertson, 1980). Further east, the melange beneath the Baer–Bassit ophiolite includes Triassic alkaline WPB-type basalts (Parrot, 1977; Al-Riyami et al., 2000). Alkaline-type protoliths also dominate the metamorphic sole of the Baer–Bassit ophiolite, although IAT-type protoliths are rarely present.

Similar Triassic volcanics associated with rift-related extrusives occur in Greece. Basalts from the melange beneath the Pindos ophiolites of northwestern Grece (Avdella Melange) reveal mainly WPB/MORB types (Jones and Robertson, 1991). Local successions preserved in melange blocks and dismembered thrust sheets include basic dykes of WPB, transitional and MOR-type, locally intruding Late Triassic sediments (Jones and Robertson, 1994).

Elsewhere, mainly in central and southern Greece, Triassic rift-related tholeiitic basalts are mainly of IAT type (e.g. Evvia island, E Greece; Gavrovo–Tripolitza unit, W Greece). These volcanics are envisaged either as being related to rifting above a subduction zone (Pe-Piper, 1982), or are interpreted as the result of partial melting of lithospheric mantle and lower crust influenced from some earlier (Hercynian?) subduction event (Dixon and Robertson, 1993; Smith, 1993; Pe-Piper, 1998). Similar, apparently subduction-influenced volcanics are found in Albania (Shallo et al., 1990 and references therein). A similar Triassic rift history is documented in the Dinarides of Serbia (Robertson and Karamata, 1994 and references therein).

Further west, in Croatia, Late Permian rifting with block faulting and localised evaporite deposition was followed by mainly shallow-water carbonate deposition. Rift volcanism climaxed in Ladinian time, but ended prior to Norian in most areas (Pamić, 1984). Platform rocks are locally cut by rift-related syenite, diorite and gabbro (Pamić and Tomljenović, 2002). The extrusives comprise altered basalts, andesites and rhyolites. Overlying, mainly shallow-water carbonates are followed by Early Jurassic condensed deposits (Ammonitico Rosso) that accumulated on a subsiding passive margin after spreading began.

### 3.2. Timing of continental break-up

In the Eastern Mediterranean, within the "eastern region" (i.e. S Turkey, Cyprus, Arabian margin) spreading to form Neotethys has variously been placed in the Permo-Carboniferous (Stampfli et al, 1998; Stampfli, 2000), Early–Late Triassic (Şengör and Yılmaz, 1981; Robertson and Dixon, 1984; Dercourt et al., 1992, or Mid-Cretaceous (Dercourt et al. 1986; Dilek and Rowland, 1993). In the "western region" (Greece, Albania, former Yugoslavia), spreading began in the Late Triassic (Robertson et al., 1991), or the Early Jurassic (Smith, 1993).

A number of lines of evidence favour continental break-up to form Neotethyan oceanic basins in Mid–Late Triassic time (following Late Permian–Early Triassic rifting) throughout the southern part of the Eastern Mediterranean region, as the following. (1) Pre-Triassic rift volcanics are insignificant. (2) Transitional to MOR-type basic extrusives were erupted during Late Triassic time (e.g. Antalya, Mamonia, Pindos, Albania). (3) The Late Triassic ribbon radiolarites within and above the extrusives indicate open-ocean circulation. The Triassic-rifted carbonate platforms and basins of the classic Dolomites, N Italy, by contrast, lack coeval basinal pelagic (radiolarian) sediments: spreading there did not take place there until the Late Jurassic (Bosellini and Rossi, 1974; Bosellini, 1996). (4) In Antalya, the Late Triassic lavas are locally interbedded and overlain by coarse terrigenous sandstones, including conglomerates, indicating a near-margin setting. (5) Deep-sea sedimentary successions bordering the carbonate platforms in the Antalya Complex persist unbroken from Late Triassic (Carnian–Norian) to Late Cretaceous time. (6) Subsidence curves for the Levant passive margin and adjacent areas indicate tectonic subsidence from Late Palaeozoic/Early Mesozoic onwards (Garfunkel, 1998).

In summary, the Neotethyan rift history in the Eastern Mediterranean region involved: (1) Late Permian–Early Triassic rifting of the northern margin of Gondwana (Apulia); (2) Early–Mid Triassic rifting (intrusion/extrusion); (3) Late Triassic continental break-up, initial MOR volcanism and initial seafloor spreading. The exact timing of ocean crust genesis probably varied locally.

### 3.3. Rift processes

The Eastern Mediterranean Triassic rift units do not conform exactly to any of the known three end-member modern rift settings: i.e. volcanic, non-volcanic or transform-rifted margins. Volcanism, though invariably an important feature (>750 m thick in Antalya), is not nearly as voluminous as in plume-dominated volcanic-rifted margins (e.g. SW Greenland). On the other hand, there is no known evidence of large-scale detachment faulting and exposure of ultramafic rocks (i.e. serpentinite diapirs), or deep-level continental crust on the seafloor during rifting, as is characteristic of non-volcanic rifted margins (Iberia and the Alps/Apennines). Transform influence is probable (e.g. in Antalya), but hard to confirm, in view of superimposed tectonic deformation.

In the above context, recent geochemical work, including Nd–Pb isotopic studies of Triassic basaltic rocks from Greece (Pe-Piper, 1998) and also for the Antalya and Mamonia Complexes further east (Dixon and Robertson, 1999) reveal a small, but distinctive plume-influenced signature. In contrast to a few very large plumes known to straddle continental margins (e.g. SW Greenland), the oceans include numerous seamounts that reflect plume influence on a smaller scale. Such small-scale plume effects are likely to be involved in rifting in some areas. It is thus possible that a number of relatively small widely spaced plume features (hundreds of km apart) were involved in Triassic rifting in the Eastern Mediterranean (Dixon and Robertson, 1999). Smith (1999) discusses three processes that could influence Triassic continental break-up: (1) trench suction; (2) trench roll-back; (3) slab-pull. Trench suction may aid break-up of relatively wide continental strips (several hundred kilometres) where subduction zones dip beneath continental margins. "Roll-back" occurs in front of related volcanic rocks, as in the modern Tyrrhenian Sea. "Slab-pull" may develop behind an established subduction zone. Forces required to initiate subduction may require more than one of these processes to act in concert. Smith (1999) favours a dominantly trench suction model. It is possible that that the driving forces of Late Triassic break-up of Gondwana were a combination of slab-pull beneath Gondwana and the presence of small plumes beneath the northern margin of Gondwana (Dixon and Robertson, 1999).

It should also be noted that there is evidence of Early Triassic rifting further north, related to rifting of an elongated marginal fragment from Gondwana to form a northerly Neotethyan oceanic basin. In north-western Turkey, the northern margin of the metamorphosed Mesozoic Anatolides, correlated with the Tauride carbonate platform further south (Şengör and Yılmaz, 1981), is marked by Early Triassic rifting and related volcanism (Okay et al. 1996; Göncüoğlü et al., 2000). Exceptionally, in the far west, unmetamorphosed Early Triassic units in the Karaburun Peninsula and Evvia island (Greece) include intermediate composition extrusives, redeposited limestones and radiolarites, passing up into a subsiding Late Triassic–Early Jurassic carbonate platform (Robertson and Pickett, 2000). Also, Triassic rifting is reported from the Vardar (Almopias) zone in northern Greece (Stais and Ferrière, 1991; Brown, 1997).

Relevant to the origin of ophiolites, the following can thus be inferred.

(1) Rifting/spreading pre-dated formation of any of the intact ophiolites, including the early Late Jurassic ophiolites of the "western region" and the Late Cretaceous ophiolites of the "eastern region". (2) Geochemical studies suggest that the Late Triassic rift extrusives bordering ophiolites show an apparent subduction influence in some areas (Dinarides, Albanides and some parts of the Hellenides), but not in others (Taurides, Cyprus (Mamonia), Arabian margin). The subduction influence is inferred to have been inherited from some earlier orogenic event (e.g. "Hercynian") that affected these areas. At least for the "eastern region" there is, thus, no evidence that a subduction signature in the Late Cretaceous ophiolites could have been inherited from bordering rifted lithosphere, as the Triassic-rift-related extrusives lack a subduction influence.

## 4. Back-arc basin ophiolites

In the modern oceans, back-arc basins fall into two classes, intra-oceanic and intra-continental. However, this simple distinction may break down where volcanic arcs straddle continental margins, as in Java–Sumatra. In this section, the main features of modern intracontinental back-arc basins are summarised and examples of ophiolites formed in comparable settings are considered. Intra-oceanic back-arc basins are covered towards the end of the paper.

Well-documented (non-emplaced) intra-continental marginal basins include the Sea of Japan, the Andaman Sea (Curray et al., 1978), the Roccas Verde/Sarmiento complex, Southern Chile (Dalziel, 1981; Aberg et al., 1984) and the Bransfield Straits, Antarctic Peninsula. The Bransfield Strait was previously interpreted as a subduction-related marginal basin (Fisk, 1990), despite the presence of near-MORB extrusives and its development on unusually thick crust (re-interpreted as an old accretionary wedge). The Bransfield Basin setting was recently interpreted as related to "roll-back" of the South Shetland Trench to the northwest after active subduction ended (Barker and Austin, 1994; Lawver et al., 1995, 1996).

One of the best documented ancient back-arc marginal basins emplaced on land is the Jurassic Josephine ophiolite, Oregon (Harper, 1984), which is bordered by an active arc to the west (Chetco arc) and a remnant arc to the east. The basinal volcanics are subduction influenced and are overlain by terrigenous-derived sediments (Galice unit). Marginal basin settings have also been proposed in older orogenic belts, including the Late Ordovician Solund–Stavfjord ophiolite (Norway; Furnes et al., 1990; Dilek et al., 1997). Extrusives range from high-magnesian basalts to ferrobasalts, with a subduction-influenced chemistry. Both the Josephine and Solund–Stavfjord ophiolites possess a terrigenous-derived sediment cover indicating a near continental setting.

In the eastern Mediterranean region important examples of ophiolites associated with intra-continental back-arc settings (Andean-margin type) are reported in the literature as follows.

### *4.1. Intra-continental marginal basin ophiolites: Early Mesozoic ophiolites of the Eurasian margin*

Ophiolites of inferred Early Mesozoic age were formed in back-arc basins along the Eurasian margin, as documented in both the central Pontides, northern Turkey and the Hellenides, northern Greece. In addition, Permo-Triassic back-arc basins may be present in the Carpathians; e.g. the dismembered Meliata ophiolites (Kozur, 1991; Ivan et al., 1994).

Metamorphosed lithological assemblages of pre-Late Jurassic age in the central and eastern Pontides were interpreted by Şengör et al. (1980) to be obducted remnants of a Palaeotethyan ocean (i.e. pre-Late Jurassic) that existed to the north and that was emplaced related to southward subduction (Yılmaz and Şengör, 1985). More recent work has confirmed the presence of Palaeotethyan ophiolites in the central Pontides (Tüysüz, 1990; Ustaömer and Robertson, 1993, 1994, 1997; Yılmaz et al., 1997). However, it now appears that mafic magmatic units of the eastern Pontides are composite in origin (e.g. arc intrusives; mafic volcanics) rather than true Palaeotethyan ophiolites (Robinson et al., 1995; Ustaömer, 1999).

Three metamorphosed Palaeotethyan ophiolite-related units are, however, present in the central Pontides (Ustaömer and Robertson, 1997; Fig. 2). The first in the north is the Küre ophiolite (Figs. 2 and 6), which is strongly dismembered and thrust interleaved with terrigenous turbidites and black shales. Its inferred age is Mid-Triassic–Mid-Jurassic, assuming that Carboniferous plant microfossils (palynomorphs) were reworked from Carboniferous coal deposits (Ustaömer and Robertson, 1997). Ophiolite thrust sheets exhibit a nearly complete (although mainly dismembered) succession of serpentinised harzburgite, cumulate and massive gabbro, sheeted dykes and basaltic extrusives. The extrusives are depositionally overlain by hemipelagic shales, passing, over a short interval ($<10$ m), into terrigenous turbidities and black shales. Economic massive sulphides occur at the lava–sediment interface (at Küre) within a large ophiolite slice. Geochemical evidence of mobile major- and trace-elements, together with that of pyroxene and chrome spinel compositions, indicate MORB to volcanic arc basalt (VAB) chemical compositions, interpreted to indicate genesis above a subduction zone (Ustaömer and Robertson, 1993, 1999). The Küre oceanic crust and sedimentary cover were deformed by northward-directed thrusting and folding prior to transgression by shallow-water carbonates in Late Jurassic time.

To the south, the Küre ophiolite and related turbidites are locally in tectonic contact with a major

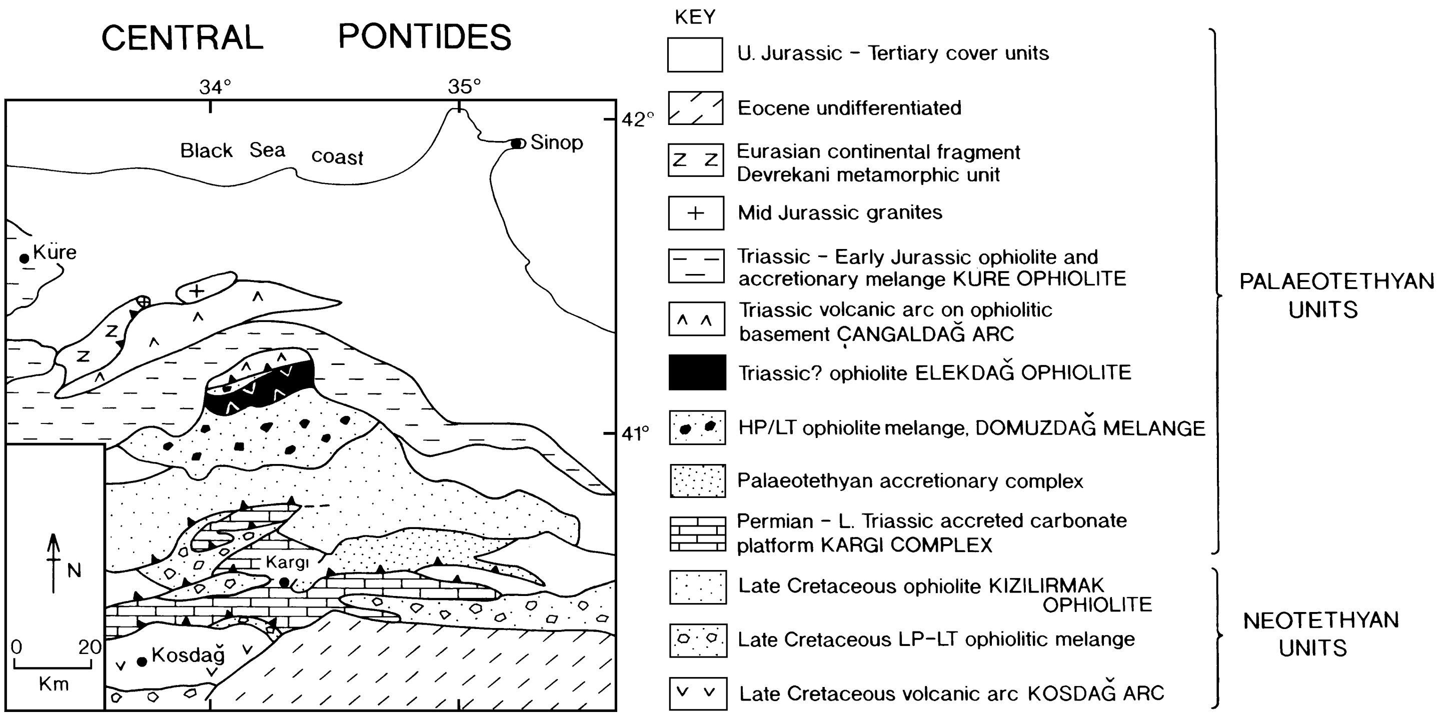


Fig. 6. Sketch map of the Central Pontides, showing occurrences of Palaeotethyan and Neotethyan ophiolites and related rocks; see text for discussion. Modified after Ustaömer and Robertson (1997).

volcanic unit, the Çangaldağ arc (Fig. 6). This begins with a dismembered meta-ophiolite, comprising sheeted dykes, with minor gabbroic intrusions, overlain by basaltic pillow lavas, associated with minor radiolarian cherts. "Immobile" major- and trace-element chemistry shows that this ophiolitic basement is of IAT-type in the north, but boninite-type in the south. The ophiolite is overlain by volcaniclastic sediments including meta-tuffs (400 m thick) and then passes into a volcanic–sedimentary succession (>5000 m thick), including porphyritic andesite, basaltic andesite, rhyolite, rhyo-dacite and dacite, with subordinate meta-tuff and volcaniclastic sediment, cut by small felsic and plagiogranite intrusions (metamorphosed under greenschist facies conditions). The uppermost lavas are overlain by black phyllites with thin lava flows and recrystallised marble. The ophiolitic basement is interpreted as having formed above a subduction zone (Fig. 7) and is then overlain by a thick calc-alkaline volcanic arc succession (Ustaömer and Robertson, 1997, 1999).

Structurally overlying the Çangaldağ arc unit to the south is the dismembered Palaeotethyan Elekdağ ophiolite (Fig. 6), which includes blueschists, indicating it underwent high-pressure/low temperature (HP/LT) metamorphism. Ultramafic tectonites at the base of the Elekdağ ophiolite are overlain by ultramafic cumulates and massive serpentinised peridotites with podiform chromites. No higher units of the ophiolite are preserved. Electron probe analysis indicates that the chrome spinels are of depleted "SSZ"-type (Ustaömer and Robertson, 1999). In addition, serpentinitic melange at the base of the ophiolite (Domuzdağ Melange; Fig. 6) contains blocks of eclogite with MORB protoliths.

Ophiolitic outcrops also occur in the eastern Pontides, within the Tokat Massif (Fig. 1), where the setting of meta-ophiolites parallels that of the Central Pontides, discussed above. The oldest cover sediments are Liassic in age (Yılmaz et al., 1997). In this area, a meta-ophiolite (Turhan unit) comprises thin thrust slices intercalated with psammitic metamorphic rocks and is intimately associated with meta-ophiolitic melange, comprising Mn-chert, red mudstone, radiolarites and altered basalts (Yılmaz et al., 1997). These ophiolite-related ophiolitic rocks can be interpreted as a subduction–accretion complex, similar to that of the central Pontides (i.e. Domuzdağ Melange; Fig. 7).

### 4.1.1. Discussion

The Küre ophiolite is interpreted as a SSZ-type ophiolite (Fig. 7). The presence of a terrigenous sediment cover without pelagic sediments (e.g. radiolarian chert), however, points to formation in a relatively narrow basin. The terrigenous sediment was derived from the Eurasian margin to the north. The Küre ophiolite is similar to the setting to the Jurassic Josephine ophiolite of southern Oregon (Harper, 1984), which shows a similar terrigenous-influenced cover, above subduction-influenced ophiolitic volcanics and is bordered by a similar volcanic arc. Thrust slices rich in volcaniclastic sediments in the

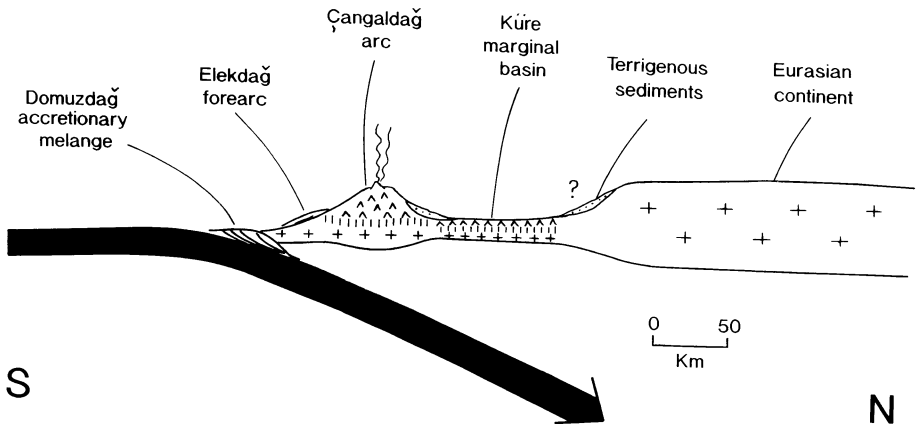


Fig. 7. Tectonic model for the formation of Palaeotethyan magmatic units in the Central Pontides; see text for explanation.

south (Ustaömer and Robertson, 1997) are interpreted as part of the deformed distal flanks of the Çangaldağ arc. The Çangaldağ arc itself is interpreted as a volcanic arc constructed on oceanic crust formed above a north-dipping subduction zone that was probably located along the periphery of the Eurasian continental margin. The overlying black shale could record collapse related to late-stage arc rifting. Arc genesis, emplacement and regional metamorphism were complete prior to accumulation of transgressive Late Jurassic neritic carbonates. The Elekdağ ophiolite is viewed as part of the forearc of the Çangaldağ arc that was later detached, subducted and underplated at depth beneath the forearc, resulting in blueschist metamorphism. The entire forearc/arc/marginal basin assemblage is envisaged as forming adjacent the southern margin of Eurasia during Triassic–Early Jurassic time. Exhumation of the HP/LT units took place during Cretaceous regional extension.

### 4.2. Hellenide marginal basin, N Greece

The second well-documented example of an intracontinental marginal basin ophiolite and related arc unit is represented by the Jurassic ophiolites of the Vardar suture, NE Greece (Figs. 1, 8 and 9). These ophiolites lie within the "Innermost Hellenic Ophiolite Belt," reflecting a northeasterly position adjacent to the metamorphic Serbo–Macedonian zone (Fig. 2), interpreted as part of the Eurasian margin (see review by Smith, 1993). The ophiolites comprise a series of NW–SE trending, variably disrupted bodies, commonly separated by strike-slip faults. By far, the most important of these is the extensive Guevgueli ophiolite (Fig. 9), divided into eastern and western parts by a fault (Bébien et al., 1986, 1987). The Guevgueli ophiolite includes cumulate and massive gabbro, hornblende diorite, sheeted dykes and basaltic lavas, locally interbedded with radiolarian shales (Fig. 8). The ophiolitic extrusives range from near MORB in the centre to more IAT-like towards the western margin of the ophiolite (Bébien et al., 1986, 1987). Rare interbedded sediments include terrigenous silt and minor volcanic quartz probably derived from a volcanic arc (Danelian et al., 1996). The eastern ophiolite outcrop is cut by granites (146–166 Ma) associated with migmatites, and exhibits cordierite/andalusite contact metamorphism with adjacent country rocks of the Serbo–Macedonian zone (Bébien et al., 1986; Dimitriadis and Asvesta, 1993; Zachariadou and Dimitriadis, 1995). The Late Jurassic isotopic ages of the granites (Spray et al., 1984) are similar to those of the ophiolite, suggested by the Oxfordian ages of radiolarians extracted from the directly overlying deep-sea sedimentary cover of the ophiolitic extrusives (Danelian et al., 1996). No metamorphic sole is present and there is little evidence that the ophiolite was emplaced by thrusting from its original site of formation.

Additional, smaller ophiolitic units further south add to the picture. First, in the northeast, the nearly complete Oreokastro ophiolite (Fig. 1) exhibits MOR-type extrusives and a contact metamorphic contact with the adjacent Serbo-Macedonian metamorphic basement (Remy, 1984; Haenel-Remy and Bébien, 1985).

Further south, the Central Chalkidiki and Metamorphosis (Fig. 1) ophiolites (Jung et al., 1980; Jung and Mussallam, 1985; Mussallam, 1991), separated from the Guevgueli ophiolite by a dextral transform fault, expose only the deeper, plutonic parts of an ophiolite, i.e. peridotite, gabbro and diorite (Bébien et al., 1986). The more southerly, Sithonia ophiolite (Fig. 1) exposes NE-trending sheeted dykes and includes intermediate-acid rocks, together with basalts of MOR to IAT-type. This ophiolite is underlain by a Middle–Late Jurassic volcanic arc unit dominated by diorite and granophyre (up to 3 km thick). Jung and Mussallam (1985) restore the Sithonia ophiolite as an elongate rift, $< 30$ km wide. The Sithonia ophiolitic rocks are depositionally overlain by shallow-water limestones of Late Jurassic age (e.g. Kelifos and Cape Lemos sections; Jung and Mussallam, 1985). This evidence has suggested a relatively young, Late Jurassic–Early Cretaceous age for the Sithonia ophiolite, in contrast to an early Late Jurassic age for the Guevgueli ophiolite (Mussallam, 1991), in turn implying ophiolite genesis over a long time period (Late Jurassic–Early Cretaceous) in this region. However, the setting of ophiolitic pillow lavas and sheeted dykes directly overlain by reef carbonates (but with a faulted contact) at the localities mentioned above is unusual, as ophiolitic rocks are generally overlain by deep-sea sediments, rather than carbonate build-ups. Other ophiolitic units in the region (e.g. Oreokastro) are unconformably overlain by clastic sediments and latest Jurassic (Portlandian) shallow-

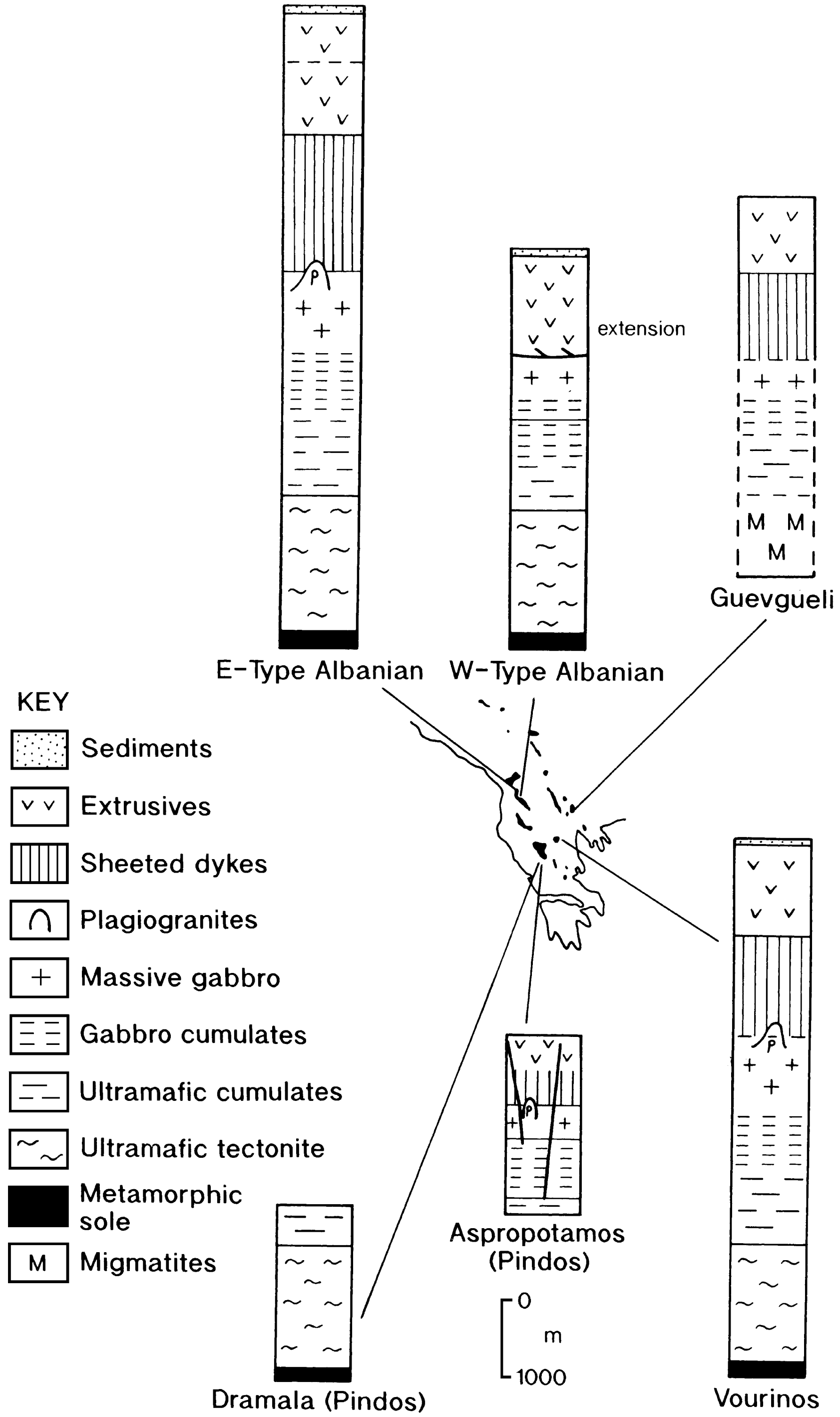


Fig. 8. Logs of selected Jurassic ophiolites from Greece and Albania. The E-Albanian and Vourinos ophiolites are seen as intra-oceanic subduction related; the Albanian western ophiolites as MORB; the Pindos (Dramala) and Asproptamos ophiolites as intermediate MOR/SSZ and Guevgueli as an intra-continental back-arc basin. See text for data sources.

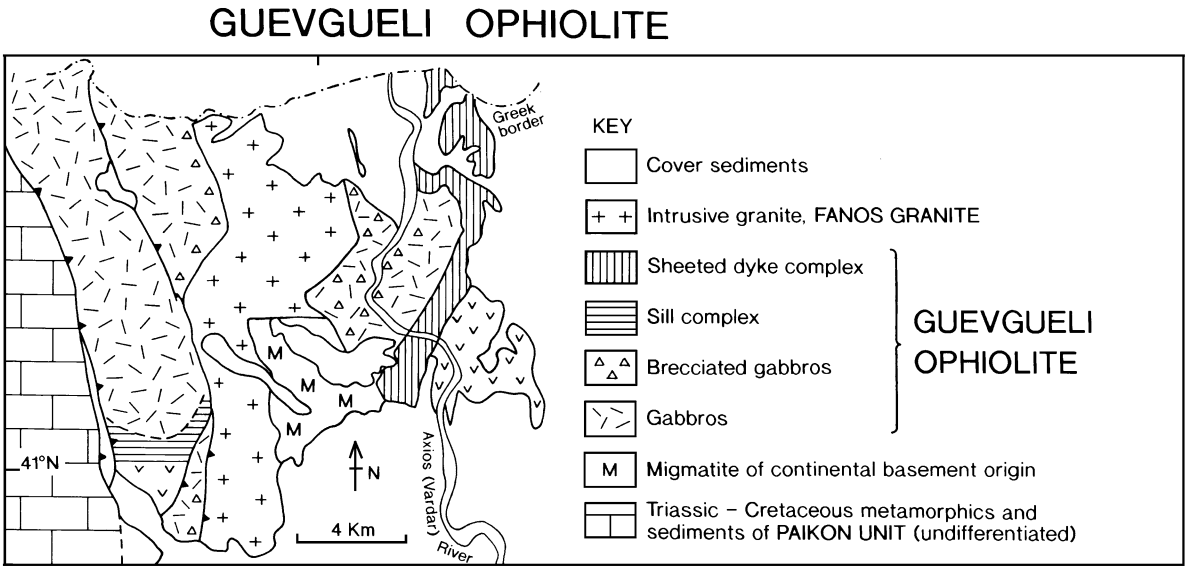


Fig. 9. Sketch map of the Jurassic Guevgueli ophiolite, NE Greece. See text for data sources.

water carbonates (Mercier, 1966), and it is therefore possible that the Sithonia ophiolite may be of the same age as the others of the Innermost Hellenide Ophiolite Belt (i.e. early Late Jurassic). Alternatively, the Sithonia ophiolite might represent a younger small Late Jurassic–Early Cretaceous pull-apart basin (Brown, 1997). Further west, on the Kassandra Peninsula (Fig. 1), a small ophiolite outcrop is mainly restricted to volcanics, up to 1.2 km thick, interbedded with radiolarian cherts. Underlying early arc volcanics include boninites, and a transition to IAT and finally MORB-type extrusives (see review by Smith, 1993). Several other small fragmentary ophiolitic bodies are present in NE Aegean region. The Evros ophiolite (Fig. 1; Magganas, 2002) includes serpentinised peridotites, cumulate and non-cumulate gabbros and basalts, showing both boninitic and IAT-type chemistry. On Samothraki island (Fig. 1), the ophiolite comprises cumulate and non-cumulate gabbros, plagiogranites and leucogranites, dolerites and basalts, ranging from MORB to IAT-type (Tsikouras and Hatzipanagiotou, 1998b). This ophiolite overlies shallow-marine to continental sediments (Kotopouli et al., 1989).

The Innermost Hellenic Ophiolite Belt is bordered to the east by a calc-alkaline assemblage of intrusive rocks (tonalites, trondjemites, granophyres and dykes) and subaqueous volcanic rocks of inferred Middle Jurassic age (Chortiatis unit; Schunemann 1985; Mussallam and Jung, 1986; Mussallam, 1991). In addition, within the SW margin of the Serbo-Macedonia zone intrusive complexes of gabbros, diorite and (NE-striking) sheeted dykes are present (Volvi complex; Fig. 1; Dixon and Dimitriadis, 1984). These magmatic rocks are intermediate between WPB type and SSZ type. Magmatism and deformation occurred simultaneously within an inferred extensional setting.

To the west, the Innermost Hellenic Ophiolite Belt is bordered by the coeval Late Jurassic Paikon arc (Fig. 1). The Guevgueli ophiolite is in (Tertiary) fault contact with the Paikon unit in the SW (Fig. 9). Within the Paikon unit, marble and calc-schists of inferred Triassic age are overlain by Lower–Middle Jurassic interbedded calc-alkaline volcanics and volcaniclastics in the west (Livadia unit). This was followed by an intercalation of Late Jurassic shallow-water limestone, prior to a further eruption of acidic volcanics and volcaniclastics, exposed in the east (Kastaneri unit; Mercier, 1966; Brown and Robertson, 1994; Brown, 1997). According to Bébien et al. (1994), the lower unit is typical of subduction-related oceanic arc volcanics, whereas the upper unit is comparable with calc-alkaline or anatectic rocks in continental areas. However, Brown (1997) found no systematic chemical difference between the upper and lower volcanic units.

*4.2.1. Discussion*

The Paikon unit is interpreted as a subduction-related volcanic arc developed along the southern margin of Eurasia in Mid–Late Jurassic time (Fig. 10). This unit initially extended eastwards as the Chortiatis arc overlying the western margin of the Serbo–Macedonian metamorphic basement and includes the arc-type basement of the Sithonia ophiolite. The Guevgueli and other ophiolites of the Innermost Hellenide Ophiolite Belt formed by back-arc extension in early Late Jurassic time, in a setting similar to that the ensialic Roccas Verde/Sarmiento ophiolite, southern Chile (Dalziel, 1981), or the Bransfield Strait in the Antarctic Peninsula (Aberg et al., 1984). The marginal basin rifted the pre-existing arc (in Sithonia), metamorphic basement (in the east of the Guevgueli ophiolite), or continental sediments (below the Samothraki ophiolite) in different areas. Where the ophiolite was intruded into continental basement, anatectic migmatites and high-temperature contact metamorphism developed. Where the pre-exiting arc rifted, a geochemical transition is observed from calc-alkaline arc, within the arc basement, to near MORB in the overlying ophiolite (Sithonia). More subtly, within the Guevgueli ophiolite there is a transition from MORB- to subduction-influenced volcanism towards the Paikon arc. The near orthogonal NE–SW trend of sheeted dykes relative to the ophiolitic belt as a whole (NW–SE) has suggested the ophiolite formed at small spreading segments offset by long (dextral?) transform faults, for which the Andaman Sea (Curray et al., 1978) is a good modern analogue.

## 5. MOR- versus subduction-related oceanic crust

The vast majority of the ophiolites of the Eastern Mediterranean region formed within Tethyan ocean basins some distance from continental margins (i.e. intra-oceanic-type ophiolites). Three settings can be identified: (1) mid-ocean ridge type (MOR); (2) transitional between MOR and subduction related; (3) subduction related. Comparable modern-day settings are mentioned below to set the scene for interpretation of the ophiolites.

Unrifted spreading ridges are typified by the East Pacific Rise (Carbotte et al., 1997) and small spreading ridges such the Juan de Fuca spreading centre (East Pacific), drilled during Leg 168 (Davis et al., 1997). Oceanic lithosphere formed by spreading at an intermediate rate was also drilled in the Eastern Pacific at Hole 504B, on the south flank of the Costa Rica Rift, where basalt flows and lava breccias were penetrated down to near the base of a sheeted dyke complex (2.1 km). The succession is intact other than for two major faults (Becker et al., 1989).

Elsewhere in the eastern Pacific, the fast spreading the Cocos–Nazca Ridge (ca. 20 cm/year) propagates into older East Pacific Rise crust, producing young

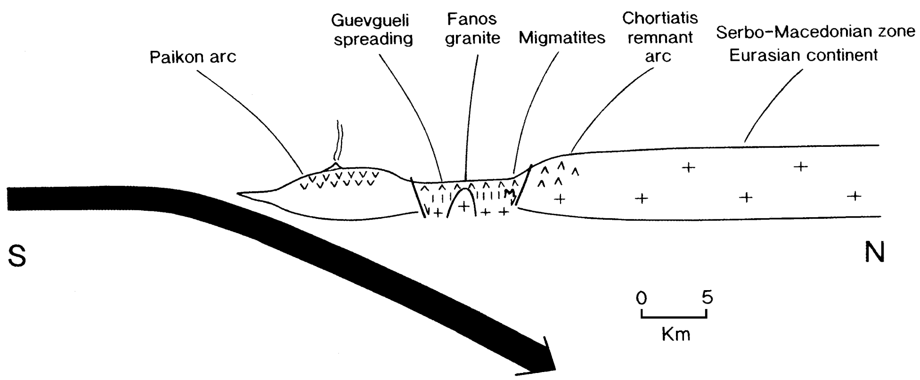


Fig. 10. Tectonic model for the formation of the Jurassic Guevgueli ophiolite, NE Greece; see text for discussion.

(< 1 Ma) lithosphere, some of which was exposed by extension within the Hess Deep (Natland and Dick, 1996; MacLeod et al., 1996; Dilek, 1998). Drilling during Leg 147 penetrated shallow-level gabbro and sheeted dykes similar to that of the Semail ophiolite, Oman. Dives by the submarine *Nautile* produced samples of tectonised mantle peridotite (i.e. harzburgite) similar to those of the Oman ophiolite (Hékinian et al., 1993). Features of non-rifted spreading ridges, thus, include: (i) near MORB composition; (ii) overlying pelagic, or Fe/Mn oceanic sediments without terrigenous-derived, e.g. turbiditic sediments (Haymon et al., 1991); (iii) a thick, intact extrusive succession, including pillow lavas and lava breccias; (iv) a well developed sheeted dyke complex; (v) a thick intact plutonic sequence similar to that of some ophiolites (i.e. Semail ophiolite, Oman).

Rifted spreading ridges, by contrast, are typified by the relatively slow, to ultra-slow spreading segments of the Mid-Atlantic Ridge and the intermediate rate-spreading SW Indian ocean ridge (Cann et al., 1997; Dick et al., 1999; Searle et al., 1998; Karson, 1998). Where extension exceeds magma supply, as in slow-spreading ridges, dominant extension results in detachment faulting and exhumation of plutonic rocks as core complexes in the form of "megamullions". On the Mid-Atlantic Ridge near the ridge-transform intersection at 25° north, a dome 10–20 km across on the seafloor exposes middle to deep crustal-level rocks and the upper and lower plates are separated by mylonitic rocks (Blackman et al., 1998; Tucholke et al., 1997).

Rifted spreading ridges, thus, exhibit the following main characteristics.

(i) Overlying pelagic sediments may include Mn-rich hydrothermal sediments (as in the TAG hydrothermal field (Humphris et al., 1994)); (ii) variable, often thin (< 100 m) extrusive sequences, including much reworked talus and volcaniclastic sediment; (iii) N-MORB composition, to locally E-type MORB; (iii) a sheeted dyke complex may be absent; (iv) low-angle extensional detachment faults may be present (i.e. core complexes).

The inference that ophiolites may be formed in subduction-related settings is supported by the widespread occurrence of similar rocks in modern forearc areas in the SW Pacific region. In the Izu–Bonin–Mariana arc, the earliest volcanism occurred in Mid–Late Eocene over a several-thousand-kilometre-long zone up to several hundred kilometres wide (Natland and Tarney, 1981; Bloomer and Hawkins, 1983; Stern and Bloomer, 1992; Taylor, 1992; Pearce et al., 1992). The oldest volcanics there are dominantly depleted arc tholeiites and boninites (Ishii, 1985; Bloomer, 1987; Murton et al., 1992). This early juvenile arc crust is locally exposed at, or near, the seafloor in the forearc region, and within a remnant arc split off by later opening of the Mariana back-arc basin (e.g. on Saipan and Guam). In the Tonga arc, the oldest known extrusives drilled during Leg 135 (Hawkins, 1995) and volcanics on Eua island (Tappin and Ballance, 1994) are again of Eocene age and include arc tholeiites and fractionates. In addition, a range of arc tholeiites, boninites, lavas, gabbro, diabase and serpentinised harzburgites were dredged from the arc-ward wall of the Tonga trench (Sharaskin et al., 1983; Falloon et al., 1987). Similar rocks dredged more recently additionally include diabase, quartz–gabbro and dunites, also basalts that were dated at 39–47 Ma using the Ar–Ar method (Bloomer, personal communication, 1999). Comparable, "primitive" arc basalts of Eocene age occur elsewhere in the SW Pacific region, including Cape Vogel in Papua New Guinea.

The ideal SSZ-type ophiolite would thus exhibit a vertical succession of harzburgites, dunites and other ultramafic rocks, gabbros, quartz gabbros, diabase and extrusives ranging from MORB to arc tholeiites and boninites. The sedimentary cover could include ash from the volcanic arc. However, future deep drilling is needed to confirm if an ideal ophiolite sequence is indeed present beneath SW Pacific forearcs.

### *5.1. Eastern Mediterranean MOR-type ophiolites*

#### *5.1.1. Slow-spread ophiolites*

The best example is the Late Jurassic Western-type ophiolite of Albania (Shallo et al., 1990; Bortolotti et al., 1996; "W-Albanian" in Fig. 8). These exhibit MOR-type volcanics, dated by overlying early Late Jurassic radiolarites (Figs. 1 and 8). A well-developed sheeted dyke complex is absent and the extrusives are separated from underlying layered and massive gabbro by shear zones, interpreted as extensional detachment faults (Nicolas and Boudier (1999). According to these authors, highly strained mylonitic lherzolite originated from more deleted harzburgite by "impregnation and tectonic dispersal" of melt during high-temperature (800–1000 °C) deformation at, or near, the "spreading ridge". The gabbros exhibit evidence of ductile flow, accompanied by high-temperature recrystallisation (Cortesogno et al., 1998). Layered gabbros, and/or the sheeted dykes are commonly missing due to synmagmatic extension. Ultramafic and mafic rocks were locally sheared together to form oceanic amphibolites (Dimo et al., 1999).

The Western Albanian ophiolite extends southeastwards within the Pindos suture (Fig. 2) into Greece where dismembered ophiolites are present (Robertson and Shallo, 2000). In NW Greece (Fig. 1), the overriding Dramala (Pindos) ophiolite is underlain by ophiolitic thrust sheets that include MOR-type extrusives, depositionally overlain by fine-grained mudstones of mixed hemipelagic and hydrothermal origin (Robertson and Varnavas, 1993). Elsewhere, in the Othris region of eastern Greece (Fig. 1), the MOR-type Sipetorrema lavas and related ophiolitic units (Smith et al., 1975) possibly also formed at a slow-spreading mid-ocean ridge. The fragmentary of the Argolis Peninsula (SE mainland Greece; Clift and Dixon, 1998; Fig. 1) probably also formed in a similar (rifted ridge?) setting. The Migdalitsa ophiolite also includes low-temperature-type hydrothermal deposits, similar to those of the Atlantic TAG hydrothermal field (Robertson and Degnan, 1998 and references therein).

The Jurassic Albanian ophiolites extend northwestwards into the former Yugoslavia area, notably Bosnia and Croatia, where lherzolitic ophiolites, mainly reduced to ultramafic slices overlying heterogeneous melange, are also interpreted as formed at a Jurassic spreading ocean ridge (Karamata et al. 1980; Pamić, 1997; Pamić and Tomljenović, 2002). A slow-spread ridge origin is likely, but needs to be tested with additional field data.

### 5.1.2. Fast spread ophiolites?

A number of ophiolites preserve thick unrifted plutonic and layered cumulate successions (e.g. the Tauride Tekirova and Mersin ophiolites; Fig. 1) and these would be interpreted as fast spreading ridges in the hypothesis of Nicolas (1989; i.e. HOT-type ophiolites). However, these ophiolites all show chemical evidence of a subduction influence on magmatism and in this paper are interpreted as having formed by spreading above subduction zones (see later discussion). If this is accepted, there are, as yet, no definite examples of fast spreading, unrifted MOR-type ophiolites preserved in the Eastern Mediterranean region.

### 5.1.3. Transitional MOR–SSZ-type ophiolites

Some ophiolites appear to show characteristics of both MOR-type and SSZ-type ophiolites and in the case of the Albanian ophiolite, an intact magmatic transition is preserved between the two ophiolite types in some areas.

The Jurassic ophiolites in the north of Albania (Figs. 1 and 8) show a well-documented magmatic transition from "MOR"- to SSZ-type ophiolites within a relatively short time period during early Late Jurassic time. U/Pb zircon ages of plagiogranites encompassing both ophiolite types indicate crystallisation ages from 165 to 162 Ma (Dilek et al., 2001).

In many areas of northern Albania (e.g. Bulqiza and Shebeniku massifs), lithological continuity is mapped between the MOR–Western-type ophiolite and the "SSZ"-type Eastern-type ophiolites (Fig. 11). Plagioclase peridotites or troctolites of the Western-type ophiolite locally exhibit primary magmatic contacts with harzburgite–dunite mantle sequences of the Eastern-type ophiolites (Bébien et al., 1998). The Western-type ophiolites are locally intruded by plagioclase–quartz diorites of the Eastern-type ophiolite (Shallo et al., 1996). The contact zones between both ophiolite types are locally overlain by IAT to boninite-type extrusives (Bortolotti et al., 1996). Also, the plutonic sequences of both ophiolite types are commonly cut by ultramafic intrusions (Manika et al., 1997; Shallo et al., 1996; Bébien et al., 1998). However, the distinction between the two ophiolite types evidently is less apparent in southern Albania, possibly due to increased tectonic complexity (Hoeck et al., 2002).

Further southeast, in Greece, no complete magmatic transitions between the two ophiolite types (MOR and SSZ) are preserved. However, all the ophiolites are interpreted to represent preserved parts of single regionally emplaced thrust sheet that was dismembered by emplacement, or post-emplacement

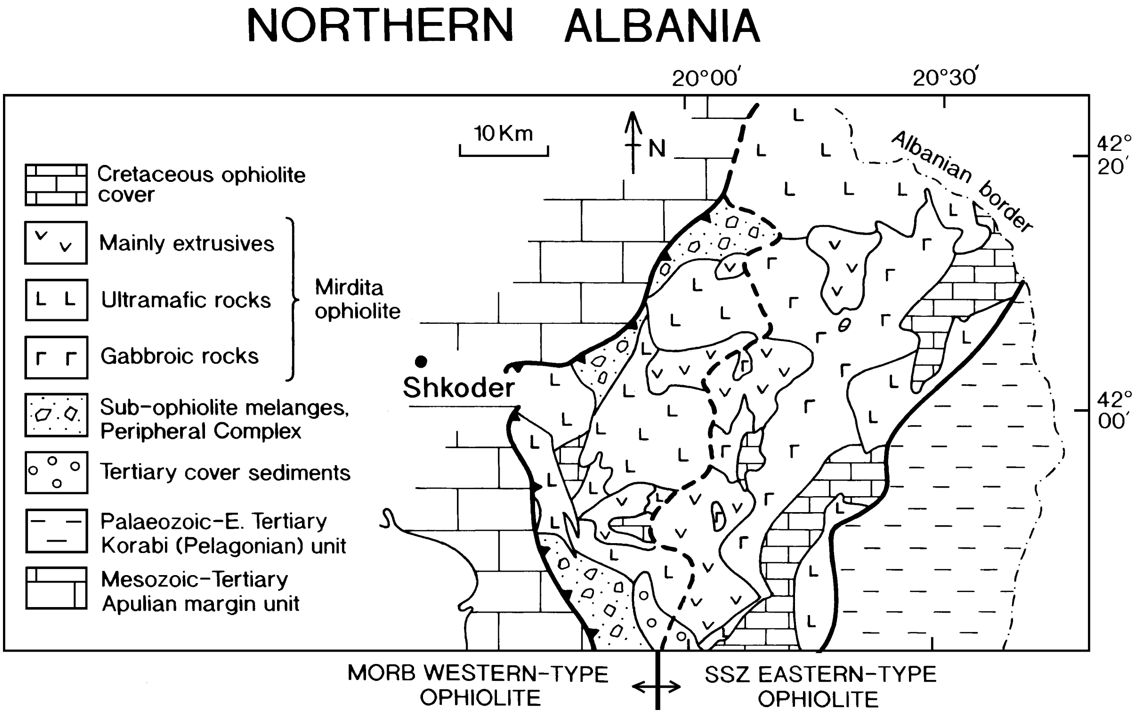


Fig. 11. Sketch map showing the setting of the Jurassic ophiolites of Northern Albania; based on the Geological Map of Albania. See text for data sources.

tectonics. As a result, different elements of a possible original magmatic transition seen in northern Albania are preserved in different local units, as follows.

In the south, the highly dismembered Migdalitsa ophiolite of the Argolis Peninsula of the eastern Peloponnese (Fig. 1) includes small volumes of picritic (boninitic) extrusives, and is interpreted to record incipient forearc magmatism (Clift and Dixon, 1998). Additional evidence of dismembered ophiolites (mainly harzburgite) is reported from Crete (Koepke et al., 2002).

Further northwest, the Pindos ophiolite (Figs. 8 and 12) represents a composite unit. The large structurally uppermost, Dramala ophiolite (Fig. 8) lacks preserved extrusives and, thus, its setting of formation remains debatable. Although largely harzburgitic, in common with SSZ-type ophiolites (see below), the layered cumulates include plagioclase dunite–troctolite–anorthosite–gabbro cumulates, typical of MOR-type ophiolites (Capedri et al., 1980). Also, chromite is sparse in contrast to the SSZ-type Vourinos ophiolite (see below; Jones et al., 1991). Locally, within the Dramala ophiolite breccias of harzburgite and jasper are cemented by ophicalcite, implying that ultramafic rocks were exposed on the seafloor, as in rifted spreading settings (Jones et al., 1991).

Structurally beneath the Dramala ophiolite is the dismembered Aspropotamos ophiolite which preserves a nearly complete oceanic crustal succession, including sheeted dykes and plagiogranites (Jones and Robertson, 1991; Jones et al., 1991). The ophiolite exhibits successive phases of dyke injection, which show an overall progressive chemical evolution from MOR-type dykes, through MORB/IAT-type dykes and finally to IAT/boninite-type dykes (Kostopoulos, 1989). The next, more evolved, SSZ-related spreading stage is represented by the Vourinos and Eastern Albanian ophiolites which include late-stage arc-like intrusive and extrusive rocks (see below). Aspropotamos ophiolite is, therefore, seen as recording a transition between contrasting MOR- and SSZ-types ophiolite-type spreading.

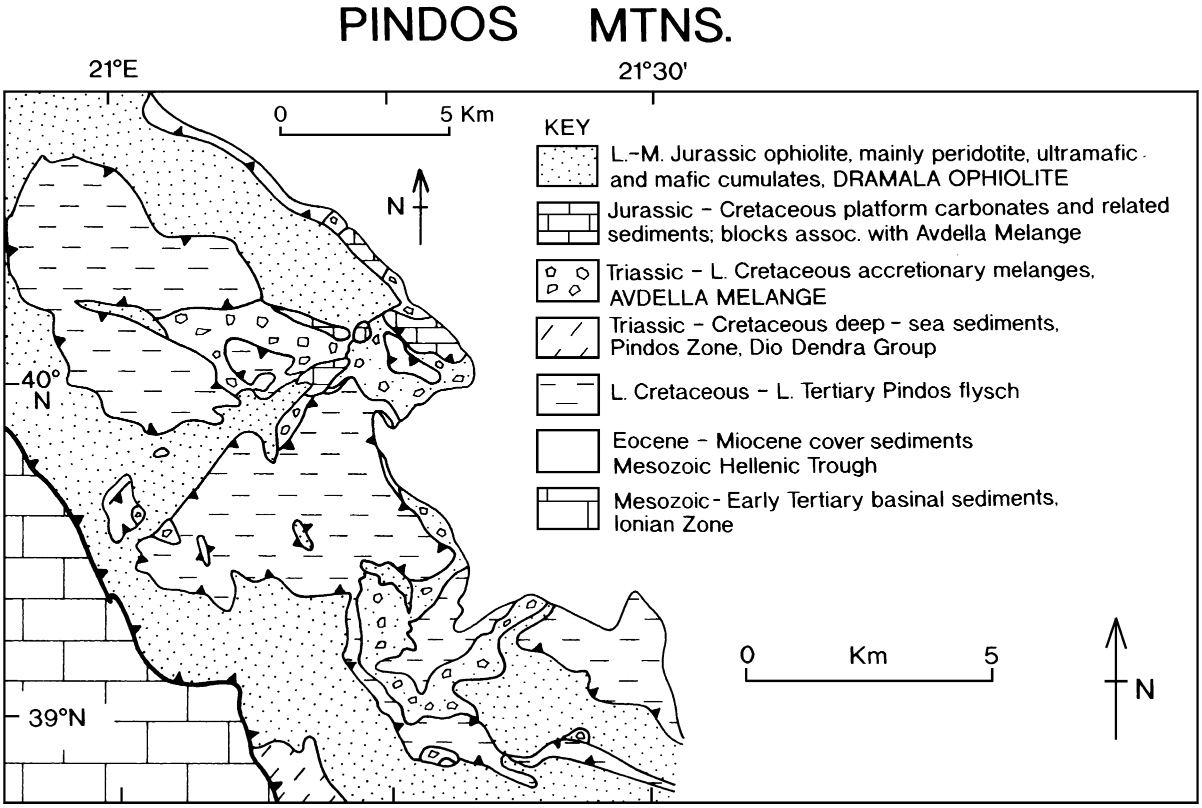


Fig. 12. Sketch map of the Jurassic ophiolites of the Pindos Mountains, NW Greece; modified from Jones and Robertson, 1991; see text for explanation. The different ophiolites record different parts of a single SSZ-type oceanic slab, whereas the downgoing plate is recorded as fragments in the underlying melange.

Further northwest from the Albanian ophiolites, within Kosovo and Serbia, large ophiolite thrust sheets are mainly preserved without higher level crustal units (dykes and extrusives). The thickness of the ultramafic thrust sheets (e.g. Zlatibor ophiolite; Fig. 1) generally decrease westwards, with cumulates only rarely being preserved in the more easterly units (e.g. Brezovica ophiolite; Fig. 1). Ophiolitic blocks within associated ophiolitic melange include peridotites, gabbros, plagiogranite, sheeted dykes and pillow lavas. Trace element analyses of some of these basaltic extrusives indicate relative Nb depletion and other features of subduction-influenced extrusives. Many of the higher crustal levels were probably detached from the leading edge of the regional emplacing ophiolite and then over-ridden, as inferred for the Aspropotamos ophiolite, but ending up more fragmented and mixed with underlying accretionary melange (Robertson and Karamata, 1994).

Traced northwestwards again into Bosnia and Croatia, similar ophiolitic melange exists, overthrust by large thrust sheets of ultramafic ophiolitic rocks. A transition is reported from lherzolitic ultramafics in the NW to more harzburgitic ultramafics in the SE (Pamić, 1997; Pamić and Tomljenović, 2002). Exceptionally in eastern Bosnia (Mt. Vardar area) an intact ophiolite, ca. 3 km thick, is reported, including tectonites, ultramafic cumulates, gabbro cumulates, sheeted dykes and basaltic lavas, capped by sediments (Pamić and Tomljenović, 2002).

In summary, all the above Jurassic intra-oceanic ophiolites are interpreted as parts of a slow-spreading mid-ocean ridge that evolved laterally into SSZ-type

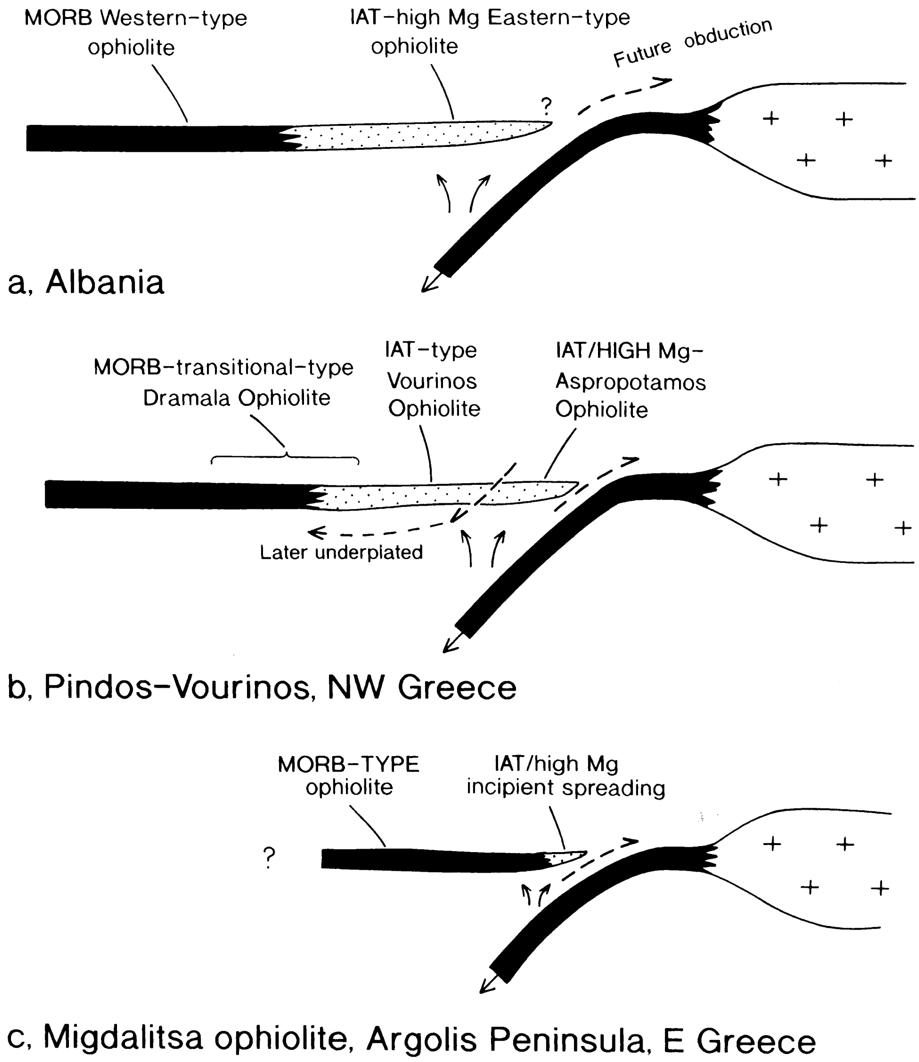


Fig. 13. Modes of inferred supra-subduction zone genesis and emplacement of ophiolites in Albania and Greece; see text for explanation.

ophiolite (Fig. 13). The present variably dismembered state relates to obduction and post-obduction tectonics.

## 6. Supra-subduction-type ophiolites

### 6.1. Jurassic SSZ-type ophiolites

The Mid–Late Jurassic ophiolites of the "western region" (Hellenides, Albanides and Dinarides) are exemplified by the "Eastern-type" ophiolite of Albania and correlatives in Greece to the SW (e.g. Vourinos, Eastern Othris; Figs. 1 and 2). These ophiolites formed in late Middle–Late Jurassic time, as inferred from the radiometric ages of the metamorphic soles, assumed to be nearly coeval with spreading (Spray et al., 1984; Smith, 1993; Fig. 4). Recently, numerous $^{40}Ar/^{39}Ar$ ages, mainly ranging from 160–174 Ma were published for the Albanian ophiolites (Vergély et al., 1998). In addition, the in situ radiolarian cherts depositionally overlying the Eastern-type Albanian ophiolite are dated as Late Bajocian (Middle Jurassic), to Bathonian (Late Jurassic) (Marcucci et al., 1994; Prela et al. 2000). Critically, the sole ages and radiolarian ages are effectively contemporaneous. All of the Jurassic ophiolites were emplaced onto continental margin units and transgressed by shallow-water carbonates during Cretaceous time (Aubouin et al., 1970; Dercourt et al., 1986, 1992; Robertson et al. 1991).

The Eastern-type Albanian ophiolite, exposed in number of separate massifs (Fig. 11), is by far the best exposed and most complete SSZ-type Jurassic ophiolite (Fig. 8). Ultramafic mantle sequences are represented by clinopyroxene-poor harzburgite–dunite, associated with thick transitional dunite, rare wehrlite–lherzolite and cumulate pyroxenite. High degrees of mantle depletion are indicated by a high dunite content and high Cr/Cr + Al ratios in the composition of residual spinel (Shallo et al. 1990). The cumulate sequence is intruded by plagiogranite and quartz diorite bodies, 1–3 km in diameter. Well-developed sheeted dykes range from near MORB to IAT and boninite-type compositions. Near the base, the overlying extrusives are of depleted IAT type, overlain by upper lavas including boninite-type compositions (Shallo et al, 1990; Beccaluva et al., 1994; Robertson and Shallo, 2000). The higher lavas are depositionally overlain by Upper Jurassic reddish radiolarian cherts and shales, up to 15 m thick (Marcucci et al., 1994; Prela et al., 2000), with no obvious volcaniclastic or tuffaceous content.

In northern Greece, the Vourinos ophiolite (Figs. 1 and 8) is a harzburgite-dominated peridotite with an overlying partly preserved crustal sequence (Moores, 1969; Rassios et al., 1983). Rare extrusives (Krapa series) of IAT type are cut by transitional- to boninite-type dykes (Asprokambo series; Beccaluva et al., 1994). Isotopic (Noiret et al., 1981) and geochemical data (Jones et al., 1991) support the genesis of the Vourinos ophiolite in a SSZ setting. The Pindos and Vourinos ophiolites are interpreted as linking beneath the Mesohellenic Trough (Rassios et al., 1983; Jones and Robertson, 1991). Thus, the Vourinos and Eastern Albanian ophiolites are seen as the most evolved Jurassic arc-like oceanic lithosphere preserved in the "western" Balkan region, prior to a collision of the subduction trench with a continental margin, which drove regional ophiolite emplacement (see Fig. 21).

### *6.2. Late cretaceous ophiolites of the "eastern region"*

In the "eastern region" (Turkey, Cyprus and Syria) the majority of the known ophiolites fall, petrologically and chemically, into the subduction-related class of oceanic lithosphere. In contrast to the above, Balkan ophiolites ("western region"), where dated, are mainly Cretaceous, rather than Jurassic in age, with the probable exception of several ophiolites located near the Aegean Sea in the west (see later). There are three main belts of Cretaceous SSZ-type ophiolites in the "western region". From north to south these are: (1) Pontide ophiolites; (2) ophiolites of the Anatolides and Taurides; (3) Troodos ophiolite, Cyprus, SE Turkey and Syria.

#### *6.2.1. Cretaceous ophiolites of the Pontides*

Ophiolites of probable Late Cretaceous age are known in both the central and eastern Pontides (Figs. 1 and 2). In the southern part of the central Pontides, ophiolitic melange is intersliced with Pontide "metamorphic basement" towards the north, and is structurally overlain by an E–W-trending klippe of intact ophiolite to the south (Kızılırmak ophiolite; Fig. 6). The succession within this ophiolite begins with massive serpentinised peridotite, including harzburgite and passes into microgabbro and a sheeted dyke complex (with N–S-trending dykes), overlain by basic extrusives, then red radiolarian cherts and shales. The sedimentary cover includes intercalations of volcaniclastic sandstone and Late Cretaceous pelagic limestones near the top. Internal imbrication and folding indicate emplacement towards the NNE (Tüysüz, 1990; Ustaömer and Robertson, 1997). The intact ophiolite is underlain by north-dipping thrust sheets of melange with blocks of serpentinite, pillow lava, shale, radiolarian chert and metamorphic rocks derived from basement units. Underlying pelagic limestones are dated as Campanian, and the melange is unconformably overlain by Palaeocene–Early Eocene sediments; a Campanian age of emplacement is inferred (Tüysüz, 1990; Ustaömer and Robertson, 1997).

Further south, close to the North Anatolian fault, is an important, but still relatively little studied, Late Cretaceous volcanic arc unit (Kosdağ arc; Fig. 6). This low-grade magmatic unit begins with foliated basic lava, tuff and volcaniclastic sediments intercalated near the base with cherts and pelagic limestones containing a Late Cretaceous microfauna. Mainly acidic lavas, with tuff and volcaniclastic sediment follow, including volcaniclastic turbidites and small granitic intrusions (Tüysüz, 1990).

Late Cretaceous ophiolitic melange also occurs in the eastern Pontides. Within the Tokat Massif, a major thrust sheet of ophiolitic melange up to 200 km long (Çamlıbel unit; Fig. 1) structurally overlies Lower Cretaceous pelagic carbonates, with an intervening foreland basin-type sedimentary succession. The ophiolitic melange includes blocks of various lithologies. In decreasing order of abundance, these are altered basalt, radiolarian chert, pelagic and neritic, limestone, sandstone, shale, siltstone and serpentinite derived from both oceanic crust and Pontide continental lithologies. The youngest known ages are Aptian for limestone blocks in the melange and Late Cretaceous for the melange matrix, which includes evidence of locally developed HP/LT glaucophane–lawsonite facies metamorphism (Yılmaz et al., 1997). The melange is unconformably overlain by Maastrichtian neritic carbonates. Ophiolitic melange formation and emplacement is thus constrained as Cenomanian–Campanian. In this area, there was a second phase of ophiolite and melange emplacement, well dated as near the Early–Mid-Eocene boundary. Serpentinised peridotites, mainly ultramafic cumulates with intrusive dunite lenses and associated chromite occur together with slices of tectonic melange beneath (Yılmaz et al., 1997).

To the south of the Eastern Pontides, there are huge ophiolite thrust sheets mainly composed of peridotite (Şengör and Yılmaz, 1981) that were emplaced southwards from the Ankara–Erzincan suture (Fig. 2) onto the Munzur platform (Munzur Dağ in Fig. 2) during Late Cretaceous (Maastrichtian) time (Görür et al., 1984). About 50 km west of the Munzur Dağ there is a lithologically similar unit of carbonate rocks associated with a dismembered ophiolite (serpentinites of the Divriği ophiolite complex; Fig. 1) which is intruded by a composite pluton of predominately monzonitic composition. This was dated by the Rb–Sr whole-rock method at around 110 Ma (Zeck and Ünlü, 1988). Ophiolite genesis and subduction were apparently active during Early Cretaceous time in this region.

*6.2.1.1. Discussion.* Both southward and northward subduction models have been proposed in order to explain the Late Cretaceous Pontide ophiolites and ophiolitic melanges (Fig. 14a–c). If units in both the central and eastern Pontides are assumed to relate to emplacement of once continuous oceanic lithosphere, then fossil ages imply a Campanian age of northward emplacement onto the Eurasian margin. In a southward subduction model (Tüysüz, 1990; Okay and Şahintürk, 1997; Fig. 14b), ophiolite emplacement is interpreted as the result of southward intra-oceanic subduction leading to genesis of an intra-oceanic arc (Kosdağ arc) and accretion of ophiolitic melange that was later emplaced in response to trench–margin collision. The subduction zone later flipped to northwards in this model, initiating an Andean-type continental margin arc as remaining Neotethyan oceanic crust to the south was consumed. In a contrasting, northward subduction model (Şengör and Yılmaz, 1981; Ustaömer and Robertson, 1997; Fig. 14a) the oceanic volcanic arc (Kosdağ arc) and ophiolitic melange formed related to northward-dipping subduction within the Neotethys ocean, leaving a Neotethyan oceanic strand to the north along the Eurasia margin. This model has the advantages in explaining: (1) the presence of N-dipping (rather then S-dipping) imbricate slices of ophiolitic melange in the Central Pontides; (2) the absence of evidence of major Late Cretaceous collisional metamorphism (the ophiolites and melange are unmetamorphosed), as the subduction zone is located within Neotethys to the south; (3) the regional Late Cretaceous southward emplacement of the ophiolites onto a carbonate platform (Keban unit; Fig. 2) to the south as a result of arc-margin collision. In a third model (Fig. 14c), subduction occurred, both northwards under the Pontide margin and southwards beneath inferred microcontinental fragments (Kirşehir metamorphic massif and Keban platform) to the south of the Ankara–Erzincan suture (Yılmaz et al., 1997). However, in this "Molucca Sea-type model" it is unclear how huge ophiolite thrust sheets were emplaced southwards onto marginal units. At present, there are inadequate field geochronological and geochemical data to fully constrain alternative tectonic models of the Pontide Cretaceous ophiolites. However, in all models, these ophiolites and associated melange relate to subduction and arc volcanism within a northerly Neotethyan oceanic basin.

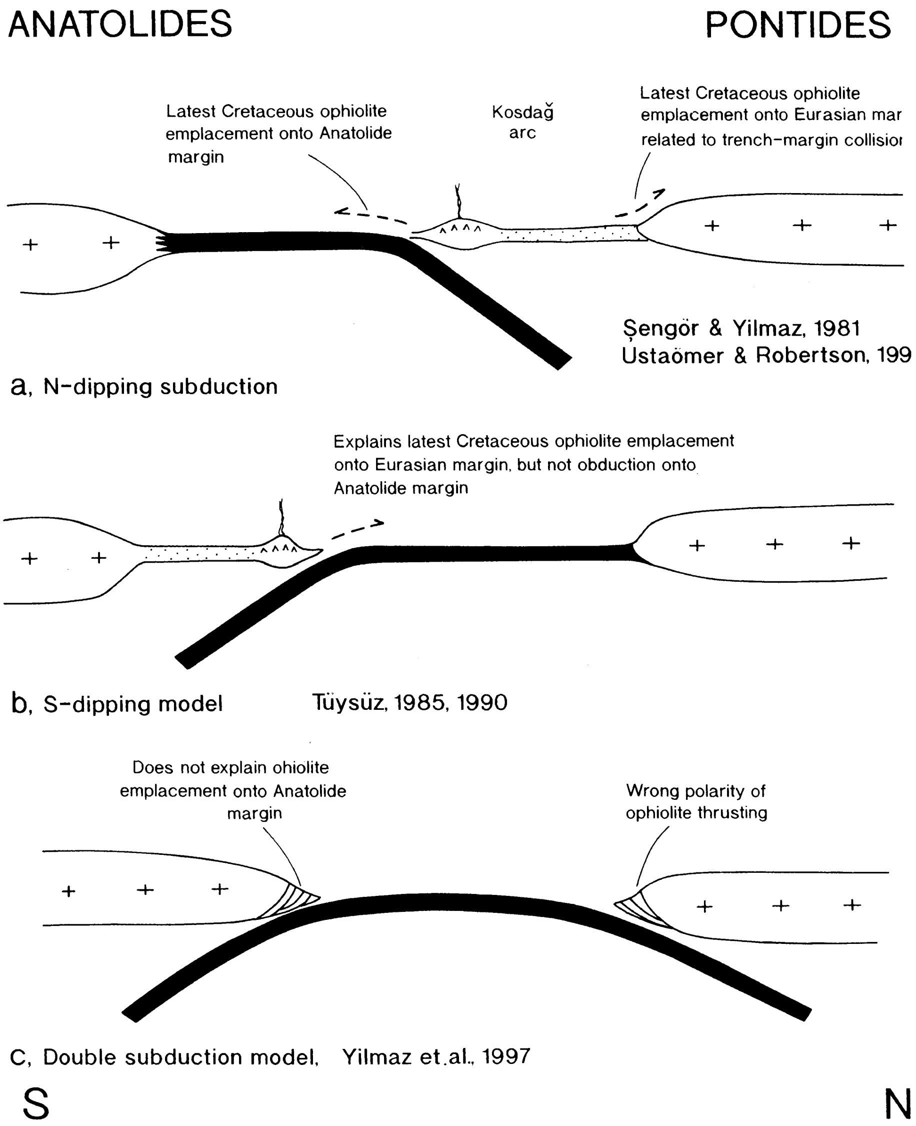


Fig. 14. Alternative tectonic models for formation and emplacement of Cretaceous ophiolites in northern Turkey; see text for explanation.

*6.2.2. Late Cretaceous ophiolites of Central Anatolia*

Late Cretaceous ophiolites and ophiolitic melange occur in a belt stretching across Anatolia, marking the westerly Izmir–Ankara and easterly Ankara–Erzincan segments of the major Neotethyan suture zone that transects Anatolia (Fig. 1). In the east, dismembered Late Cretaceous ophiolites of the Central Anatolian ophiolite complex structurally overlie the Kirşehir and Niğde metamorphic massifs (Fig. 2). Further west, near Ankara, Late Cretaceous-dismembered ophiolites occur within ophiolitic melange (Ankara Melange; Fig. 2). Further west again, both metamorphosed and unmetamorphosed ophiolitic melanges are found bordering the northern margin of the Menderes Massif, including the Late Cretaceous–Early Tertiary unmetamorphosed Bornova Melange (Fig. 2; Robertson and Pickett, 2000; Okay et al., 2001).

### 6.2.3. Central Anatolian ophiolite complex

Isolated dismembered ophiolites occur structurally above the Kirşehir metamorphic massif and smaller Niğde metamorphic massif further southeast (Yalınız and Göncüoğlü, 1998; Floyd et al., 2000; Figs. 1 and 2). Although scattered and dismembered (e.g. Sarikaman ophiolite), an overall ophiolite succession has been reported (Fig. 15) as follows. The ophiolite begins with ultramafic rocks overlain by layered, then isotropic gabbros, followed by plagiogranite, then dolerite dykes and pillow basalts, mainly olivine-poor plagioclase–clinopyroxene–phyric tholeiites. Plagiogranite dykes are believed to correlate with acidic extrusives higher in the succession. The high-level gabbros are intruded by net-vein trondjemites and numerous dykes (Floyd et al., 1999). "Immobile" element geochemistry shows that the basic extrusives are of IAT type, whereas "late" dykes are transitional to MOR-type (Yalınız et al., 1996).

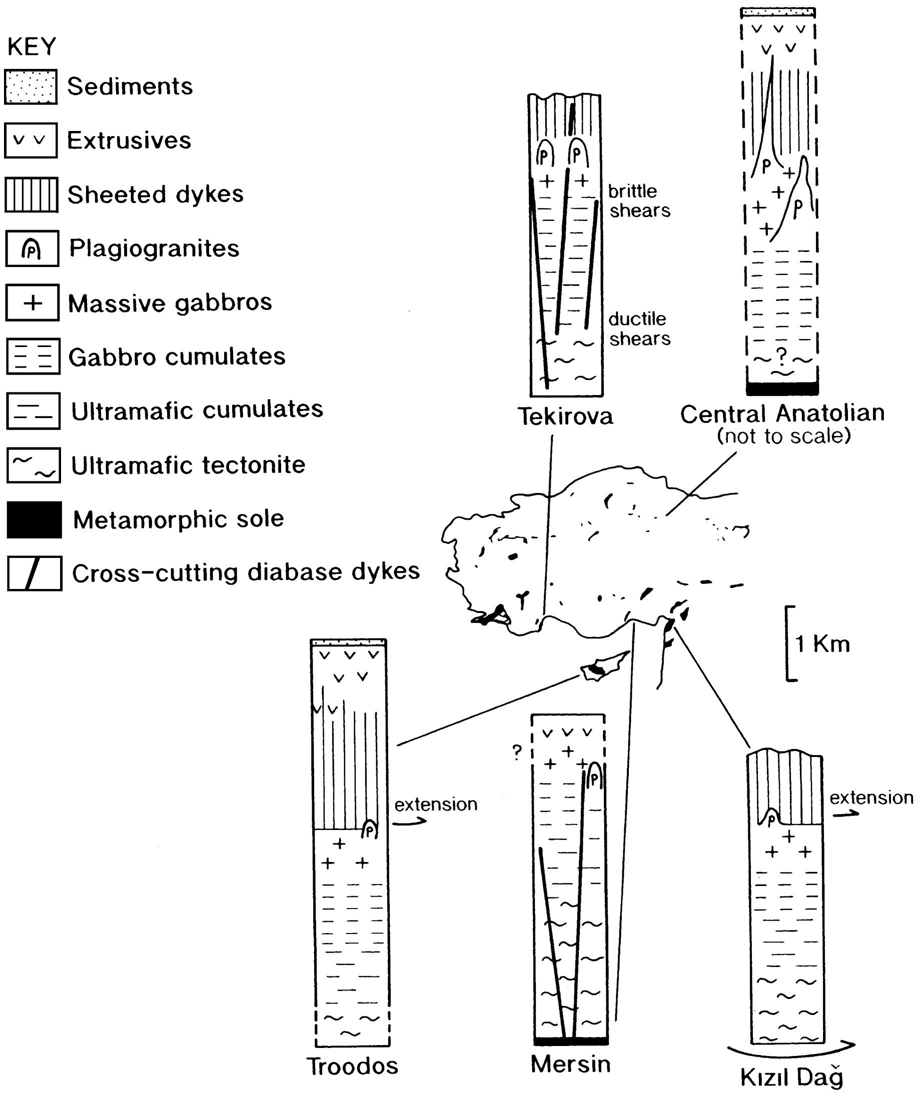


Fig. 15. Logs of selected Cretaceous ophiolites from Turkey. All are interpreted as SSZ-type ophiolites in variable stages of development. See text for data sources.

There is a locally intact Late Cretaceous pelagic/volcaniclastic sedimentary cover of the above ophiolites. Red mudstones within and above the highest pillow lavas locally pass upwards into siliceous limestones, radiolarian and manganiferous cherts and micritic limestones of Middle Turonian–Early Santonian age. These sediments are reported to pass depositionally upwards into inferred debris flow deposits ("olistostromes"), of latest Maastrichtian–lowermost Palaeocene age, then into shallow-marine carbonates of Danian age. Both the ophiolite and overlying sediments are cut by Late Cretaceous–Lower Palaeocene monzogranites dated at 81–76 Ma by the K–Ar technique (Yalınız et al., 1996). Following tectonic emplacement, the area was transgressed by Middle Eocene sediments. To the south of the Niğde metamorphic massif, conglomerates (Elmadere Formation) of latest Maastrichtian age are reported to transgress both the ophiolite and the metamorphic basement. The Central Anatolian ophiolites are underlain by both amphibolite and greenschist facies rocks, including melanges and meta-basalts exhibiting MOR-type protoliths ("Kirşehir type basement"). These units are, in turn, underlain by more intact metamorphic successions, including amphibolites of WPB-type composition and meta-pelagic sediments ("Niğde-type basement") (Floyd et al., 1998, 2000).

### 6.2.4. Cretaceous Ankara Melange

Further west, the classic Ankara Melange (Bailey and McCallien 1950; Norman, 1984) is located between the Sakarya metamorphic massif to the west and the Kirşehir metamorphic massif to the east (Fig. 2). The ophiolitic melange includes most or all of the units of an ophiolite; i.e. serpentinite, peridotite, gabbro, mafic volcanics and diabase dykes, together with ribbon radiolarites and pelagic carbonates. Ophiolitic material ranges from clast-sized fragments to disrupted thrust sheets several hundreds of metres long, together with a few isolated large slices of peridotite and gabbro. One such body comprises ultramafic–tectonite overlain by mafic cumulate. Both units are cut by isolated sub-parallel gabbroic dykes, but extrusives and a sheeted dyke complex proper are missing at this locality. Small ophiolitic clasts within the melange include serpentinite, serpentinised harzburgite, dunite and websterite, layered and massive gabbros, dolerite and basalt. Basalts are mainly aphyric and non-vesicular, but vesicular amygdaloidal varieties are locally present. Geochemical studies show that most of the ophiolitic clasts match the larger dismembered ophiolitic slices. The basic igneous rocks fall into two compositional groups: one of near MOR type and other of overlapping, more depleted IAT type similar to the composition of the cross-cutting diabase dykes, and suggesting a subduction influence (Tankut, 1990). In addition, other components of the Ankara Melange, including alkaline lavas and related sediments, are interpreted as remnants of accreted seamounts/or arc units and are discussed in a later section.

*6.2.4.1. Discussion.* The Late Cretaceous dismembered ophiolites above the Kirşehir/Niğde metamorphic massifs and within the Ankara Melange are interpreted mainly as remnants of SSZ-type ophiolites formed in the Late Cretaceous within a northerly Neotethyan oceanic basin (see Fig. 22). The acidic intrusives and the volcaniclastics of Middle Turonian–Early Santonian age are indicative of contemporaneous arc volcanism. The late-stage MOR-like dykes could represent rifting to form an incipient back-arc basin (Floyd et al., 1998; see later). Widespread acidic extrusives emplaced further north in the Pontides (Çiçekdağı unit) confirm the existence of a related volcanic arc within the northern part of the Neotethyan ocean (Yalınız and Göncüoğlü, 1998). The Late Cretaceous Central Anatolian ophiolite was emplaced southwards from the Ankara–Erzincan suture zone onto the Kirşehir/Niğde metamorphic basement prior to latest Maastrichtian time.

The Kirşehir metamorphic massif was traditionally interpreted as ancient (Precambrian?) metamorphic basement, possibly forming a microcontinent within the northerly Neotethyan ocean during the Mesozoic (Şengör and Yılmaz, 1981; Görür et al. 1984; Robertson and Dixon, 1984). Alternatively, Yalınız et al. (1996) interpret the metamorphic basement units beneath the ophiolite as a deeply buried accretionary melange ("Kirşehir-type basement"), overlying continental basement ("Niğde-type basement"). They see this as a regional northward extension of the Tauride/Anatolide continent further south. If so, the Kirşehir/Niğde metamorphic massifs could represent a continental promontory. However, in the alternative model, the Kirşehir/Niğde metamorphic massif is seen as a microcontinent within Neotethys, rifted from the Tauride/Anatolide continent, the two being separated by an Intra-Tauride ocean basin (Fig. 22). In either model, the region located between the Kirşehir/Niğde metamorphic massif to the east and the Sakarya metamorphic massif to the west probably formed an oceanic embayment. Within this embayment, SSZ-type ophiolites were created above a northward-dipping subduction zone and were later dismembered and admixed with accretionary melange during Late Cretaceous–Early Tertiary final closure of the Northern Neotethys ocean.

### *6.2.5. Ophiolites of the Izmir–Ankara suture zone, Anatolides and Taurides*

Ophiolites associated with the Izmir–Ankara suture zone (Anatolides and Taurides) show many features in common, as summarised below. One Late Cretaceous Tauride ophiolite, the Tekirova ophiolite of the Antalya Complex, SW Turkey (Fig. 1) will, however, be discussed separately as it formed in a contrasting tectonic setting, probably along an oceanic transform fault. The Anatolides are generally interpreted as the metamorphosed leading edge of the Tauride continent (Tauride platforms in the west; Bolkar Dağ further east; Fig. 2) during collision with the Eurasian margin to the north (Şengör and Yılmaz, 1981).

In western Turkey, metamorphosed ophiolites occur associated with the Izmir–Ankara suture (Okay, 1989; Yılmaz et al., 1997; Göncüoğlü et al., 2000). The Izmir–Ankara suture zone was created by final closure of the northerly Neotethyan ocean in latest Cretaceous–Early Tertiary time, and includes both metamorphic and non-metamorphic ophiolites and ophiolitic melange. Meta-ophiolitic rocks are found in two main structural positions: (1) within the core of the Sakarya metamorphic massif (Central Sakarya unit; Fig. 2) in the north; (2) along the southern margin of the suture, within the Anatolides.

Within the Sakarya metamorphic massif (Fig. 2), a stack of metamorphic thrust sheets can be assigned to one or another of the Anatolides to the south (southern margin), or the (pre-Early Jurassic) Karakaya Complex (Fig. 1) and related crystalline basement to the north (former northern margin units not considered here). The lowest unit in the south, the HP/LT Sömdiken metamorphics, is interpreted as the subducted leading edge of the Tauride–Anatolide passive margin (Göncüoğlü et al., 2000). Above this, an "ordered ophiolite" (Taştepe ophiolite), with a metamorphic sole, is itself underlain by a tectonic melange (Dağküplü Melange). The ophiolite (ca. 4 km thick) comprises slices of tectonites and mafic/ultramafic cumulates. Near the base, serpentinised harzburgites contain chromite pods. The cumulates consist of dunite–clinopyroxene/wehrlite, with clinopyroxenite–gabbro bands. Upwards, the layered gabbro comprises troctolites, two-pyroxene gabbros and gabbro norites. Low-grade metamorphic minerals appear towards the top of the ophiolite. The underlying HP/LT melange includes huge blocks (>1 km across) of sheeted dykes and ophiolitic lavas, together with blocks of schist, radiolarian chert, pelagic limestone, serpentinite and recrystallised shallow-water limestone of mainly Mesozoic age (Göncüoğlü et al., 1996–1997, 2000). There are also minor blocks of amphibolite, gabbro, pyroclastics and intermediate/acidic extrusives. The limestone are correlated with low-grade Mesozoic carbonates of the Anatolides, and also with unmetamorphosed Middle Triassic–Jurassic equivalents of the western Taurus carbonate platform further south (Fig. 2). "Immobile"-element chemical studies of the melange basalts reveal variable WPB, MORB and IAT-type compositions, based on a limited database, suggesting the protoliths were incorporated from several different tectonic settings (Göncüoğlü et al., 2000). Radiolarian cherts associated with the MORB-type extrusives have yielded Late Jurassic–Early Cretaceous ages.

The above meta-ophiolites and melange (Sakarya metamorphic massif) are interpreted as remnants of the northerly Neotethyan ocean (Fig. 22) that existed north of the Tauride–Anatolide continent. These lithologies are basically metamorphosed equivalents of the ophiolites and melange within the western Taurides to the south (e.g. Lycian Nappes; Fig. 1). The harzburgitic ophiolite, with chromites, is assigned to a SSZ-type origin, whereas the underlying melange is seen as a subduction–accretion complex, including Late Jurassic–Early MORB-type crust. Counterparts of the Lycian perodotite are exposed on Karpathos and Rhodes (Koepke et al., 2002), within an extension of the same regional nappe system. The common WPB-type extrusives of the Lycian melange may record seamounts or rift-margin basalts. The over-riding ophiolite was located on the upper plate during emplacement, where it escaped HP/LT metamorphism. The HP/LT units beneath were unroofed by Early Tertiary time as a result of regional crustal extension.

In a second area, further southwest, meta-ophiolites are well exposed in the Kütahya area (Fig. 1), HP/LT ductile metamorphic "basement" (Ovacik unit) is overlain by volcanic–sedimentary thrust sheets and melange showing incipient blueschist metamorphism. This is then overlain by a less-metamorphosed, dominantly ultramafic, ophiolite. The entire assemblage was thrust southwards onto foredeep-type clastics in latest Cretaceous time. In the Kütahya area, the metamorphic sole (Göncüoğlü, 1990) beneath the harzburgitic ophiolite is dated as early Late Cretaceous (101–90 Ma) (Önen and Hall, 1993; see also Harris et al. 1994; Fig. 4). The high-level gabbros and dykes of the ophiolite in this area yielded ages of around 85 Ma (Santonian; Önen and Hall, 1993) and may record the latest stages of spreading prior to initial emplacement onto the Anatolide/Tauride passive margin. The tectonic history of this region is very comparable to the emplacement of the Late Cretaceous Semail ophiolite over HP/LT continental margin units in Oman (in the Saih Hatat region). This was related to attempted subduction of the Arabian passive margin, followed by rapid exhumation of HP rocks (Glennie et al., 1990; Lippard et al., 1986; Searle and Cox, 1999).

### 6.2.6. Late Cretaceous Tauride ophiolites

Huge ophiolite thrust sheets were emplaced onto the Tauride carbonate platforms during latest Cretaceous time. From east to west, three segments can be recognised that exhibit contrasting local structural histories after initial regional obduction onto the Anatolide–Tauride margin.

### 6.2.7. Western segment Lycian Nappes

In the west, the Menderes metamorphic massif is overlain by the Lycian ophiolite (De Graciancky, 1972; Figs. 1 and 2), with intervening melange (Collins and Robertson, 1997, 1998). The ophiolite (>2 km thick) crops out over >45,000 km$^2$ and is dominated by serpentinised harzburgite, with minor pyroxene, podiform dunite and chromite, and very rare gabbro, all cut by isolated N–NW striking altered diabase dykes. Chrome spinels analysed from the harzburgites and podiform chromites are enriched in Cr relative to Al (Collins and Robertson, 1998), similar to modern island-arc rocks and inferred supra-subduction zone ophiolites (e.g. Oman; Dick and Bullen 1984). Whole-rock analysis of selected peridotite samples reveals compositions similar to other inferred SSZ-type ophiolites, but contrasts with typical abyssal peridotites. In addition, the immobile trace-element compositions of cross-cutting dolerite dykes are similar to supra-subduction zone basalts, with a very marked Nb depletion on MORB-normalised "spider" diagrams (Collins and Robertson, 1998). Beneath the Lycian Peridotite, there is a well-developed inverted-grade amphibolite/greenschist facies metamorphic sole (up to 500 m thick). This sole was dated at 188–102 Ma using the K–Ar technique on hornblende and plagioclase separates (Thuizat et al., 1981; Fig. 4) and also recently underwent further dating studies (Çelik and Delaloye, 2001; Çelik et al., 2001).

After Late Cretaceous emplacement and deep erosion, the Lycian ophiolite was transgressed by peridotite derived conglomerates and then by shallow-marine limestones of Late Palaeocene–Early Eocene age. Overlying Mid-Eocene clastic sediments including debris flows relate to renewed thrusting, marking final continental collision in the Izmir–Ankara suture zone to the north. Oligo–Miocene time saw final southward translation of the Lycian ophiolite atop a stack of thrust sheets (Poisson, 1977, 1984; Collins and Robertson, 1998).

### 6.2.8. Central segment: Beyşehir–Hoyran–Hadim Nappes

Further east, the regionally extensive Beyşehir–Hoyran Nappes (Fig. 1) includes large peridotite thrust sheets, mainly composed of serpentinised harzburgite with minor dunite and/or pyroxenite and rare cumulate gabbro. The ophiolite is transected by a NE-striking swarm of basic dykes, individually up to 1 m thick (Monod, 1977; Whitechurch et al., 1984). Large ophiolite thrust sheets are exposed in the west (in the Pisidian Taurus; Fig. 1), southeast of Lake Beyşehir, together with a well-developed metamorphic sole (Elitok, 2001), but serpentinite melange is more common, as seen further east, in the central Taurus Mountains (Özgül, 1997; Fig. 1). Throughout this region, Mesozoic Tauride platform carbonates are overlain by a mainly Late Cretaceous melange, including blocks of serpentinite, basalt, chert and pelagic sediments. Fragments of metamorphic sole occur as blocks within the melange. The ophiolite is structurally overlain by thrust sheets of Mesozoic shallow- to deep-water carbonate. Regionally, the Beyşehir–Hoyran ophiolite was initially thrust southwards onto the Tauride carbonate platform in latest Cretaceous time, and later thrust further southeastward, together with underlying Mesozoic platform carbonates (and older units) in Late Eocene time (Monod, 1977; Özgül, 1976, 1984, 1997; Andrew and Robertson, 2000).

*6.2.9. Eastern segment: Pozantı–Karsantı and Mersin ophiolites*

Further east again, the eastward extension of the Tauride carbonate platform (Bolkar platform) was again overthrust by ophiolites in latest Cretaceous time. These ophiolites are collectively known as the Pozantı–Karsantı ophiolite (Juteau, 1980; Whitechurch et al., 1984; Lytwyn and Casey, 1995; Polat and Casey, 1995; Parlak et al., 2000; Fig. 16). Recently, individual massifs were described separately, as the Alihoca ophiolite along the northern margin of the Bolkar Mountains; the Kızıltepe ophiolite, a klippe on the Mesozoic carbonate platform of the Bolkar Mountains further south, and the Aladağ ophiolite above the Aladağ platform east of the Tertiary left-lateral Ecemis fault zone (Dilek and Whitney, 1997; Dilek et al., 1997, 1999; Jaffey and Robertson, 2001).

The most northerly unit, the Alihoca ophiolite, is dismembered as thrust sheets and blocks within widespread ophiolitic melange along the northern margin of the Bolkar platform (Demirtaşlı et al., 1984). Large intact thrust sheets are made up of serpentinised peridotites, pyroxenite, ultramafic cumulates, layered to isotropic gabbros, basic dykes and rare extrusive (Dilek and Whitney, 1997; Parlak et al., 2000, 2001), locally overlain by siliceous pelagic carbonates. The most extensive intact units are layered to massive gabbros, with subordinate interlayered wehrlite and pyroxenite. The ophiolite is cut by basic dykes as swarms and individual dykes up to 2 m thick. The ophiolitic melange (including the Alihoca ophiolite) is transgressed by shallow-water carbonates of Maastrichtian age (Demirtaşlı et al., 1984).

Further south, a number of isolated ophiolitic klippen, up to several hundred metres thick, are found above the mountainous Mesozoic Bolkar carbonate platform (Dilek and Whitney, 1997). The most notable of these, the Kızıltepe ophiolite in the northeastern part of the Bolkar platform, includes serpentinised peridotite, meta-lava and minor underlying foliated amphibolite (Fig. 16).

East of the Tertiary left-lateral Ecemis fault zone, again above the regional Mesozoic carbonate platform, is the Aladağ ophiolite. This includes serpentinised peridotite, with harzburgite and harzburgite–dunite intercalations, ultramafic cumulates (interlayered dunite, wehrlite and pyroxenite), layered gabbro, gabbronorite and massive gabbro and minor diorite, plagiogranite and cross-cutting pegmatitic gabbroic dykes, up to several metres thick (Çakir, 1978; Tekeli et al., 1984). The ophiolite is underlain by an unusually thick metamorphic sole, including banded amphibolite with marble, calc schist, quartzite and metachert. Beneath this a non-metamorphosed melange includes blocks of ophiolitic lithologies, metamorphics, pelagic limestone and radiolarites, and, in turn, unconformably overlies Mesozoic platform carbonates (Tekeli et al., 1984; Polat et al., 1996; Dilek et al., 1997; Parlak et al., 2000, 2001). Both the ophiolite and metamorphic sole rocks are again cut by basic dykes (individually up to 10 m thick), commonly trending NNE.

On the southern side of the Bolkar carbonate platform is the large Mersin ophiolite (60 km long by 25 km wide). This ophiolite includes common serpentinised harzburgite, ultramafic and mafic cumulates (dunite, wehrlite interlayers, pyroxenite lenses and dunite) associated with stratiform chromite, isotropic gabbro, minor plagiogranites and rare basalts, interbedded with deep-sea sediments (Juteau, 1980; Parlak and Delaloye, 1999; Parlak et al., 1995, 1996a,b,c).

Rarely preserved basaltic extrusives are of depleted SSZ-type (Parlak et al., 1997). Beneath the ophiolite is a well-developed metamorphic sole (ca. 50–70 m thick) of amphibolites, quartzite and marble, and below this again is an unmetamorphosed melange (Parlak et al., 1995). Both the sole and the ophiolite are cut by swarms of dolerite–microgabbro dykes (each up to 5 m thick) trending ENE–SSW (dated at ca. 91–96 Ma). According to Parlak et al. (1996c)

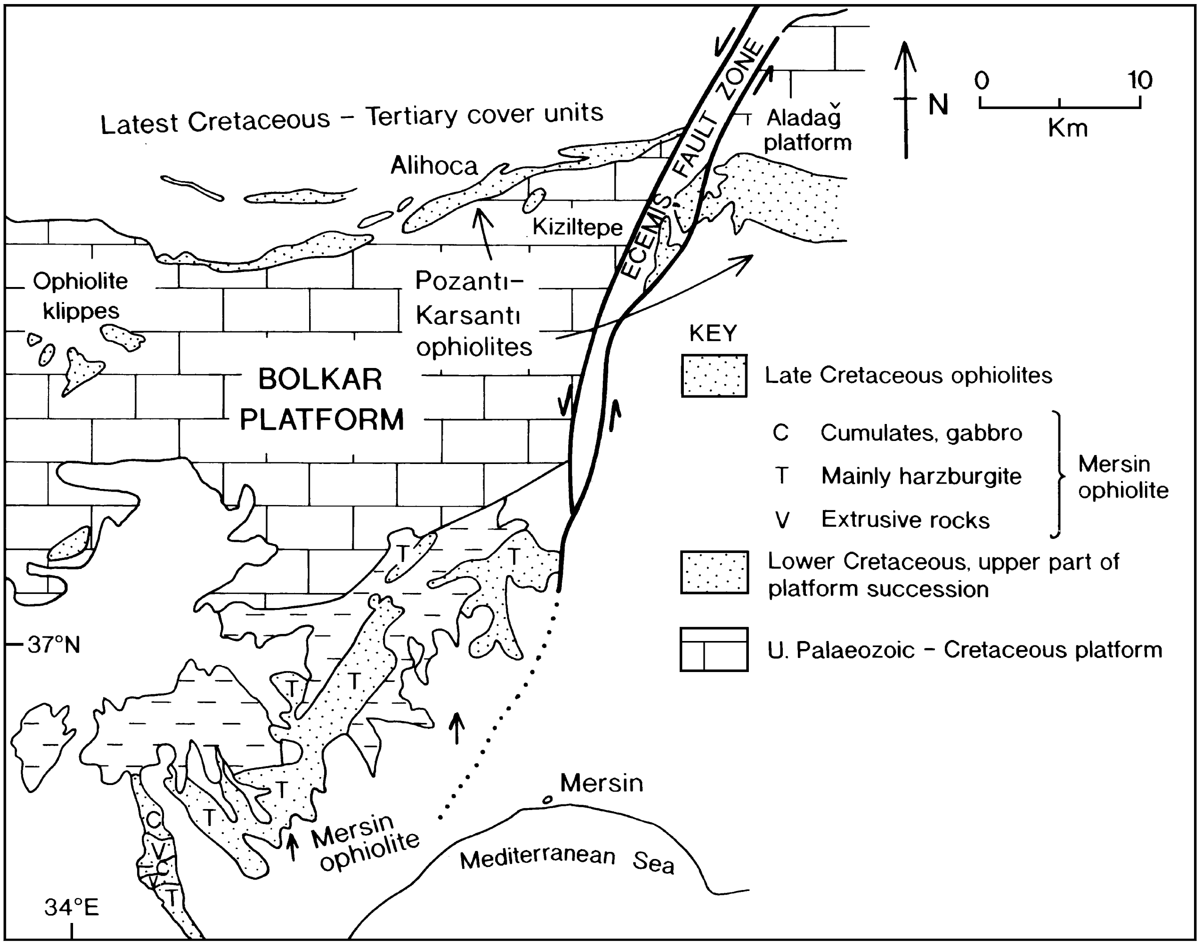


Fig. 16. Sketch map to show the setting of Cretaceous Tauride ophiolites in southern Turkey. See text for data sources.

the metamorphic sole was folded and thrust-imbricated before being cut by microgabbro dykes. K–Ar ages of hornblende on these dykes yielded an age of around 93 Ma (Cenomanian). Immobile element chemistry indicates mainly WPB protoliths for the "sole" amphibolites. In contrast, the intrusive dykes show MORB/VAB compositions with a marked negative Nb anomaly on MORB-normalised plots suggesting a supra-subduction zone origin. Parlak et al. (1996a) describe thrusting and folding of the entire stack (i.e. sub-ophiolite melange, sole and amphibolite) towards the NW, which they take to indicate emplacement from a Neotethyan oceanic basin to the south.

*6.2.9.1. Discussion.* All of the above Late Cretaceous Tauride ophiolites are here interpreted as remnants of a single vast ophiolite thrust sheet generated within Neotethys to the north of the Tauride (Bolkar/Aladağ) carbonate platform, in agreement with many previous workers (Özgül, 1976, 1984; Monod, 1977; Şengör and Yılmaz, 1981; Lytwyn and Casey, 1995; Dilek et al., 1997, 1999). This ophiolite was comparable in scale to the Semail ophiolite, Oman (Glennie et al., 1990), and the large Ordovician Bay of Islands ophiolite in Newfoundland. The Tauride SSZ-type ophiolites formed above a N-dipping intra-oceanic subduction zone, as shown by mineralogical and geochemical data (Lycian ophiolite: Collins and Robertson, 1998; Pozantı–Karsantı ophiolite: Parlak et al., 2000). The Cretaceous ophiolites are believed to have formed around 78–110 Ma, based on a compilation of metamorphic sole radiometric age data (assuming sole formation does not significantly post-date ophiolite genesis (Fig. 4). After genesis within a northern Neotethyan oceanic basin, the Cretaceous ophiolites were emplaced southwards over the Anatolide margin, onto the Tauride/Bolkar carbonate platforms in Campanian–Maastrichtian time.

Lytwyn and Casey (1995) correlate the metamorphic sole beneath the Tauride ophiolites with the trace of a subduction zone. Dyke swarms intruded both the metamorphic sole and the overlying ophiolites prior to obduction (Whitechurch et al., 1984). An inferred complex fractionation history involved both harzburgitic and less-depleted lherzolitic sources for the dykes. Lytwyn and Casey (1995) invoked two coeval sub-parallel spreading ridges; the metamorphic sole formed when a northerly ridge collapsed, whereas the dyke swarms were intruded when a second, more southerly, ridge entered a subduction trench at a later stage. Several known settings of ridge–trench collision (e.g. Kula–Farallon Ridge, S Alaska; Taito ophiolite, S Chile) have indeed produced similar MORB–IAT-type basalts. Lytwyn and Casey (1995) note that slab fusion is an alternative means of producing the dyke magmas, but this involves petrogenetic difficulties in the authors' view.

More recently, Dilek et al. (1999) obtained new $^{40}Ar/^{39}Ar$ dates of 90–92 Ma from the "sole" amphibolites of the Aladağ, Kızıltepe and Mersin ophiolites and also cross-cutting (pre-emplacement) dykes from the Alihoca and Mersin ophiolites, in agreement with the earlier results of Thuizat et al. (1981) (ca. 94 Ma) and those of Parlak et al. (1995), and Parlak and Delaloye (1999). However, dolerite dykes gave ages of around 91 Ma (close to the Mersin ophiolite dyke ages; 91–96 Ma), compared to ca. 70–75 Ma (Campanian–Maastrichtian) obtained by Thuizat et al. (1981). It thus appears that $<2$ Ma separates the time of formation of the metamorphic sole and the cross-cutting dykes. Dilek et al. (1997) suggested a model involving asymmetrical collapse of a spreading ridge, allowing subduction-influenced magma to escape upwards through an "asthenospheric slab window", cutting through the overlying oceanic plate, together with its metamorphic sole. Several problems with this model, however, are as follows. (1) Collapse of the spreading axis would be expected to duplicate the oceanic crust rather than opening a "slab window". (2) Similar diabase dykes cross-cut many of the Tauride ophiolites that restore as oceanic lithosphere at least several hundred kilometres across. This suggests that the dyke injection process must have operated widely in space or in time and cannot readily be explained by an essentially instantaneous local process. (3) If the collapsed spreading ridge was underplated, as in this ridge collapse model, the amphibolite sole should be compositionally similar to the overlying ophiolitic extrusives (Searle and Cox, 1999), yet the protoliths of the meta-igneous rocks beneath the Tauride ophiolites exhibit WPB/MORB compositions, in contrast to the subduction-influenced character of the over-riding ophiolites (see below).

An alternative model is that subduction began near the spreading ridge (as inferred for the Jurassic Albanian ophiolites). This initiated "roll-back" and SSZ-spreading of the Cretaceous Tauride ophiolites. MORB–WPB protoliths were underplated to the hanging wall of the subduction zone. The downgoing, hydrated slab began to melt as it "rolled-back", generating hybrid, subduction-influenced magmas that were injected through the structurally overlying metamorphic sole. These magmas may have fed overlying arc-type extrusives that are not preserved following deep erosion after ophiolite emplacement. In other words, the subduction-influenced dykes record the onset of intra-oceanic arc volcanism.

#### *6.2.10. Transform-related Tekirova ophiolite, SW Turkey*

The Tekirova ophiolite is unusual as there is evidence of strike-slip (transform) tectonics dominating both its genesis and emplacement within SW Turkey (Fig. 5). Late Cretaceous ophiolites occur most widely along the SW limb of the Isparta Angle, where the largest ophiolite outcrop, the Tekirova ophiolite, borders the Mediterranean coast (Juteau, 1970; Juteau et al., 1977; Reuber, 1984; Yılmaz, 1984; Fig. 5). This ophiolite exposes a nearly complete ophiolitic succession, split between several different massifs (Fig. 15). In the south (Ardrasan–Çıralı areas), tectonite harzburgites (cut by isolated diabase dykes) locally dominate, although clinopyroxene-bearing harzburgites are locally present. Layered ultramafics include pyroxenite, dunite with chromite and websterite. Dunite bodies increase in number and abundance upwards and pass into layered dunites, overlain by alternations of wehrlite, dunite and plagioclase-bearing wehrlite. In addition, gabbroic dykelets occur, mainly higher up, within the upper tectonites and cumulates. Higher levels further north (Kemer area) comprise layered cumulate gabbros, then massive amphibolitic gabbros with diabase dykes and pegmatitic gabbro. Finally, there are sheeted diabase, together with isolated dykes composed of tholeiitic diabase, quartz–diabase dykes, minor plagiogranite and pegmatitic gabbro (Juteau, 1970; Juteau et al. 1977; Reuber, 1984; Yılmaz, 1984). No metamorphic sole is exposed and the ophiolite lacks preserved extrusives.

The tectonites exhibit early high-temperature, top-to-the-south displacement, interpreted as a spreading-related fabric (Juteau, 1970; Reuber, 1984). In addition, the tectonites, extending up into the cumulates, are cut by pervasive shear zones ranging from individual crystal to kilometre scale (Reuber, 1984). The tectonites are widely transformed to porphyroclastic and mylonitic harzburgite. The foliations are near vertical and the lineations sub-horizontal, with a mainly sinistral shear sense. Localised shear zones are also seen in the gabbros. For example, wehrlite is cut by sub-vertical serpentinite schistosity, and brecciated wehrlite is injected and cemented by leucogranites. Leucogranite dykelets represent residual melts of the cumulates that were commonly sheared to produce mylonite, under high-strain, low-temperature conditions. Mutual magma injection shear relations indicate synchronous dyke injection and shearing near a spreading ridge. The high temperature ridge-related S1 deformation is cut at a high angle by the S2 mylonitic deformation, implying that the latter is the result of strike-slip tectonics. In addition, sheeted dykes are brecciated and disrupted into kilometre-scale slabs oriented parallel to the S2 shear zones. The observation that the S2 deformation appears to increase in intensity towards the WSW suggests that the main transform fault zone was located in this direction. The Tekirova ophiolite is overlain by mega-breccias that include up to house-sized blocks of the underlying ophiolitic rocks, locally interbedded with Maastrichtian shallow-water sediments, which contain no continentally derived sediment (Robertson and Woodcock, 1982; Lagabrielle et al., 1986).

Further west, the Gödene zone is characterised by highly sheared ophiolitic strands (associated with Triassic volcanics and sediments), dominated by sub-vertical, anastomosing sheets of sheared serpentinised harzburgite, together with minor subordinate cumulates, gabbros and sheeted dykes. Small slices of metamorphic sole-type amphibolites are locally present (e.g. near Gödene (Robertson and Woodcock, 1981; Yılmaz, 1984).

*6.2.10.1. Discussion.* The Tekirova ophiolite formed near an E–W spreading axis in the Late Cretaceous, cut by a nearly N–S sinistral oceanic transform fault (after taking account of later anti-clockwise rotation, as determined palaeomagnetically) (Kissel and Poisson, 1986; Morris and Robertson, 1993). There is a continuum of shearing from ductile to brittle, implying persistent deformation while still in an oceanic setting. The ophiolite was uplifted and underwent mass wasting in subaerial to shallow-water conditions in latest Cretaceous time while still in an oceanic setting, reminiscent of the formation of transverse ridges along fracture zones in the Atlantic (e.g. Vema and Romanche fracture zones) (Searle et al., 1994), or the SW Indian ocean ridge. Although little modern geochemical work is available (e.g. on chromite chemistry), the general plutonic succession, including the dominance of harzburgite, is suggestive of a SSZ-type origin for the Tekirova ophiolite, as for other Tauride ophiolites. The intact Tekirova and dismembered Gödene zone ophiolites (further west) are separated by a sliver of continental crust (Kemer Zone; Fig. 5) that exhibits an intact succession extending from Lower Palaeozoic to Late Cretaceous and is depositionally overlain by latest Cretaceous serpentinite debris flows. The Gödene zone ophiolite is highly dismembered, but includes ultramafic and mafic plutonic rocks, gabbros and rare sheeted dykes, also fragments of a metamorphic sole (Juteau, 1970, 1980; Robertson and Woodcock, 1981; Yılmaz, 1984; Çelik and Delaloye, 2001).

By contrast, the succession in the relatively autochthonous Tauride carbonate platform further west (Bey Dağları) passes unbroken from the Late Cretaceous to Early Tertiary without any major break in deposition or tectonic disruption (Poisson, 1977, 1984; Robertson and Woodcock, 1982). During the latest Cretaceous, the Tekirova oceanic fracture zone underwent transpressional deformation, resulting in uplift, localised overthrusting and intershearing with earlier Mesozoic WPB/MORB-type marginal volcanics and deep-water sediments (Robertson and Woodcock, 1982). The amalgamated complex was thrust over the Bey Dağları carbonate platform to the west in Late Palaeocene–Lower Eocene time and was finally emplaced in the Late Miocene. This general history parallels that of the Masirah ophiolite, Oman. This formed near a fracture zone in the palaeo-Indian ocean; it was later uplifted, partly eroded, overlain by WPB-type lavas, then by neritic carbonate buildups, before being finally emplaced onto the Arabian margin in latest Cretaceous time (Immenhauser, 1996).

Ophiolitic rocks, mainly serpentinised ultramafics, are also seen as thin slices interthrust with Mesozoic carbonate platform units around the NE and W margins of the Isparta Angle (Waldron, 1984; Robertson, 1993). By far the largest of these in the NE of the area is the Kızıl Dağ of Eğrıdır (Figs. 1 and 5), a sub-circular body ca. 10–15 km across, composed of harzburgite tectonite, with bands and lenses of dunite pyroxenite, dunite and chromite (Juteau, 1970; Dilek and Rowland, 1993). The peridotite is cut by swarms of microgabbro to dolerite dykes, each, 2 m thick. The ophiolite is underlain in the SE by greenschists, interpreted as remains of a low-grade metamorphic sole. Structurally beneath is a melange that includes clasts of MOR-type basalt, peridotite, radiolarian chert and pelagic limestone. The MOR-type lavas (Havutlu Lavas) are dated as Late Jurassic–Early Cretaceous based on the extraction of radiolarians from interbedded radiolarian cherts (Robertson and Waldron, 1990). The melange, including the meta-volcanic rocks, is interpreted as an accretionary wedge and low-grade metamorphic sole to the over-riding harzburgitic (SSZ-type) Kızıl Dağ ophiolite.

The Isparta Angle, which includes the Tekirova and Kızıl Dağ (Eğrıdır) ophiolites can be restored as a seaway separating Tauride carbonate platforms to the west and east (Şengör and Yılmaz, 1981; Robertson and Dixon, 1984; Poisson, 1984; Waldron, 1984; Robertson, 1993; Dilek and Rowland, 1993). This basin remained partly open until Late Palaeocene–Early Eocene time (Poisson, 1984; Robertson, 1993). The most likely scenario is that the ophiolite originated actually within an oceanic basin within the Isparta Angle region, separated by opposing Tauride carbonate platforms. An alternative is that the Late Cretaceous oceanic crust originated within the northern branch of Neotethys, together with the Lycian and Beyşehir–Hoyran ophiolites. These latter ophiolites were emplaced as a result of trench-passive margin collision onto the northern edge of the Anatolide–Tauride platform in latest Cretaceous time. If the eastern and western Tauride platforms were indeed separated by oceanic crust within the Isparta Angle region (Fig. 22), it is possible that the encroaching oceanic plate was able to "roll back" into an Isparta Angle oceanic gap where it impinged on marginal platforms on both sides. This process could be similar to the "roll-back" of oceanic crust in the Tyrrhenian Sea, Western Mediterranean (Malinverno and Ryan, 1986; Dvorkin et al., 1993). In either scenario, a remnant oceanic basin within the Isparta Angle finally closed by Upper Palaeocene–Lower Eocene time.

### 6.2.11. Cretaceous ophiolites of SE Anatolia

In the following section, the Late Cretaceous ophiolites of the eastern Taurus Mountains, extending from the easternmost Mediterranean Sea to the Iranian border are discussed (Figs. 1 and 17).

The most northeasterly carbonate platform related to the Tauride/Anatolide platforms in Turkey is the Munzur Dağ (Fig. 2). This is overlain by ophiolites assumed to have been thrust southwards from the Northerly Neotethys (Fig. 22) by Maastrichtian time (see earlier; Şengör and Yılmaz, 1981; Görür et al., 1984). Southwards, the Munzur platform tectonically overlies the metamorphosed Permo-Carboniferous Keban unit (Fig. 17). The northern margin of the Keban platform is overlain by Late Cretaceous foredeep-type clastic sediments and melange, including radiolarite, basalt and other ophiolitic debris. Further south, there is a prominent E–W-trending ophiolitic zone, known as the SE Anatolian Ophiolite Belt. Further south again are the E–W-trending Malatya, Pütürge and Bitlis metamorphic massifs, with discontinuous ophiolites at their structural base (Fig. 2).

The discussion of the ophiolites in this region begins with the SE Anatolian Ophiolite Belt and works southwards to the Arabian continent. First, in the west, there are unmetamorphosed ophiolitic rocks

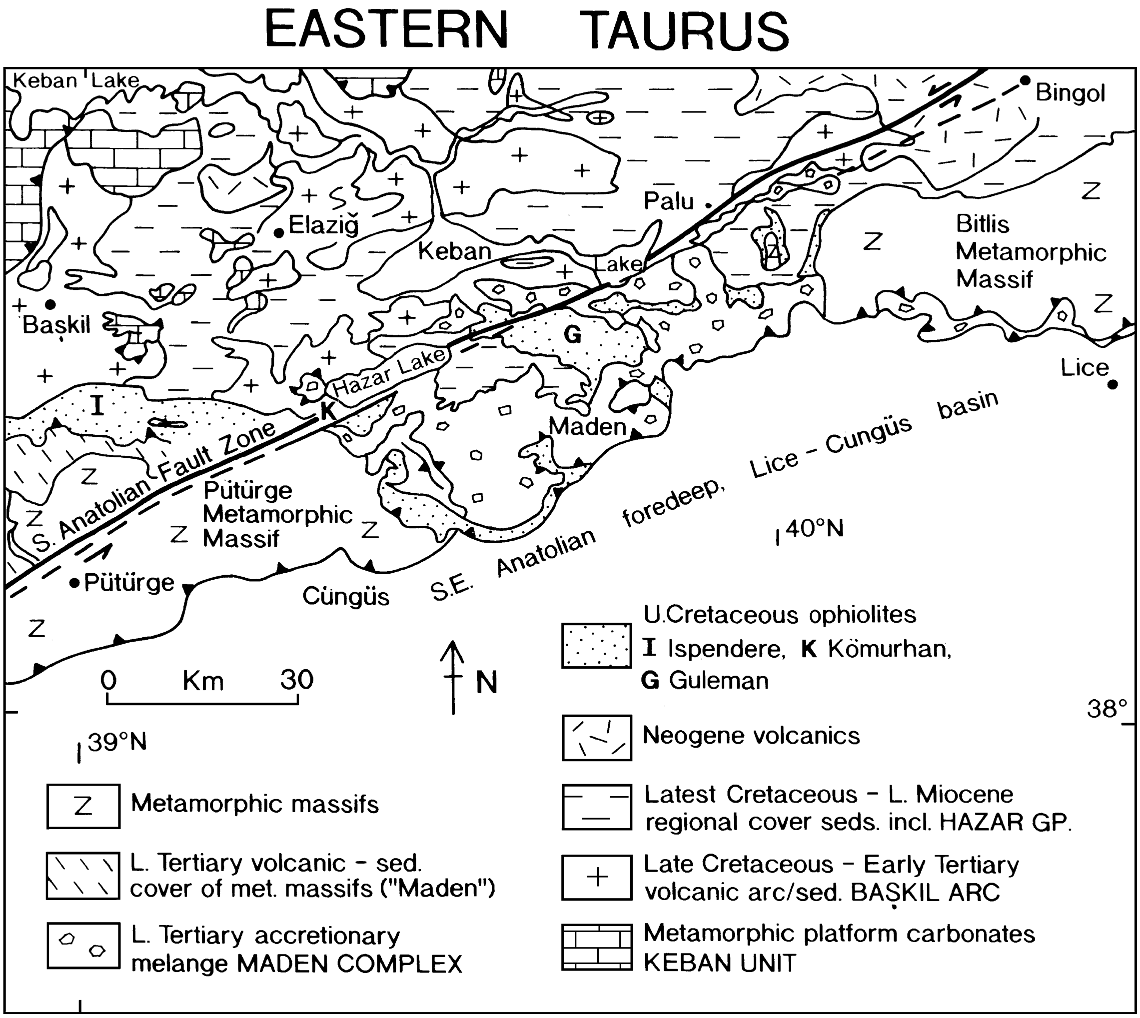


Fig. 17. Sketch map to show the setting of the Upper Cretaceous ophiolites and related units in SE Turkey. See text for data sources.

located south of the Malatya Metamorphic unit (Fig. 2). Very recently, Parlak et al. (2001) have confirmed the existence of a mainly complete ophiolite in this area, of inferred SSZ type. This they correlate with the Yüksekova complex in its type area further east near Lake Van (Perincek, 1979). The ophiolite in the Malatya area is intruded by syn-collisional granitic rocks dated at about 74–51 Ma (Parlak et al., 2001). Further east is located the unmetamorphosed İspendere ophiolite (Fig. 15), which begins with wehrlitic and gabbroic cumulates and isotropic gabbros, overlain, in turn, by diabase-sheeted dykes, passing into basic extrusives. The extrusives are cut by acidic dykes and terminate with intermediate-composition volcaniclastics, pelagic limestones and radiolarites. The ophiolite is overlain by folded Campanian–Lower Maastrichtian turbidites, considered to reflect coeval southward emplacement (Michard et al., 1984; Yazgan and Chessex, 1991).

Further east, on strike, is the large (ca. 200 sq. km of outcrop), unmetamorphosed, Guleman ophiolite (Fig. 17). Amphibolite–greenschist facies rocks are interleaved with serpentinised ultramafics at the base of the ophiolite and are interpreted as a tectonically disrupted metamorphic sole. Within the Guleman ophiolite, the base of the overlying cumulate succession begins with dunite overlain by wehrlite, olivine–clinopyroxenite and clinopyroxenite, then by troctolite, olivine–gabbro, "normal" gabbro and quartz-bearing hornblende diorite (Yazgan and Chessex, 1991). Sheeted dykes are not represented, possibly because of erosion after emplacement, prior to deposition of unconformably overlying Lower Tertiary clastic–carbonate sediments (Hazar Group of Aktaş and Robertson, 1984). However, ophiolitic extrusives correlated with the Guleman ophiolite occur as thrust slices within the subjacent Maden Complex (Fig. 17). These lavas are interbedded with radiolarian cherts of Late Turonian–Lower Campanian age in different thrust sheets (Aktaş and Robertson, 1984). The ophiolitic extrusives are mainly of SSZ-type, although one tectonic slice in the east (Goma) yielded a MORB to WPB compositions (Aktaş and Robertson, 1984, 1990).

Between the two above ophiolite outcrops (İspendere and Guleman), to the west of Hazar Lake, is the Kömürhan meta-ophiolite (Fig. 17). According to Yazgan and Chessex (1991), this can be divided into two main large thrust sheets, separated by a broad shear zone. The lower thrust sheet comprises foliated diorites and quartz–diorites, leucogranites and foliated amphibolites, formed around 85–76 Ma, based on dating biotite separates and whole-rocks using the K–Ar method. The second, overlying major thrust sheet comprises olivine gabbro and massive gabbro (Kara Dağ; Yazgan and Chessex, 1991; see below). Early structures within ductile shear zones are cut by granitic intrusives, dated around 76 Ma. Folding and shearing indicate southward vergence.

More recently, a relatively coherent ophiolitic stratigraphy was reported within the lower thrust sheet of the Kömürhan meta-ophiolite (Bingöl, 1990; Beyarslan and Bingöl, 1996). This succession begins with gabbro (diorite of Yazgan and Chessex, 1991), with minor pyroxenite and serpentinised dunite, overlain in turn by gabbros, then by fine-grained gabbro and sheeted dykes. The diorites (gabbros) include magmatic breccias within amphibolites, as noted above. Granodioritic dykes are intruded into metagabbros with intervening sheaths of amphibolite. Within overlying high-level gabbros, dykes become increasingly more abundant and pass into a sheeted dyke complex. The contact zone between the pyroxenite gabbro and the gabbros above is cut by wehrlitic intrusions, lacking chilled margins. The gabbros are cut by isolated diabase dykes. The upper part of the gabbros and the sheeted dykes are cut by unmetamorphosed Late Cretaceous granitic plutons. Where exposed in an adjacent area, an extrusive succession comprises basaltic pillow lavas, intermediate-composition lava flows and pyroclastic sediments. Chemical analysis shows these extrusives are of low-potassium island arc (Beyarslan and Bingöl, 1996).

#### 6.2.12. *Başkil arc*

The above ophiolitic units are structurally overlain by the Late Cretaceous Başkil arc (Aktaş and Robertson, 1984; Yazgan and Chessex, 1991; Fig. 17), or Elaziğ Metamorphics (Beyarslan and Bingöl, 1996). The Başkil arc is dominated by basaltic–andesitic extrusives and related volcaniclastic sediments, including silicic ash flows. Pyroclastic rocks locally contain upper Maastrichtian fossils. Cross-cutting intrusives include gabbro, diorite, monzodiorite, granodiorite and tonalites of Coniacian–earliest Campanian age. Granitic and dacitic dykes cut the entire succession and are interpreted as part of an arc-type assemblage (Beyarslan and Bingöl, 1996). More recent work (Parlak et al., 2001) has confirmed that the Başkil arc comprises a plutonic sequence together with calc-alkaline volcanics of Cenomanian–early Campanian age and may represent an Andean-type arc constructed on the southern margin of the Tauride microcontinent to the north (i.e. Keban platform), as proposed by Robertson (1998, 2000).

Late Cretaceous intrusive rocks (e.g. Başkil batholith) cut both the extrusives of the Başkil arc and the Permo-Carboniferous Keban platform to the north (Bingöl, 1990). In general, the Keban platform (Keban unit; Fig. 17) is assumed to have been thrust southwards over the Başkil magmatic rocks, although the contact is locally obscured by Middle Eocene sediments. The intrusives are cross-cutting the Başkil arc zone and are mainly gabbro, diorite, monzodiorite, quartz—monzonite, granodiorite and tonalite, of Coniacian–earliest Campanian age, and extend up to 50 km north of the ophiolitic suture (Yazgan and Chessex, 1991).

*6.2.12.1. Discussion.* The Kömürhan ophiolite was metamorphosed to amphibolite facies, whereas the İspendere and Guleman ophiolites, Başkil arc and

Keban platform intrusives are effectively unmetamorphosed (Yazgan and Chessex, 1991). Despite the difference in metamorphic grade, it is generally accepted that the Kömürhan, İspendere, Guleman ophiolites and counterparts along strike to the west (e.g. Berit, Malatya) and east (Yuksekova complex; near Lake Van) all originated as a single vast Late Cretaceous ophiolitic thrust sheet (Şengör and Yılmaz, 1981; Yazgan and Chessex, 1991; Beyarslan and Bingöl, 1996). The nature of the Kömürhan meta-ophiolite, including the presence of quartz diorites and diorites points to a supra-subduction zone origin. Also, the stratigraphy (harzburgite dominated) and available "immobile" trace element chemistry suggest a SSZ-type origin for all of the unmetamorphosed ophiolitic volcanic suites (e.g. Guleman ophiolite).

Several alternative tectonic models can be suggested as follows (Robertson, 1998, 2000; Fig. 18). (1) All of the ophiolites were rooted far to the north, in a northern Neotethyan ocean (Fig. 18a). However, this would not explain the calc-alkaline arc-like rocks cutting the Keban platform that cannot be considered simply as a passive margin to the south. (2) All the above ophiolites (Guleman, İspendere, etc.) were formed by SSZ-type spreading in Santonian–Turonian time above a single northward-dipping intra-oceanic subduction zone within a southerly Neotethys ocean (Fig. 22). This single subduction zone also gave rise to an Andean-type Baş kil arc to the north. (3) Two northward-dipping subduction zones were involved, one to create the Andean-type continental margin arc to the north and a second, intra-oceanic subduction zone to generate the SSZ-type ophiolites (e.g. Malatya, Guleman, İspendere; Fig. 18c). Available metamorphic ages (85–76 Ma) of the Baş kil arc plutonics appear to partly post-date the timing of the genesis of

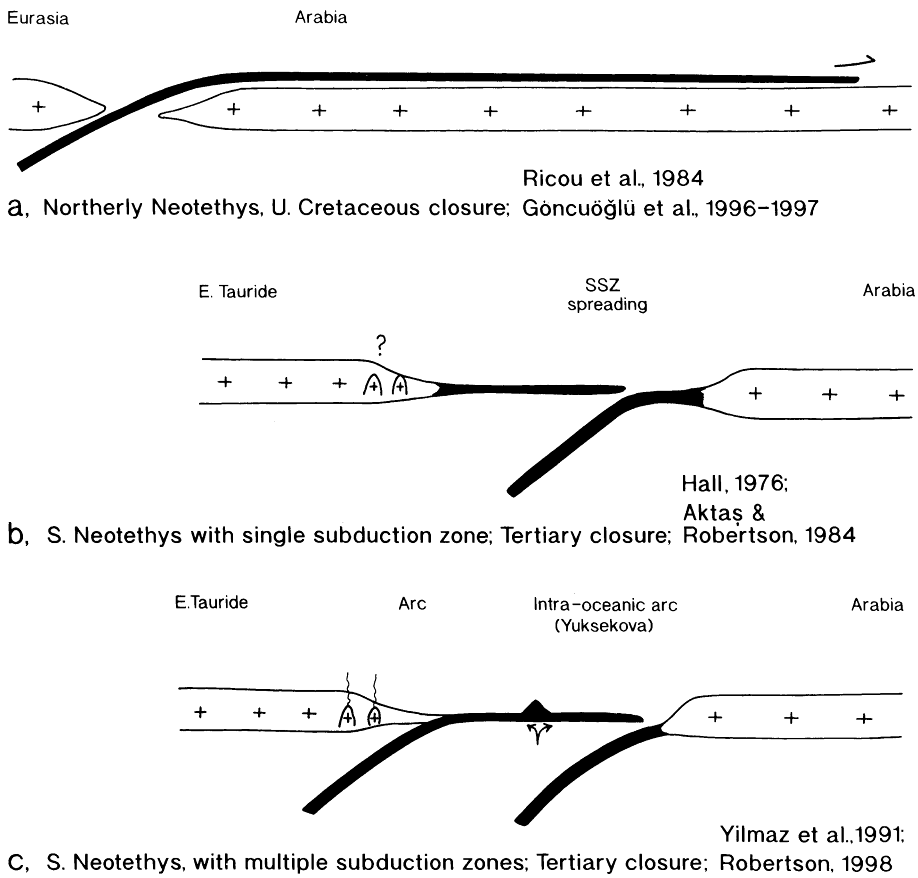


Fig. 18. Alternative tectonic models for the origin and emplacement of Cretaceous ophiolites in SE Turkey. See text for data sources.

the SSZ-type ophiolites (ca. 90 Ma). This favours the "double subduction zone model", since the "single SSZ roll-back" model would imply abandonment of the arc prior to the genesis of SSZ-type ophiolites several hundred kilometres to the south. In this model, the Andean-type Başkil arc and the SSZ-type ophiolites formed above different subduction zones, the former along the southern margin of the Tauride Keban platform and the latter within the southerly Neotethys ocean. After initial Late Cretaceous emplacement, the ophiolites were re-thrust in response to Tertiary regional collisional tectonics, discussed in Ophiolite root zones at the end of the paper.

*6.2.13. Ophiolites on the Arabian platform*

It is generally agreed that ophiolites were emplaced over the northern margin of the Arabian platform in latest Cretaceous (Campanian–Maastrichtian) as a vast laterally continuous sheet, of which the Kocali, Amanos and Kızıldağ (Hatay) (S Turkey) and Baer–Bassit (Syria) ophiolites (Figs. 1 and 19) remained following Tertiary tectonic disruption and differential erosion (Rigo de Righi and Cortesini, 1964; Şengör and Yılmaz, 1981; Yılmaz, 1991, 1993).

In the east, the Kocali ophiolite (Fig. 1) begins with serpentinised harzburgite/dunite, passing into alternating wehrlite, pyroxenite and gabbro, overlain by isotropic gabbro. The ophiolite is then cut by a low-angle shear zone marked by serpentinite blocks. No sheeted dyke complex is preserved. The succession resumes with altered basaltic lavas and radiolarian cherts. The ophiolite is reported to be depositionally overlain by pyroclastic rocks (e.g. tuff, lapilli tuff) and volcaniclastic rocks (e.g. sandstones and breccias) and micritic limestone, together with a "melange" including gabbroic and rare granitic blocks near the top of the unit (Bingöl, 1994). However, it is unclear to what extent these sediments are coeval with the ophiolite, as opposed to melange related to tectonic emplacement. Eocene clastics and neritic carbonates (Midyat Group) transgress the ophiolitic rocks and melange. Sparse published analyses of the altered ophiolitic volcanics reveal MORB/IAT-type patterns (Bingöl, 1994). The Kocali ophiolite is regionally underlain by a melange that includes blocks of Permian and Triassic mafic volcanics, neritic limestone, radiolarite and serpentinite set in a pelitic matrix (Fourcade et al., 1991).

Further southwest, the Kızıldağ (Hatay) ophiolite (Fig. 19; Delaloye and Wagner, 1984; Tekeli and Erendil, 1986) is split into a large northwest-trending massif and a smaller northeasterly massif by a high-angle fault (Tahtaköpru Fault). The main ophiolite massif is separated from the underlying Arabian platform by only a thin melange and no metamorphic sole is preserved. The succession in the northeasterly massif (NE of the Tahtaköpru Fault) is exposed at several localities. At one, serpentinised peridotites are tectonically overlain by gabbro, rotated dykes and lavas (Dilek and Thy, 1998). Elsewhere, serpentinised peridotites are overlain, above a gently dipping normal fault, by massive and pillow lavas and are rarely interbedded with and overlain by metalliferous sediments (Erendil, 1984; Robertson, 1986). Pillow flows are now sub-vertical and are reported to be intruded by less steeply dipping dykes (Dilek and Thy, 1998). Several high-angle oblique faults are affected by sulphide mineralisation.

The succession in the main Kızıldağ massif (Delaloye and Wagner, 1984) begins with serpentinised harzburgite tectonite with local intercalations of dunite, wehrlite, lherzolite and feldspathic peridotites. The ultramafics are separated from the overlying gabbros by a shear zone, 50–100 m thick, that extends upwards into the base of overlying layered gabbros (Dilek and Thy, 1998). Layered gabbros, in turn, pass into isotropic gabbros, intruded by small bodies of plagiogranite, leucocratic gabbro and dolerite. Diabase dykes increase towards the top of the gabbros and pass upwards into a sheeted dyke complex, marked by several generations of dyke intrusion. Locally, the gabbro–dyke contact is a low-angle shear zone marked by hydrothermal alteration. In places, the dykes are cut by high-angle faults suggestive of a horst–graben spreading fabric (Dilek and Thy, 1998), as inferred for the Troodos ophiolite (see below). In the northeast, sheeted dykes are unconformably overlain by Maastrichtian non-marine to shallow-marine sediments, presumably after erosion of ophiolitic extrusives (Erendil, 1984; Pişkin et al., 1986).

Further south (south of Antakya) gabbros or sepentinites are in low-angle fault contact with overlying pillow lavas, including rare metalliferous sediments (Erendil, 1984). These extrusives include highly magnesian, boninite-type lavas ("sakalavite"; Delaloye and Wagner, 1984).

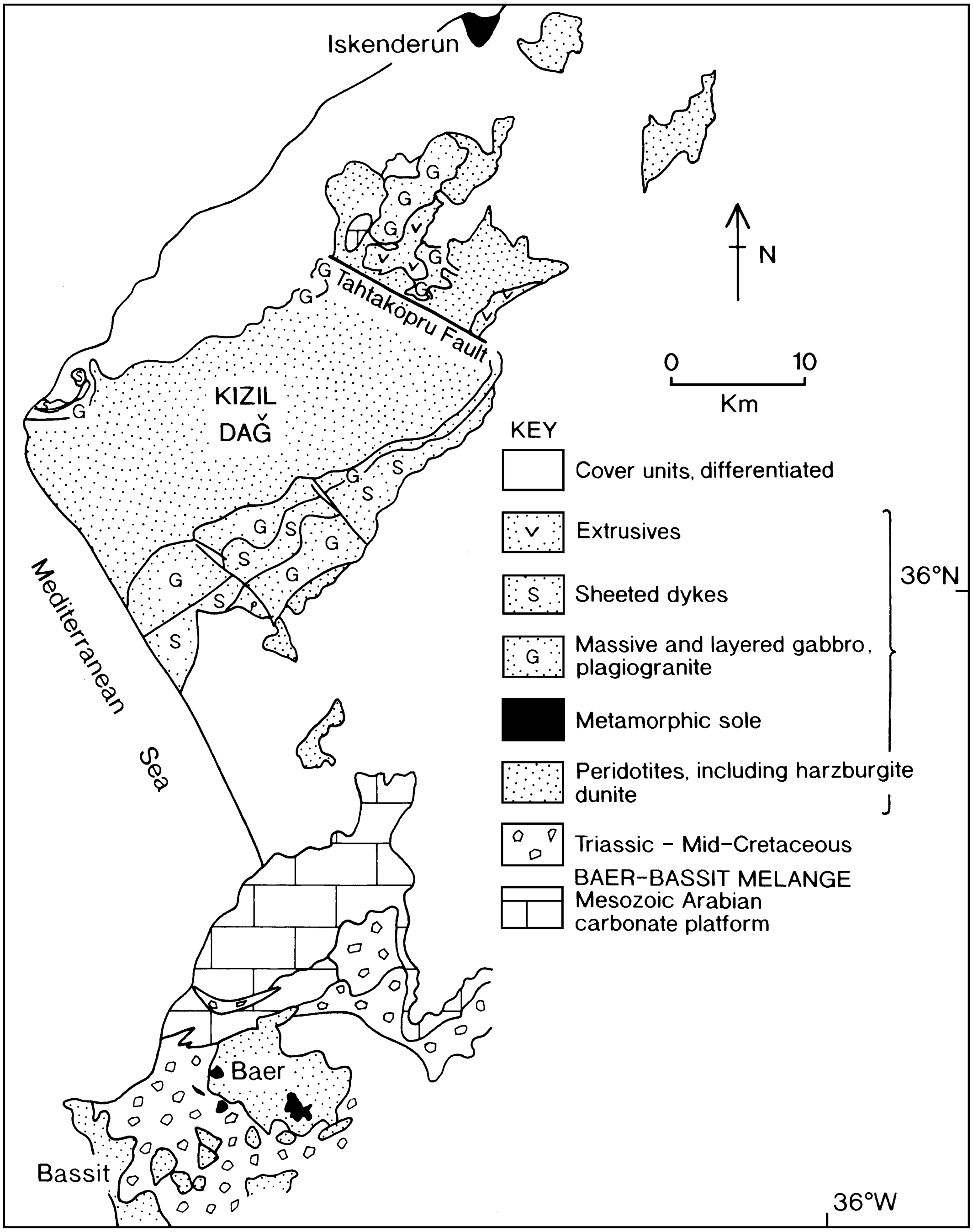


Fig. 19. Sketch map of the setting of Late Cretaceous ophiolites in the Hatay (S Turkey) and Baer–Bassit (N Syria). See text for data sources.

The sheeted dykes and extrusives are markedly depleted in both high-field-strength and rare-earth elements and are relatively enriched in large ion lithophile elements relative to MORB (Delaloye and Wagner, 1984; Lytwyn and Casey, 1993; Dilek and Thy, 1998). MORB-normalised plots show a small distinctive Nb anomaly, indicative of a subduction influence.

Further south, the Baer–Bassit ophiolite is more tectonically dismembered (Parrot, 1977; Al-Riyami et al., 2000; Al-Riyami et al., 2002). A well-developed inverted amphibolite/greenschist facies metamorphic sole (Whitechurch, 1977) was dated at 86–93 Ma, using hornblende and plagioclase separates by the K–Ar method (Fig. 4; Thuizat et al. 1981; Delaloye and Wagner, 1984). Palaeomagnetic study of various ophiolitic units indicates the presence of both normal and reversed polarity episodes which may exclude formation during the long Cretaceous period of normal magnetic polarity (Morris et al., 1999). The ophiolite outcrop comprises two large massifs of mainly ultramafic rock, Baer in the NE (inland) and Bassit in the SW (near the coast), together with smaller masses of highly dismembered ophiolitic rocks further southeast (Fig. 19). The Baer massif is subdivided into several large thrust sheets, dominated by harzburgite (with rare lherzolite), overlain by cumulate ultramafic rocks (Parrot, 1977; Al-Riyami et al., 2000). Layered gabbros (< 1 km thick) are locally cut by dolerite dykes. The Bassit massif is dominated by depleted mantle harzburgite, cumulates, massive gabbro, pegmatitic gabbro and isolated diabase dykes. Gabbro and extrusive rocks are thrust imbricated near the base of the ophiolite, above melange (Baer–Bassit Melange) (Al-Riyami et al., 2000). Chemical analysis of sparse ophiolitic extrusives reveals strongly depleted, highly magnesian boninite types (Al-Riyami et al., 2000).

The metamorphic sole of the Baer–Bassit ophiolite records displacement towards the SE; a similar emplacement direction is inferred for the underlying Baer–Bassit Melange (Al-Riyami et al., 2000). Protoliths of the amphibolite and greenschist metabasites are mainly WPB and rarely MORB in type (Al-Riyami et al., 2000). The Baer–Bassit Melange is well documented as a Late Triassic to mid-Cretaceous deep-water passive margin succession (Delaune-Mayère, 1984; Al-Riyami et al., 2000). Thrust slices of alkaline to peralkaline extrusives, locally overlain by Cenomanian Fe/Mn-rich pelagic limestones, are dated as Middle Jurassic–Early Cretaceous using radiolarians (Al-Riyami et al., 2000; Danelian, personal communication, 1999).

*6.2.13.1. Discussion.* The Kocali, Kızıldağ (Hatay) and Baer–Bassit ophiolites are correlated as representing a vast laterally continuous slab of oceanic crust and mantle generated above a northward-dipping intra-oceanic subduction zone. Boninite-type extrusives characterise the Kızıldağ (Hatay) and Baer–Bassit ophiolites. The sedimentary cover of the Kocali ophiolite includes pyroclastic tuff that suggests near proximity to a magmatic arc, originally to the north. During genesis of the Kızıldağ (Hatay), ophiolite (and possibly also the Kocali ophiolite) extension at times exceeded magma supply and this resulted in oceanic detachment faulting; this was most pronounced to the northeast of the Tahtaköpru fault, possibly reflecting different rates of extension in different spreading segments (Dilek and Thy, 1998). The Baer–Bassit ophiolite is interpreted to represent the leading edge of a supra-subduction zone oceanic slab; this was internally imbricated during collision with the Arabian margin in Maastrichtian time. The Baer–Bassit metamorphic sole formed by underplating of mainly WPB-type protoliths to the base of the hot over-riding ultramafic slab. The melange beneath the Kocali ophiolite is interpreted as an early Mesozoic-rifted continental margin and oceanic crust that were partially subducted to form an accretionary prism ahead of the emplacing SSZ-type ophiolite. The well-dated passive margin sequence, preserved as dismembered thrust sheets and blocks within the Baer–Bassit Melange, clearly shows that deep-water passive margin conditions persisted at least from Late Triassic (oldest known rocks) to the Albian–Cenomanian (youngest known), with the addition of hot-spot type(?) seamounts of Middle Jurassic–Early Cretaceous age (Al-Riyami et al., 2000).

*6.2.14. Troodos ophiolite, Cyprus*

The Troodos ophiolite (Fig. 21) is so well known that only a very brief summary is given here to allow comparison with other Eastern Mediterranean ophiolites. The Late Cretaceous Troodos ophiolite is unique, as it shows no evidence of regional emplacement-related deformation (Moores and Vine, 1971; Moores et al., 1984; Gass, 1990; Malpas and Robinson, 1990; Robertson and Xenophontos, 1993). The ophiolite formed around 92–90 Ma (Cenomanian–Turonian), based on U–Pb isotopic dating of plagiogranites (Mukasa and Ludden, 1987). No basal metamorphic sole is exposed and, indeed, none may be present. Seismic refraction evidence indicates that the Troodos ophiolite is underlain at depth by crust of normal continental thickness (Makris et al., 1983), but the timing of its emplacement is not known. The ophiolite begins with tectonised harzburgite, interpreted as refractory mantle, together with inclusions of dunite and lherzolite. Overlying layered cumulates, including minor podiform chromites, are cut by gabbroic intrusives, favouring a multiple magma chamber spreading model (Robinson and Malpas, 1990). The upper, massive gabbros are locally overlain by small plagiogranite bodies that, in places, intrude overlying sheeted dykes. The contact between the massive gabbros and overlying sheeted dykes is commonly a low-angle extensional detachment fault zone (Varga and Moores, 1985). The overlying sheeted dyke complex trends nearly N–S (in contrast more NE–SW in the Kızıldağ, Hatay). Dykes are commonly rotated to low angles and locally re-injected by later dykes (Dietrich and Spencer, 1993). Spreading took place either by steady-state processes (Allerton and Vine, 1987), or by formation of discrete, ephemeral, seafloor grabens (Varga and Moores, 1985). Dykes dominate near the base of the overlying extrusives, but decrease in abundance upwards. Overlying traditional "Lower" and "Upper" pillow lava units are now seen as a collage of "volcanic–tectonic–hydrothermal cycles", largely reflecting growth and destruction of pillow lava volcanoes at, or near, a spreading centre (Schmincke and Bednarz, 1990). Variable hydrothermal alteration occurs throughout the lava pile. The volcanics include massive sulphides and associated stockworks, with one of the largest massive sulphides (Skouriotissa) being located at the overlying lava–sediment interface (Constantinou, 1980). The preservation of fresh volcanic glass in places throughout the lava pile (in common with Baer–Bassit and Hatay) confirms that the lower level extrusives are typical calc-alkaline andesites, whereas higher volcanics include depleted high-magnesian andesite (boninite-type magmas) (Robinson et al., 1983). However, this simple two-fold division may break down in some areas of the Troodos. The extrusives are overlain by metalliferous umbers within small seafloor half grabens (Robertson and Boyle, 1983). In southern Cyprus, a prominent E–W seafloor fault zone (South Troodos Transform Fault Zone) is widely, but not universally, interpreted as an oceanic transform fault (Simonian and Gass, 1978; MacLeod and Murton, 1993, 1995; Morris et al., 1990). The ophiolite and the South Troodos Fault Zone are overlain by latest Cretaceous Turonian–Campanian radiolarites and Maastrichtian pelagic carbonates. The ophiolite did not emerge into shallow water until Early Miocene time (Robertson, 1977).

In SW Cyprus, the Troodos ophiolite is juxtaposed, via a combination of thrusting and strike-slip, with highly dismembered thrust sheets of Mesozoic lavas and sediments (Mamonia Complex; Lapierre, 1972; Swarbrick, 1980; Fig. 20). Late Triassic–Early Cretaceous sediments are restored as the deep-water slope/base-of-slope of a Mesozoic passive margin (Robertson and Woodcock, 1979). Late Triassic volcanics include both MOR-type basalts associated with radiolarites and pelagic limestones, and subordinate alkaline WPB-type volcanics and reef limestones interpreted as seamounts formed within a Triassic Neotethys ocean (Robertson, 1990; Malpas et al., 1992, 1993; see earlier discussion of rift processes). The earlier Mesozoic Mamonia Complex and the Late Cretaceous Troodos ophiolite are separated by slivers of amphibolites (dated at 93–90 Ma; Spray and Roddick, 1981) and greenschists, both with WPB-type protoliths (Robertson, 1990; Malpas et al., 1993). The greenschists are interpreted as having formed by underplating of WPB-type crust (seamounts?) beneath hot Troodos-type upper mantle in the vicinity of an oceanic transform fault (see Robertson, 1990 for alternative models).

*6.2.14.1. Discussion.* The Troodos ophiolite is markedly similar, lithologically and chemically, to the Kızıldağ (Hatay) and Baer–Bassit ophiolite to the east. Each of these ophiolites possess similar upper mantle and crustal sequences and at least two (Kızıldağ and Troodos) preserve evidence of extensional faulting during spreading. The extrusives in each case include boninite-type lavas and are overlain by similar metalliferous sediments (umbers), interpreted as largely hydrothermal precipitates. The Troodos extrusives show an exceptionally strong subduction influence throughout, possibly resulting from enhanced water flux. The Troodos is, thus, reasonably interpreted as a westward extension of the same Late Cretaceous supra-subduction ophiolite as the Kızıldağ (Hatay),

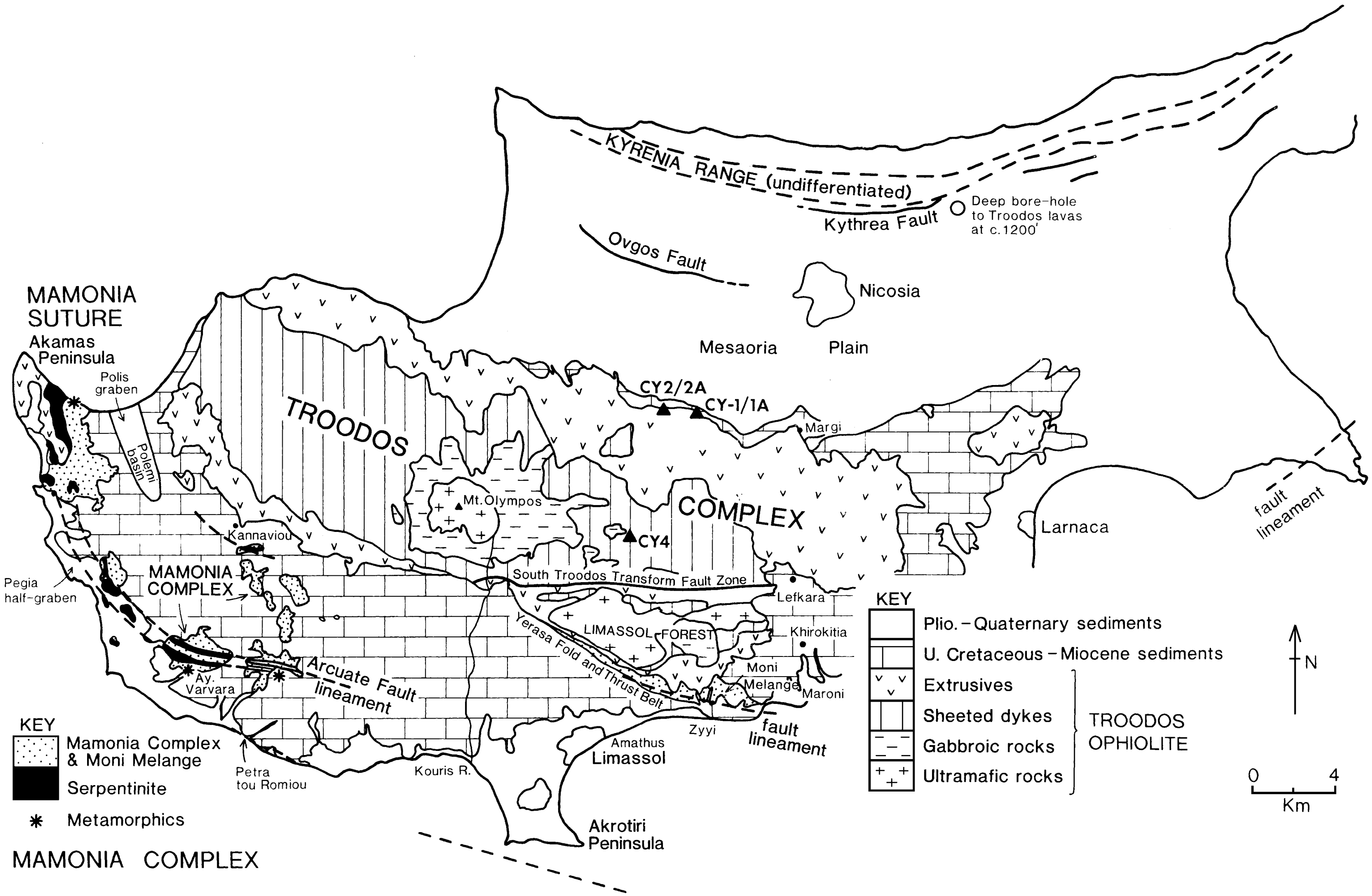


Fig. 20. Sketch map of the setting of the Late Cretaceous Troodos ophiolite, Cyprus; from Robertson and Xenophontos (1993). See text for data sources.

Baer–Basit and Kocali ophiolites. These all formed within the southerly Neotethys (Fig. 22). The emplacement-related deformation of the Baer–Bassit and Hatay ophiolites can be explained by collision of the subduction trench (above which they formed by SSZ-type spreading) with the Arabian passive margin to the south. By contrast, the Troodos remained within an embayment of the Neotethys ocean west of the Arabian promontory, in which it underwent 90° of anticlockwise rotation during Campanian–Early Eocene time (Clube and Robertson, 1986; Morris et al., 1990).

## 7. Intra-oceanic back-arc basins

One remaining intra-oceanic basin type that might be represented associated with ophiolites in the Eastern Mediterranean region is intra-oceanic back-arc basins. In the modern oceans, such settings are exemplified by the Mariana and Lau basins, SW Pacific.

The Lau Basin includes three back-arc spreading segments that generally propagated from the north in several stages (Parson and Hawkins, 1994; Parson et al., 1994). ODP drilling showed that the back-arc marginal basin crust includes extended arc basement, with or without a veneer of volcanics. In general, there is a change from near MOR-type extrusives in the axial zones of the Lau Basin to subduction-influenced magmatism towards its margins, represented by the Valu Fa Ridge adjacent to the active Tofua arc (Hawkins, 1995). Further north (N of the Peggy Ridge), the Central Lau spreading centre reveals a complex interaction between upper mantle convection, a subduction-influenced component and an enriched component related to the Samoan mantle plume. Boninites are present where the Peggy Ridge approaches to the subduction zone to the NE, possibly reflecting a combination of elevated heat flux and input of water via the subduction zone (Falloon et al., 1987). It is, thus, likely that boninites may erupt in a range of tectonic settings where the conditions are met (i.e. remelting of previously depleted upper mantle).

The main features of intra-oceanic back-arc type oceanic crust are: (i) a basement that may include oceanic lithosphere and/or stretched arc crust; (ii) extrusives of near-MOR composition, increasing to more arc-influenced towards the marginal arc and, or remnant arc; (ii) an episodic rift history, marked by propagating rifts; (iii) possibly anomalous volcanics, e.g. related to mantle plume activity, or ridge subduction; (iv) overlying dispersed hydrothermal deposits; (v) volcaniclastic and tuffaceous sediments mainly derived from a coeval volcanic arc.

No well-developed intra-oceanic back-arc basins are presently known to be preserved in the Eastern Mediterranean region. Marginal basins typically form by rifting of pre-existing arcs. Subduction in the region was generally insufficient to generate large intra-oceanic arcs. However, several examples of incipient back-arc basins may be present associated with the Eastern Mediterranean ophiolites. These include evidence of rifting of the Çangaldağ arc in the Central Pontides (Ustaömer and Robertson, 1997) and rifting of the Central Anatolian ophiolites (Yalınız et al., 1996; Yalınız and Göncüoğlü, 1998). Recently, it was suggested, based on chemical evidence, that meta-basalt blocks within a HP/LT melange in the Konya area (SW of the Kirşehir Massif; Fig. 2) might have formed in an oceanic back-arc setting (Floyd et al., 2001).

## 8. Oceanic seamounts and Large Igneous Provinces

Any discussion of the origins of ophiolites in the Eastern Mediterranean region must also take account of other oceanic remnants, notably oceanic seamounts and possible oceanic plateaus (Large Igneous Provinces, LIPs), as these may provide a useful indication of the former locations of wide ocean basins and hotspots.

In the modern oceans, oceanic plateaus are few in number, but of vast extent (e.g. Ontong–Java; Kerguelen; Shatsky Rise; Coffin and Eldholm, 1994; Saunders et al., 1996), whereas seamounts are smaller, but much more numerous. The Caribbean LIP is of particular interest, as emplaced fragments are preserved in surrounding orogenic belts. Deformed fragments of the Ontong–Java LIP are exposed on land within a suture zone (Petterson et al., 1997), where they mainly comprise massive and pillow basaltic lava flows with minimal intercalated pelagic sediment. Basic extrusives of the Ontong–Java LIP and the Caribbean LIP range from near-MORB (transitional tholeiites) to highly magnesian (recording high fusion temperatures) in the Caribbean case (Mahoney et al., 1993; Mahoney and Coffin, 1997; Kerr et al., 1997; Donnelly et al., 1973). Highly magnesian lavas are also exposed on land in numerous adjacent areas, including Gorgona Island (Dietrich et al, 1981), Curacao (Netherlands Antilles) and the Chilean Andes (Spadea et al., 1989).

Typical oceanic seamounts exhibit plume-influenced, "enriched" basalts (E-MORB to WPB) and alkalic fractionates, as extensively documented in Hawaii, Reunion and many other oceanic islands. Overlying sediments may include drowned atolls in low-latitude settings, or siliceous sediments in high productivity zones. There is an absence of land-derived sediments. Underlying plutonic rocks remain poorly documented in the modern oceans. Submarine seamounts can be expected to include large volumes of slope volcaniclastic talus compared to much larger oceanic plateaus that are dominated by sheet flows and pillow lavas. Where seamounts enter trenches, they are mainly subducted, but fragments may be accreted as blocks of lavas and sediments within a melange (Cadet et al., 1987). On the other hand, LIPs may be sufficiently large to block or reverse subduction.

In the Eastern Mediterranean Tethys candidates for preserved seamounts, or fragmented LIPs, occur in sub-parallel belts of different ages; these are generally located further south with time. There is currently a debate over whether these represent a number of emplaced seamounts or fragments of one, or several, much larger LIPs.

### 8.1. Palaeotethyan accreted seamounts/LIP?

The Karakaya Complex, extending across northern Turkey from the Aegean to Iran (Fig. 1) is widely interpreted as an accretionary melange that includes fragments of seamounts (or a fragmented LIP; Okay, 2000) derived from a Palaeotethyan ocean (Tekeli, 1981; Okay et al. 1991; Pickett and Robertson, 1996). The main candidate for accreted seamounts (or a dismembered LIP) is the Triassic Nilufer unit in the west (Edremit area), which includes thick successions (hundreds of metres) of altered basalts, volcaniclastic debris flows and volcanogenic sediments, in places interbedded with Late Triassic limestones. Whole-rock geochemical analysis and the pyroxene chemistry of the basalts indicate a WBP, enriched-type composition (Pickett and Robertson, 1996). The Nilufer unit locally exhibits HP/LT greenschist facies metamorphism (Monod and Okay, 1999) and includes blueschist and eclogite facies rocks as exotic blocks and slices (Okay and Monie, 1997; Okay et al., 1996; Okay, 2000). The Nulifer unit is interpreted as one of a number of accreted oceanic seamounts (Pickett and Robertson, 1996), or as a fragment of a much larger LIP (Okay, 2000). A combination of the WPB-chemistry of these units and the abundance of slope-related talus suggest an origin as discrete volcanic build-ups rather than plateau-like LIPs. Elsewhere, in northern Turkey, the Palaeotethyan melanges (pre-Late Jurassic) of the central Pontides include blocks and dismembered thrust sheets of meta-basaltic rocks (HP/LT) that exhibit MORB- to WPB-type compositions; these are interpreted as oceanic seamounts that were accreted, subducted and later exhumed (Ustaömer and Robertson, 1999).

### 8.2. Neotethyan accreted seamounts

In the "western" area (Greece, Albania, former Macedonia), ophiolite-related melanges including units that can be interpreted as accreted seamounts; these record the subduction of Neotethys during both Jurassic and Late Cretaceous–Early Tertiary time. Such melanges are unmetamorphosed and include the Jurassic Avdella Melange, beneath the Pindos ophiolites in NW Greece (Jones and Robertson, 1991, 1994; Fig. 1), the Jurassic Pagondas Melange, Evvia (Robertson, 1991; Danelian and Robertson, 2001) and Early Tertiary melange in the Peloponnese (Degnan and Robertson, 1994). Other (undated) melanges experienced HP/LT metamorphism as in the Aegean region (e.g. South Evvia and Cyclades; Avigad and Garfunkel, 1991; Mukhin, 1996; Fig. 1).

In the "Eastern area" (Turkey, Cyprus, Syria) the classic example of a subduction/accretion complex is the Ankara Melange, which, in addition to fragmented ophiolites (see earlier), contains common alkaline basalts (OIB type) and subordinate MORB-type extrusives (Çapan and Floyd, 1985; Floyd, 1993). Associated radiolarian cherts are dated as Upper Norian, Kimmeridgian–Tithonian, Lower Cretaceous and Albian–Turonian (Bragin and Tekin, 1996). The WPB/MORB-type extrusives are interpreted as Mesozoic oceanic crust and seamounts that were accreted at a subduction trench (Koçyğit, 1991; Koçyğit et al., 1998). Recently, studies of dismembered units within the Central Sakarya region have revealed contrasting units of basaltic volcanics of WPB type interbedded with radiolarites of Early Cretaceous age and N-MORB-type basalts, also interbedded with radiolarites of Late Cretaceous (Cenomanian) age (Göncüoğlü et al., 2001). Chemical analysis combined with dating thus allows the evolution of the Northerly Neotethys to be determined with increasing precision.

*8.2.1. Discussion*

From the above summary, it is clear that that both unmetamorphosed and HP/LT melanges record the locations of both Palaeotethyan and Neotethyan sutures. The distinction between units that were derived from rifted margin, as opposed to open-ocean settings (see earlier rift processes section), can only be accomplished by careful study, especially of associated sediments. As in the case of the Ankara Melange, the various accreted blocks with Triassic to Cretaceous radiolarian cherts confirm the existence of a long-lived Northerly Neotethyan ocean, including seamounts, and possibly dating from Late-Triassic time (Fig. 22). By contrast, many of the ophiolites record relatively short periods of supra-subduction zone spreading.

## 9. Ophiolitic root zones

The paper concludes with a brief discussion of the still controversial question of ophiolite root zones in the Eastern Mediterranean region. There are three key issues. First, the root zones of the Palaeotethyan (pre-Late Jurassic) ophiolites; secondly, the root zones of the Jurassic ophiolites of the "western region" (Hellenides, Albanides and Dinarides) and thirdly, the root zone of the Cretaceous ophiolites of the Eastern area (Taurides, Cyprus, Arabian margin; Fig. 2).

*9.1. Palaeotethyan root zones*

The Palaeotethyan ophiolites (Küre, Elekdağ) and related units (Çangaldağ arc) are here interpreted as a marginal basin complex formed and emplaced along the southern margin of Eurasian in pre-Late Jurassic time (Fig. 6). The HP/LT Elekdağ ophiolite is interpreted as the emplaced forearc related to the Çangaldağ arc, and the Küre ophiolite with its terrigenous deep-sea sediment cover as a marginal basin located near the Eurasian margin.

The Palaeotethyan HP/LT ophiolites (e.g Elekdağ ophiolite) and ophiolitic melange (Domuz Dağ Melange) root within a main Palaeotethys to the south. In an alternative model, Triassic-inferred seamounts and related units of the Karakaya Complex (southern Pontides) formed by back-arc rifting of the northern margin of Gondwana above a southward-dipping subduction zone (Şengör and Yılmaz, 1981). A third option is that the Karakaya units formed as a marginal basin generated above a northward-dipping subduction zone, within Palaeotethys located somewhere further south, closer to Gondwana (Stampfli et al., 1998; Stampfli, 2000). However, the Karakaya complex basalts do not exhibit a subduction influence in keeping with a back-arc origin. The view favoured here is that the main Palaeotethys lay to the south of the Eurasian margin, within the area represented by the Karakaya Complex, prior to its consolidation as the Mesozoic Sakarya microcontinent (Sakarya metamorphic massif; Fig. 2).

*9.2. Jurassic root zones, "western region"*

Here, it is assumed that that Late Jurassic ophiolites of the Inner Hellenide Ophiolite belt (and any equivalents along strike) formed as an Andean-type marginal basin, related to (oblique?) northward subduction beneath the southern margin of Eurasia and that these ophiolites are rooted effectively in situ. In addition, the large Jurassic MORB/SSZ-type Jurassic ophiolites of the Hellenides, Albanides and Dinarides that were all obducted onto continental margins during Late Jurassic–Early Cretaceous time. Three main alternatives are proposed for the root zones of these Jurassic ophiolites. (1) They originated in a single Neotethyan oceanic basin in the northeast (Vardar suture), or even in a more easterly "ultra-internal" location(??) (Papanikolaou, 1984). (2) Ophiolites formed in separate Vardar and Pindos oceanic basins to the east and west, respectively, of a microcontinent (Pelagonian/Korabi zone) within Neotethys (Fig. 2). (3) All the ophiolites formed in a single oceanic basin, but were later dissected into parallel belts as exotic terranes related to regional strike-slip faulting (Smith and Spray, 1984).

A Vardar (Almopias) suture origin is the simplest hypothesis, but one that faces many difficulties. In this model (no. 1), the ophiolites formed within the Vardar (Almopias) ocean either at a mid-ocean ridge or SSZ-type setting, or both, and later were emplaced southwestwards onto the Pelagonian microcontinent (Aubouin et al., 1970). In one variant, the Vardar ocean was the main ocean separating Apulian (Gondwana)-related units (e.g. Pelagonian zone) from Eurasia (Dercourt et al., 1986, 1992). In an alternative, the Vardar ocean is seen as a marginal basin developed north of, and behind, an earlier (Palaeotethyan) oceanic basin which is believed to be rooted beneath the Pindos suture further south (Stampfli et al., 1998; Stampfli, 2000). In this model, the Jurassic ophiolites were obducted from a Vardar marginal basin over the Pelagonian continent, onto a "remnant Palaeotethyan suture" located beneath the Pindos zone. Problems with either of these related ("internal derivation") hypotheses include: (1) ductile structures in the Albanian and Greek ophiolites indicate northeastward displacement, coeval with ocean floor genesis (Rassios et al., 1994); (2) kinematic evidence of the direction of movement recorded in the metamorphic sole locally indicates northerly displacement of the western ophiolites, at least in Serbia/Kosovo (e.g. Zlatibor ophiolite); (3) timing of emplacement. In northern Greece ophiolites within the Vardar (eastern Almopias Zone) were emplaced, deeply eroded (down to ultamafics) and transgressed by shallow-water carbonates during Late Jurassic (Kimmeridgian) time (Sharp, 1994), whereas the westerly ophiolites were only finally emplaced in Lower Cretaceous time (Hauterivian–Berriasian).

The second model ("external derivation") is favoured by Mercier et al. (1975), Smith et al. (1979), Robertson et al. (1991, 1996), Doutsos et al. (1993), Rassios et al. (1994) and others. Robertson et al. (1991) proposed onset of SSZ-type spreading within the southerly Pindos oceanic basin, whereas Smith (1993) favoured genesis of the Jurassic ophiolites within the Pindos ocean by spreading in a marginal basin behind a subduction zone. In the latter model, the subduction zone dipped southwestwards along the eastern margin of the Vardar (Almopias ocean) and the slab was thereby able to influence the chemistry of ophiolites forming at a spreading ridge within the Pindos ocean. However, there is no evidence, e.g. of coeval accretionary prisms along the westerly Vardar zone margin, or of arc magmatic rocks within the Pelagonian zone to support this option. The third scenario, as a single ophiolite belt duplicated by strike-slip has not found favour as there are strong difference in the tectono-stratigraphy of the ophiolites and related units within the Pindos and Vardar sutures.

In summary, an origin of the Jurassic ophiolites within a southerly Pindos oceanic basin (Fig. 21) best fits the overall tectonic context. Spreading occurred in the Late Triassic/Early Jurassic at a slow-spreading rifted ridge (e.g. Albanian Western-type ophiolites), followed by convergence and conversion of the spreading ridge into a SW-dipping subduction zone, allowing SSZ-type ophiolites to form as the down-going plate "rolled-back" (Fig. 23). This continued until the leading edge of the subduction zone collided with the Pelagonian microcontinent, emplacing ophiolites northeastwards onto the Pelagonian microcontinent by Early Cretaceous time.

### *9.3. Pull-apart basins in the Vardar suture?*

In addition to ophiolites emplaced within the Vardar zone in Late Jurassic time ("Eo–Hellenic" orogeny), there is also evidence within the Vardar zone of incompletely exposed ophiolites, which escaped the above orogenesis and were not deformed until Early Tertiary time.

An example of a Vardar ophiolite of probable latest Jurassic–Early Cretaceous age is the Meglenitsa ophiolite in the western Vardar suture in NE Greece (Fig. 1). This is located between the Pelagonian zone to the west and the Paikon unit to the east. The Meglenitsa ophiolite is preserved only as MOR-type extrusives overlain by schistose sediments (< 50 m thick) that originated as black ferruginous and micaceous mudstones, passing, in turn, into radiolarites, then volcaniclastic and terrigenous turbidites. The black, organic-rich sediments are suggestive of formation in a restricted basin. After formation in latest Jurassic–Early Cretaceous time, the Meglenitsa ophiolite was not deformed and regionally emplaced until Early Tertiary collisional deformation (Sharp and Robertson, 1994). One possibility is that the

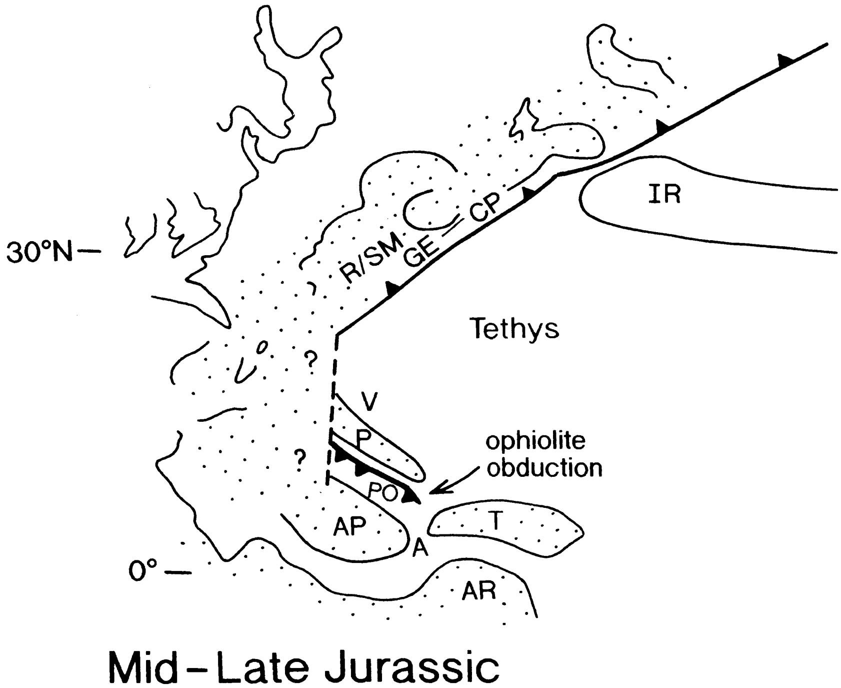


Fig. 21. Simplified palaeogeographic sketch map of Mid-Jurassic time (see text for explanation), focusing on the origin of Jurassic ophiolites. Key to letters: A Antalya, AP Apulia, AR Arabia, CP Central Pontides, GE Guevgueli, IR Iranian, P Pelagonian, PO Pindos ocean, R/SM Rhodope/SerboMacedonian, T Tauride, V Vardar.

latest Jurassic–Cretaceous Vardar ophiolite may have formed in one, or several, trans-tensional pull-apart basins developed along the southern margin of Eurasia after (at least) partial closure of the Vardar ocean in Late Jurassic time. More work is needed on comparable "post-Eo–Hellenic" ophiolites in the Vardar zone within former Yugoslavia to test this alternative.

In addition, Late Cretaceous Vardar-related dismembered ophiolites are present in eastern Evia (locally), the eastern Argolis Peninsula and in southern Crete (Arvi unit; Fig. 1). The ophiolitic extrusives in Argolis show a subduction-influenced chemical composition and are dated based on the presence of interbedded and/or overlying pelagic carbonates of Late Cretaceous age (Clift and Robertson, 1989; Clift, 1992). It seems likely that the Vardar oceanic basin closed diachronously, with an oceanic remnant surviving in the south-Tethyan region into Early Tertiary time.

### *9.4. Problem of the Lesbos and Denizgören ophiolites*

Another regional problem is the root zone of the Denizgören ophiolite in NW Turkey and the correlative Lesbos ophiolite on the adjacent Greek island (Fig. 1). The Denizgören ophiolite has an elongate outcrop 2–3 km wide and 25–30 km long. The ophiolite is almost entirely composed of serpentinised harzburgite, with a well-preserved amphibolitic metamorphic sole. Chemical analysis of the peridotites indicates typical SSZ-type composition (Pickett and Robertson, 1996). The ophiolite tectonically overlies a Permian shallow-water carbonate platform along its eastern margin. The amphibolite facies metamorphic sole, which includes gabbroic protoliths, is underlain by sheared meta-sedimentary and meta-volcanic rocks. Associated structures indicate top-to-the north and-northwest emplacement (Okay et al, 1991; Pickett and Robertson, 1996). The Lesbos ophiolite is compositionally similar and includes an amphibolite facies sole unit, above a volcanic–sedimentary melange which includes poorly preserved fossils within recrystallised limestone of Lower–Middle Triassic age. According to Papanikolaou (1999), Triassic conodonts are present.

Conscious of the inferred Triassic age of the Lesbos sole rocks and the emplacement of the Denizgören ophiolite onto a Permian carbonate platform, Okay et al. (1991) and Pickett and Robertson (1996) interpreted the Denizgören and Lesbos ophiolites as Palaeotethyan (i.e. pre-Late Jurassic) ophiolites. However, K–Ar ages on the Lesbos metamorphic soles yielded Late Jurassic ages (Hatzipanagiotou and Pe-Piper, 1995) and Ar–Ar ages for the sole of the Denizgören ophiolite gave Lower Cretaceous ages (Okay et al., 1996). Secondly, the Lesbos and Denizgören ophiolites could be correlated with the Jurassic (back-arc) ophiolites of NW Greece (Tsikouras and Hatzipanagiotou, 1998a,b). However, these ophiolites are dissimilar as they lack well-exposed ultramafic sequences and metamorphic soles. A third possibility (favoured here) is that Lesbos and Denizgören are Jurassic(?) (Neotethyan) ophiolites that formed in a SSZ-type setting within the Vardar ocean and were obducted onto the western margin of the Sakarya microcontinent (Sakarya metamorphic massif) during Early Cretaceous time.

### 9.5. Cretaceous root zone "eastern region"

The main issues here are the number and location of the root zones for the Cretaceous ophiolites. Alternatives are as follows. (1) All the Cretaceous ophiolites, including the Troodos, were thrust from the a single northerly suture bordering the Pontide (Eurasian) margin (Ricou et al., 1979, 1984; Hirsch et al., 1995; Göncüoğlü et al., 1996–1997; Stampfli et al., 1991). (2) Some of the Cretaceous ophiolites (e.g. Lycian, Beyşehir–Hoyran; Pozantı–Karsantı) were derived from a northern Neotethyan ocean (Fig. 22), whereas others (Troodos, Baer–Bassit, Hatay, S E Turkish) were derived from a separate southerly Neotethyan oceanic basin. As a variant, Dilek et al. (1999) see the Troodos as unique in being southerly derived.

The single northerly suture model is problematic, as: (1) the central Tauride platforms (e.g. Isparta region) include sedimentary successions that pass upwards,

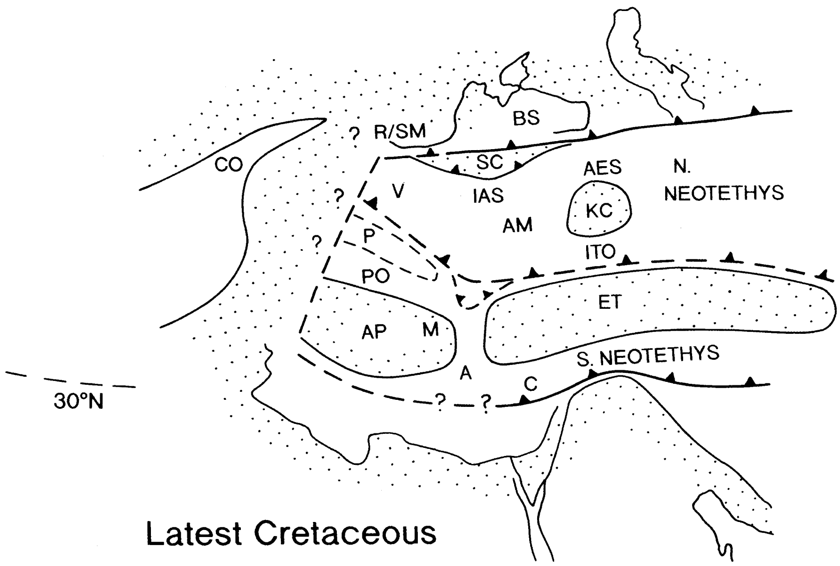


Fig. 22. Simplified palaeogeographic sketch map, focusing on the origin of Cretaceous ophiolites. Key to letters: A Antalya, AES Ankara–Erzincan suture zone, AM Ankara Melange, AP Apulia, BS Black Sea marginal basin, C Cyprus, CO Carpathian ocean (Western Tethys). IAS Izmir–Ankara suture zone; ITO Inner Tauride ocean, K Kirşehir/Niğde metamorphic massif, M Menderes metamorphic massif, P Pelagonian, PO Pindos ocean, R/SM Rhodope/Serbo–Macedonian, SC Sakarya metamorphic massif, ET EastTauride (Bolkar), V Vardar.

unbroken, from late Mesozoic into Early Tertiary time, unaffected by ophiolite emplacement (Şengör and Yılmaz, 1981; Robertson, 1993); (2) the Troodos ophiolite shows no evidence of Late Cretaceous compressional tectonics and its sedimentary cover remained undisturbed from Late Cretaceous through Early Tertiary time (Robertson and Hudson, 1974). A common northerly origin of many of the Tauride ophiolites (e.g. Lycian and Beyşehir–Hoyran and Pozantı–Karsantı) has long been accepted by many workers (Özgül, 1976, 1984, 1997; Monod, 1977). Recent structural work (Collins and Robertson, 1998, 1999) does not confirm the possibility of northward thrusting (Poisson, 1984) of Lycian units over the Menderes metamorphic massif. Thus, the Lycian and Hoyran–Beyşehir ophiolites were rooted in a northerly Neotethyan oceanic basin (Fig. 22) and thrust southwards over the leading edge of the Anatolide–Tauride carbonate platforms in Campanian–Maastrichtian time, probably as a result of trench–passive margin collision. Subsequently, the upper level of the underlying platform and the over-riding ophiolites were detached and thrust further south during Late Eocene time in the east (Hoyran–Beyşehir ophiolites) and Oligo-Miocene time in the west (Lycian ophiolites).

The Late Cretaceous Central Anatolian ophiolites overlying the Kirşehir/Niğde metamorphic massifs (Fig. 1) are seen as rooted to the north within the northern Neotethys. These ophiolites, with their common plagiogranite intrusives, intercalated acidic extrusives and overlying pyroclastic sediments formed in close proximity to a subduction-related oceanic arc. This arc possibly correlates with the Upper Cretaceous Kosdağ arc exposed in the central Pontides. The Late Cretaceous ophiolites and ophiolitic melanges of the Pontides were also rooted in the Northern Neotethys (Ankara–Erzincan suture).

According to some workers, the Central Anatolian ophiolites, the dismembered ophiolites of the Ankara Melange, the Pozantı–Karsantı and Mersin ophiolites all root in the Ankara–Erzincan suture and were thrust over the Kirşehir–Niğde metamorphic massifs, then over the Bolkar Dağ/Aladağ carbonate platforms in the Late Cretaceous (Göncüoğlü et al., 1996–1997). Alternatively, the Pozantı–Karsantı ophiolites were rooted in a separate "Inner Tauride ocean" located between the Bolkar platform (eastern part of the Anatolide–Tauride platform) and a Kirşehir/Niğde microcontinent (Şengör and Yılmaz, 1981; Görür et al., 1984; Fig. 22). Several lines of evidence favour the latter alternative. (1) The Central Anatolian ophiolites may differ lithologically and chemically from the those emplaced over the Bolkar/Aladağ platform (see above). (2) The presence of HP/LT metamorphics locally along the northern edge of the Bolkar platform (Şengör and Yılmaz, 1981; Dilek and Whitney, 1997; Floyd et al., 2001) suggests that the leading edge of the Bolkar platform was subducted, then exhumed locally, similar to the Anatolides further west. If the Kirşehir/Niğde metamorphic massif formed part of the Tauride platform, presumably as a promontory of the Bolkar platform, a large amount of continental crust would have to be subducted, yet there is little evidence of regional HP/LT metamorphism within these metamorphic units. (3) No definite correlation has yet been established between Kirşehir/Niğde and Tauride/Anatolide metamorphic "basement" units. Evidence of retrograde metamorphism beneath the obducted Central Anatolian ophiolites may suggest that the "basement" was metamorphosed prior to ophiolite emplacement, unlike the Anatolide platform.

For the ophiolites in SE Turkey and along the north-Arabian margin, alternative hypotheses are as follows. (1) All of these Late Cretaceous ophiolites were rooted in the Ankara–Erzincan suture, north of the Munzur platform (Göncüoğlü et al., 1996–1997). However, this is difficult to reconcile with the evidence of Late Cretaceous arc volcanism cutting the Keban platform further south, as this area would be part of the foreland. (2) The Late Cretaceous ophiolites along the northern margin of the Malatya–Pütürge–Bitlis metamorphic massifs were rooted in a small Neotethyan basin located between microcontinents represented by the above metamorphic massifs to the south and the Keban–Munzur platform to the north (Şengör and Yılmaz, 1981). Ophiolites were emplaced southwards onto a "Malatya–Pütürge–Bitlis microcontinent" in response to southward subduction (Perincek, 1979). In this model, favoured here, the ophiolites along the north-Arabian margin (Kocali, Hatay, Baer–Bassit) were derived from a southerly Neotethyan oceanic basin, located south of a "Malatya–Pütürge–Bitlis microcontinent" (Şengör and Yılmaz, 1981; Demirtaşlı et al., 1984; Aktaş and Robertson, 1984).

It is now widely accepted that: (1) Late Cretaceous thrusting was regionally southwards, reflecting northwards subduction (Hall, 1976, Aktaş and Robertson, 1984, 1990; Michard et al., 1984; Yazgan and Chessex, 1991; Yılmaz, 1993); (2) most authors correlate the Late Cretaceous ophiolites, both to the north (e.g. Berit, Malatya, İspendere; Guleman) and to the south (e.g. Kocali) of the Malatya–Pütürge–Bitlis metamorphic massifs as remnants of a single slab of supra-subduction zone-type oceanic lithosphere, based on similar geochemistry, age and structural relations, as discussed earlier (Aktaş and Robertson, 1984; Yazgan and Chessex, 1991; Yılmaz, 1993; Fig. 17). Thrust slices related to the Guleman ophiolite can be traced structurally downwards through a corridor between the Pütürge and Bitlis metamorphic massifs (Killan Imbricate Unit; Aktaş and Robertson, 1984, 1990). It is, therefore, likely that all of the above ophiolites were rooted in a southerly Neotethyan ocean bordering the Arabian margin (Fig. 22).

Two main hypotheses have been proposed to explain the present-day structural separation of the ophiolites above and below the metamorphic massifs in SE Turkey. In the first (considered unlikely here), the ophiolites were obducted southwards over the Malatya–Pütürge–Bitlis metamorphic massifs (correlated with the northerly margin of the Arabian plate), far onto the Arabian platform (as the Hatay/Baer–Bassit ophiolites). This Late Cretaceous emplacement was correlated with closure of Neotethys and continental collision. Later, during the Tertiary (Oligo–Miocene), in response to tightening of the suture, the Malatya–Pütürge–Bitlis metamorphic units were reactivated and emplaced southwards, duplicating the Late Cretaceous ophiolitic suture. Problems with the hypothesis, however, are as follows. (1) The absence of evidence that ophiolites were regionally emplaced over the northern margin of the Malatya–Pütürge–Bitlis metamorphic massifs; the Pütürge Massif is transgressed by Early Tertiary volcanogenic sediments (Maden Group), without intervening ophiolites. (2) The Bitlis metamorphic massif is underlain in the east by HP/LT metamorphics (Mutki area) implying Late Cretaceous subduction beneath it (Hall, 1976). (3) Middle Eocene pelagic carbonates overlie hybrid high-Al and subduction-influenced lavas, interbedded with terrigenous turbidites, structurally beneath the Bitlis Massif (Lice Formation; Aktaş and Robertson, 1984; 1990). Rather than just being part of the regional Arabian foreland, the presence of pillow lavas overlain by coeval Middle Eocene pelagic carbonates implies the existence of a suture (a possible transtensional basin) between the Arabian margin to the south and the Bitlis massif to the north during Early Tertiary times. (4) Redeposited carbonates and other sediments within melange beneath the Baer–Bassit ophiolite are interpreted as being derived from the northern margin of the Arabian margin, rather than far to the north. (5) The Kocali/Hatay/Baer–Bassit ophiolites correlate with the Troodos ophiolite in terms of lithology and geochemistry (see above), again suggesting an origin within a southerly Neotethys.

The second (favoured) hypothesis is that the Malatya–Pütürge–Bitlis metamorphic massifs and the Keban–Munzur platforms represent an eastward extension of the Tauride–Anatolide–Bolkar–Aladağ carbonate platform located to the north of a southerly Neotethyan oceanic basin (Yılmaz, 1993). Late Cretaceous northward subduction within this oceanic basin (Fig. 18) involved either one or two subduction zones (Robertson, 1998, 2000). The Malatya–Pütürge–Bitlis metamorphic massifs represented a forearc region located south of the Keban platform in the Late Cretaceous–Early Tertiary. During the later Tertiary (Oligo-Miocene) the still-intact continental unit to the north was thrust southwards over the previously emplaced Late Cretaceous ophiolites and then re-imbricated, carrying the Keban platform over the northern margin of the Malatya–Pütürge metamorphic massifs and its lower Tertiary volcaniclastic sedimentary cover (Yılmaz, 1993). This scenario needs to be tested with further fieldwork. In addition, the timing of final closure of the southerly Neotethys requires confirmation, as latest Cretaceous, mid-Tertiary (Late Eocene–Oligocene) and Late Miocene ages were all suggested. However, it is probable that northward subduction of the southerly Neotethys in SE Turkey ended not long prior to Early Miocene time.

In summary, the Troodos, Baer–Bassit, Hatay, Kocali ophiolites south of the Malatya–Pütürge–Bitlis metamorphic massifs and the ophiolites to the north (Guleman, İspendere, Kömürhan) all formed in a southerly Neotethyan ocean above a northward-dipping subduction zone. This culminated in trench-margin collision and ophiolite obduction in latest

Cretaceous time. A separate northerly subduction zone formed along the margin of the microcontinent to the north, represented by the combined metamorphic massifs (e.g. Berit, Malatya, Pütürge, Bitlis), giving rise to Andean-type arc volcanism (Başkil arc). The northward edge of the SSZ ophiolitic slab was possibly thrust under the forearc in the Late Cretaceous creating the Kömürhan meta-ophiolite. Subduction resumed in the Early Tertiary culminating in southward overthrusting of the forearc over the Late Cretaceous ophiolites, coupled with large-scale thrust imbrication of the over-riding northerly microcontinent.

### *9.6. Problem of the Intra-Pontide suture, NW Turkey*

One final problematic suture remains to the considered. In NW Turkey the pre-Jurassic metamorphic basement of the Pontides is separated from the Sakarya metamorphic massif (a composite unit) to the south by a Mesozoic suture zone, the Intra-Pontide suture. This former basin, best exposed in the Armutlu region (Fig. 1), was believed to have rifted in Early Jurassic time, followed by formation a small oceanic basin (of unknown width). This then closed, associated with ophiolite emplacement, prior to a Maastrichtian transgression (Yılmaz, 1991; Yılmaz et al., 1997). The ophiolitic suture runs into the sea in the west (to link with the Vardar suture) and merges with the Ankara–Erzincan suture in the east (Şengör and Yılmaz, 1981). Further south, Sakarya metamorphic units are overlain by the enigmatic Çetmi melange. This crops out over a wide area (e.g. W of the Kazdağ metamorphic massif) and comprises altered, but unmetamorphosed basic volcanics and pyroclastics, shallow- and deep-water limestone of Late Triassic–Late Cretaceous age (Beccaletto and Stampfli, 2001), radiolarite, shale and greywacke turbidites; also several large tectonic slices of eclogite and garnet–mica schist (Okay et al., 1991). The oldest transgressive sediments are mid-Eocene (Lutetian). The Çetmi melange can be interpreted as an emplaced subduction–accretion complex. Its root zone is unclear, but might be either the Izmir–Ankara suture zone to the south or the Intra-Pontide suture zone to the north. The Intra-Pontide suture zone itself is reported to include meta-ophiolites and ophiolitic melanges of various ages (Yılmaz et al., 1997; Yığıtbaş et al., 2001), but remains poorly understood. An intra-Pontide basin appears to have rifted in Late Triassic time, opening a Jurassic small oceanic basin that separated a Sakarya microcontinent from the Eurasian (Pontide) margin to the north. This might be considered either as a back-arc marginal basin or a transtensional rift basin, but more data are needed on alternatives.

## 10. Conclusions

(1) Ophiolites in the Eastern Mediterranean formed in a variety of tectonic settings and can be interpreted in the light of discoveries in the modern oceans, coupled with a detailed understanding of the geological history of the region.

(2) Thick units (up to 700 m thick) of alkaline to MOR-type extrusives of Triassic age, commonly associated with ribbon radiolarites, throughout the Eastern Mediterranean Tethyan region, record Middle–Late Triassic rifting and initial stages of spreading to form a southerly Mesozoic oceanic basin (Southerly Neotethys in the east; Pindos ocean in the west).

(3) MOR-type oceanic crust is typically subducted and may be preserved only as blocks (locally blueschists) within accretionary prisms (e.g. Triassic Karakaya Complex, N Turkey). Seamounts were preferentially obducted and, thus, record regions where wide oceanic basins once existed.

(4) Intact MOR-type ophiolites are rarely preserved, the chief example being the Jurassic Western-type ophiolite in Albania, and more dismembered counterparts in Greece. Elsewhere, dismembered ophiolites are mainly preserved as disrupted thrust sheets or blocks in melange, which in some cases underwent HP/LT metamorphism.

(5) By far, the largest ophiolites are of, chemically, supra-subduction zone (SSZ) type and include the Jurassic ophiolites of Greece, Albania and former Yugoslavia, and most of the Late Cretaceous ophiolites of Turkey, Cyprus, and Syria (Fig. 23).

(6) Some ophiolites formed in Andean-margin type back-arc basins along the southern margin of Eurasia (e.g. Jurassic Guevgueli ophiolite). These ophiolites show intrusive relations with adjacent continental units, lack metamorphic soles and were typically exposed by uplift without significant thrust displacement.

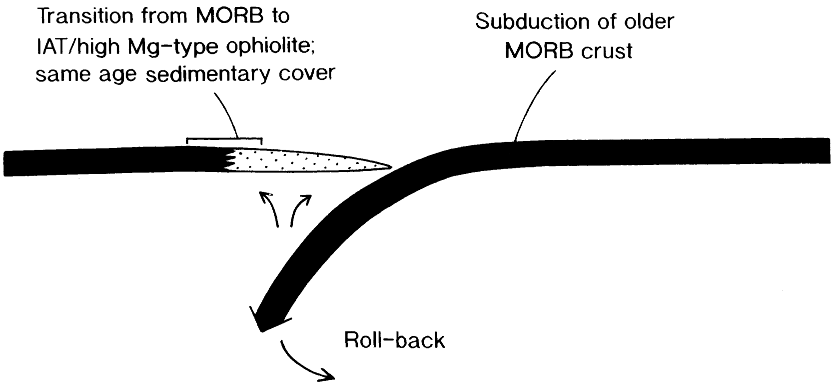


Fig. 23. Model for the genesis of SSZ-type intra-oceanic ophiolites, based on the Jurassic Albanian ophiolites; see text for explanation.

(7) During ophiolite formation, extension varied relative to magma supply, creating ophiolites that range from strongly rifted with thin crustal sequences (e.g. Jurassic Western-type Albanian ophiolite), to less rifted, with thick intact plutonic sequences (e.g. Troodos and Kızıldağ [Hatay], Eastern-type Albanian ophiolite).

(8) Several ophiolites formed in the vicinity of intra-oceanic transforms, notably the Troodos (Cyprus) and Tekirova ophiolites (SW Turkey). Other ophiolites showing structural segmentation may reflect the existence of smaller non-transform offsets (i.e. eastern Hatay ophiolite).

(9) Taking account of the regional geological evidence the Eastern Mediterranean ophiolites of SSZ-type, i.e. both the Jurassic ophiolites of the "western region" (Greece, Albania, Serbia) and the Late Cretaceous ophiolites of the "eastern region" (Turkey, Cyprus, Syria) formed in several adjacent oceanic basins separated by microcontinents and cannot be interpreted as far-travelled nappes from single Jurassic and Cretaceous oceanic basin.

(10) Subduction-related ophiolites were mainly generated during specific periods of the Late Triassic (N Turkey), Mid–Late Jurassic ("western region") and Late Cretaceous ("eastern region") and correspond to times of regional plate convergence, rather than divergence at mid ocean ridges.

(11) A supra-subduction model involving onset of intra-oceanic spreading at a pre-existing mid-ocean ridge, coupled with "roll-back" of the downgoing oceanic plate, can explain the origin and emplacement of many of the large SSZ-type ophiolites throughout the Eastern Mediterranean region (e.g. Troodos).

(12) In the above model, the reason why MORB-type ophiolites are preserved intact in the "western area", but not in the "eastern" Turkish area may be that in the former SSZ-spreading immediately followed MOR spreading, whereas in the latter Late Cretaceous ophiolite genesis long post-dated initial MOR-type spreading; this old crust was thus cold, dense and hard to obduct. However, throughout the region, fragments of MOR-type crust and former seamounts are commonly preserved within accretionary melanges beneath the ophiolites (e.g. Ankara Melange).

(13) Ophiolite emplacement correlates with discrete periods of regional to global plate re-organisation. The large ophiolites were emplaced when the leading edges of supra-subduction zone slabs collided with Tethyan continental margins.

## Acknowledgements

I am indebted to Prof. Volker Hoeck for his helpful scientific and editorial comments. Dr. Osman Parlak kindly reviewed aspects of the Turkish ophiolite geology. The diagrams were drafted by Mrs. Diana Baty. The paper originated as an invited contribution to a symposium on Eastern Mediterranean ophiolites held at the European Union of Geoscience in Strasbourg, April, 1999.

## References


Aberg, G., Aguirre, L., Levi, B., Nystrom, J.O., 1984. Spreading-subsidence and generation of ensialic marginal basins: an example from the early Cretaceous of Central Chile. In: Kokelaar, B.P., Howells, M.F. (Eds.), Marginal Basin Geology. Geol. Soc. London, Spec. Publ., vol. 16, pp. 185–193.

Aktaş, G., Robertson, A.H.F., 1984. The Maden Complex, S.E. Turkey: evolution of a Neotethyan continental margin. In: Dixon, J.E., Robertson, A.H.F. (Eds.), The Geological Evolution of the Eastern Mediterranean. Geol. Soc. London, Spec. Publ., vol. 17, pp. 375–402.

Aktaş, G., Robertson, A.H.F., 1990. Tectonic evolution of the Tethys suture zone in S.E. Turkey: evidence from the petrology and geochemistry of Late Cretaceous and Middle Eocene extrusives. In: Moores, E.M., Panayiotou, A., Xenophontos, C. (Eds.), Ophiolites—Oceanic Crustal Analogues. Proc. Int. Symp. "Troodos 1987" Geological Survey Department, Cyprus, pp. 311–329.

Allerton, S., Vine, F.J., 1987. Spreading structure of the Troodos ophiolite, Cyprus: some palaeomagnetic constraints. Geology 15, 593–597.

Al-Riyami, K., Robertson, A.H.F., Xenophontos, C., Danelian, T., Dixon, J.E., 2000. Tectonic evolution of the Mesozoic Arabian passive continental margin and related ophiolite in Baer–Bassit region (N W Syria). In: Panayides, I., Xenophontos, C., Malpas, J. (Eds.), Proc. 3rd Internat. Conf. on the Geology of the Eastern Mediterranean. Geological Survey Department, Cyprus, pp. 61–81.

Al-Riyami, K., Robertson, A., Dixon, J., Xenophontos, C., 2002. Origin and emplacement of the Late-Cretaceous Baer–Bassit ophiolite and its metamorphic sole in NW Syria. Lithos 65, 225–260 (this volume).

Amstutz, G.C., 1980. The early history of the term Ophiolites and its evolution until 1945. In: Panayiotou, A. (Ed.), Ophiolites Proc. Internat. Symp., Cyprus 1979. Cyprus Geological Survey Department, Nicosia, pp. 143–149.

Andrew, T., Robertson, A.H.F., 2001. The Beyşehir–Hoyran–Hadim (B-H-H) Nappes: Mesozoic marginal and oceanic units of the Northern Neotethys in Southern Turkey. J. Conf. Abstr. 11, European Union of Geosciences, Strasburg, p. 17.

Anonymous, A.H.F., 1972. Penrose field conference on ophiolites. Geotimes 17, 24–25.

Aubouin, J., Bonneau, M., Celet, P., Charvet, J., Clément, B., Degardin, J.M., Mallot, H., Mania, J., Mansy, J.L., Terry, J., Thiebault, P., Tsoflias, P., Verrieux, J.J., 1970. Contribution à la géologie des Héllenides: Le Gavrovo, le Pinde et la Zone Ophiolitique Subpélagonian. Ann. Soc. Géol. Nord 90, 277–306.

Avigad, D., Garfunkel, Z., 1991. Uplift and exhumation of high-pressure metamorphic terrains: the example of the Cycladic blueschist belt (Aegean Sea). Tectonophysics 188, 357–372.

Bailey, E.M., McCallien, W.J., 1950. Serpentine lavas, the Ankara Melange and the Anatolian Thrust. Trans. R. Soc. Edinb. 62, 403–442.

Barker, D.H.N., Austin Jr., J.A. 1994. Crustal diapirism in Bransfield Strait, West Antarctica—evidence for distributed extension in marginal basin formation. Geology 22, 657–660.

Bébien, J., Dubois, R., Gauthier, A., 1986. Example of ensialic ophiolites emplaced in a wrench zone: innermost Hellenic ophiolite belt (Greek Macedonia). Geology 14, 1016–1019.

Bébien, J., Baroz, J., Caperdi, S., Venturelli, G., 1987. Magmatisme basique associées à l'ouverture d'un basin marginal dans les Héllenides internes au Jurassic. Ofioliti 12, 53–70.

Bébien, J., Platevoet, B., Mercier, J., 1994. Geodynamic significance of the Paikon Massif in the Hellenides: contribution of the volcanic rocks studies. Bull. Geol. Soc. Greece XXX/1, 63–67.

Bébien, J., Shallo, M., Manika, K., Greca, D., 1998. The Shebenik Massif (Albania), a link between MOR and SSZ-type ophiolites? Ofioliti 23, 7–15.

Beccaletto, L., Stampfli, G.M., 2001. Geodynamic evolution of the Biga Peninsula (N.W. Turkey). J. Conf. Abstr. (EUG X1) 6, 320.

Beccaluva, L., Coltori, M., Premti, I., Saccani, E., Siena, F., Zeda, O., 1994. Mid-ocean ridge and supra-subduction zone ophiolites in Albania. Ofioliti 19, 77–79.

Becker, K., Sakai, H.et al., , 1989. Drilling deep into young oceanic crust, Hole 504B, Costa Rica Rift. Rev. Geophys. 27, 79–102.

Beyarslan, M., Bingöl, A.F., 1996. Elaziğ magmatitlerinin jeokimyasi ve petrolojisi. Mineral. Petrogr. 30, 208–224.

Bingöl, A.F., 1990. Petrographical and petrological features of intrusive rocks of Yuksekova Complex in the Elaziğ region (Eastern Taurus—Turkey). J. Firat Univ., Sci. Technol. 3, 1–17.

Bingöl, A.F., 1994. Çermik yöresinde (Diyarbakır, Güneydoğu Türkiye) Koçali karmaşiğina ait magma kayalarının Jeokimyası ıve petrologisi. Turk. J. Earth Sci. 3, 1–5.

Blackman, D.K., Chan, J.R., Janssen, B., Smith, D.K., 1998. Origin of extensional core complexes: evidence from the Mid-Atlantic Ridge at Atlantis fracture zone. J. Geophys. Res. 103, 21315–21334.

Bloomer, S.N., 1987. Geochemical characteristics of boninite and tholeiite—series boninitic rocks from the Mariana forearc and the role of an incompatible element-enriched fluid in ore petrogenesis. Spec. Pap.—Geol. Soc. Am. 215, 151–164.

Bloomer, S.H., Hawkins, J.W., 1983. Gabbroic and ultramafic rocks from the Mariana trench: an island arc ophiolite. In: Hayes, D.E. (Ed.), The Tectonic and Geologic Evolution of Southeast Asian Seas and Islands (Pt. II). Am. Geophys. Union Monogr., vol. 27, pp. 294–317.

Bloomer, S.H., Taylor, B., MacLeod, C.J., Stern, R.J., Fryer, P., Hawkins, J.W., Johnson, L., 1995. Early arc volcanism and the ophiolite problem: a perspective from drilling in the western Pacific. In: Taylor, B., Natland, J.H. (Eds.), Active Margins and Marginal Basins of the Western Pacific. Amer. Geophys. Union Monogr., vol. 88, pp. 1–30. Washington, DC.

Bortolotti, V., Kodra, A., Marroni, M., Mustafa, F., Pandolfi, L., Principi, G., Saccani, E., 1996. Geology and petrology of ophiolitic sequences in the Mirdita region (Northern Albania). Ofioliti 21, 3–20.

Bosellini, A., 1996. Geologia delle Dolomit Casa Editrice Athesia, Tulsa, 192 pp.

Bosellini, A., Rossi, D., 1974. Triassic carbonate buildups of the Dolomites, northern Italy. Soc. Econ. Paleontol. Mineral., Spec. Publ. 18, 209–233.

Boudier, F., Nicholas, A., 1995. Nature of the Moho transition zone in the Oman ophiolite. J. Petrol. 36, 777–796.
Boudier, F., Chouchz, J.F., Nicolas, A., Cannat, M., Ceuleneer, G., Misseri, M., Monthgy, R., 1985. Kinematics of oceanic thrusting in the Oman ophiolite: model for plate convergence. Earth Planet. Sci. Lett. 75, 215–222.
Boudier, F., Nicholas, A., Ildefonse, B., 1996. Magma chambers in the Oman Ophiolite: fed from the top and the bottom. Earth Planet. Sci. Lett. 144, 239–250.
Bragin, N.Y., Tekin, U.J., 1996. Age of radiolarian chert blocks from the Senonian ophiolitic melange (Ankara, Turkey). Isl. Arc 5, 114–122.
Brown, S.A.M., 1997. The Geological Evolution and Regional Significance of the Mesozoic to Tertiary Paikon Massif, Northern Greece. Unpublished University of Edinburgh PhD thesis, 379 pp.
Brown, S., Robertson, A., 1994. New structural evidence from the Mesozoic–early Tertiary Païkon Unit, Northern Greece. Bull. Geol. Soc. Greece XXX/1, 159–170.
Cadet, J.-P., Kobayashi, K., Aubouin, J., Boulegue, J., Deplus, C., Dubois, J., von Huene, R., Jolivet, L., Kanazawa, T., Kasahara, J., Koizumi, K., Lallamd, S., Nakamura, Y., Pautot, G., Suyehiro, K., Tani, S., Tokuyanma, H., Yamazaki, T., 1987. The Japan Trench and its juncture with the Kuril Trench: cruise results of the Kaiko Project, Leg 3. Earth Planet. Sci. Lett. 83, 267–284.
Çakir, U., 1978. Pétrologue du massif ophiolitique de Pozantı–Karsantı (Taurus cilicien, Turquie): Etude de la partie centrale. Thèse troisième cycle, Strasbourg, France, Université Louis Pasteur, 251 pp.
Cann, J.R., Blackman, D.K., Smith, D.K., McAllister, E., Janssen, B., Mello, S., Avgerinos, E., Pascoe, A.R., Escartin, J., 1997. Corrugated slip surfaces formed at ridge-transform intersections on the Mid-Atlantic Ridge. Nature 385, 329–332.
Çapan, U., Floyd, P.A., 1985. Geochemical and petrographic features of metabasalts within units of the Ankara melange, Turkey. Ofioliti 10, 3–18.
Capedri, S., Venturelli, G., Bocchi, G., Dostal, J., Garuti, G., Rossi, A., 1980. The geochemistry and petrogenesis of an ophiolite sequence from Pindos, Greece. Contrib. Mineral. Petrol. 74, 189–200.
Carbotte, S.M., Mutter, J.C., Xu, L., 1997. Contribution of volcanism and tectonism to axial and flank morphology of the southern East Pacific Rise, 17°10′–17°40′S, from a study of layer 2A geometry. J. Geophys. Res. 120, 10165–10184.
Casey, J.F., Dewey, J.F., 1984. Initiation of subduction zones along transform and accreting plate boundaries, triple junction evolution, and forearc spreading centres—implications for ophiolite geology and obduction. In: Gass, I.G., Lippard, S.J., Shelton, A.W. (Eds.), Ophiolites and Oceanic Lithosphere. Geol. Soc. London, Spec. Publ., vol. 13, pp. 269–290.
Çelik, Ö.F., Delaloye, M., 2001. Origin of the ophiolite related metamorphic rocks and their postkinematic mafic dike swarms in the Antalya and Lycian ophiolites. 4th Internat. Symp. Eastern Mediterranean Geol. Süleyman Demirel University, Isparta, Turkey, p. 61. Abstract.
Çelik, Ö.F., Delaloye, M., Parlak, O., 2001. Characteristics and age of the metamorphic sole rocks in the serpentinite of the Beyşehir ophiolites. Fourth Internat. Turkish Geol. Symp., (ITGS IV). Süleyman Demirel Univ. Press, p. 228. Abstract.
Clift, P.D., 1992. The collision tectonics of the Southern Greek Neotethys. Geol. Rundsch. 81, 669–679.
Clift, P.D., Dixon, J.E., 1998. Jurassic ridge collapse, subduction initiation and ophiolite obduction in the southern Greek Tethys. Eclogae Geol. Helv. 91, 128–139.
Clift, P.D., Robertson, A.H.F., 1989. Evidence of a Late Mesozoic ocean basin and subduction accretion in the southern Greek Neo-Tethys. Geology 17, 559–563.
Clube, T.M.M., Robertson, A.H.F., 1986. The palaeorotation of the Troodos microplate, Cyprus in the Late Mesozoic–Early Tertiary plate tectonic framework of the Eastern Mediterranean. Surv. Geophys. 8, 375–437.
Coffin, M.F., Eldholm, O., 1994. Large igneous provinces: crustal structure, dimensions and external consequences. Rev. Geophys. 31 (1), 1–36.
Coleman, R.G., 1981. Tectonic setting for ophiolite obduction in Oman. J. Geophys. Res. 86, 2497–2508.
Collins, A., Robertson, A.H.F., 1997. Lycian melange, southwestern Turkey: an emplaced Late Cretaceous accretionary complex. Geology 25, 25–258.
Collins, A., Robertson, A.H.F., 1998. Processes of late Cretaceous to late Miocene episodic thrust-sheet translation in the Lycian Taurides, S.W. Turkey. J. Geol. Soc. London 155, 759–772.
Collins, A., Robertson, A.H.F., 1999. Evolution the Lycian Allochthon, western Turkey, as a north-facing Late Palaeozoic to Mesozoic rift and passive continental margin. Geol. J. 34, 107–138.
Constantinou, G., 1980. Metallogenesis associated with the Troodos ophiolite. In: Panayiotou, A. (Ed.), Ophiolites: Proc. Internat. Symp., 1979. Cyprus Geological Survey Department, pp. 663–674.
Cortesogno, L., Gaggero, L., Taho, E., Marroni, M., Pandolfi, L., Shtjefanaku, D., 1998. The gabboric complex of the western ophiolite belt, Northern Albania: an example of multi-layered sequence on an intermediate-spreading ocean ridge. Ofioliti 23, 49–64.
Crawford, A.J., Falloon, T.J., Green, D.H., 1989. Classification, petrogenesis and tectonic setting of boninites. In: Crawford, A.J. (Ed.), Boninites and Related Rocks. Unwin Hyman, New York, pp. 1–49.
Curray, J.R., Moore, D.G., Lawer, L.A., Emmel, F.J., Raitt, R.W., Henry, M., Kieckhefer, J., 1978. Tectonics of the Andaman Sea and Burma. In: Watkins, J., Montardert, L. (Eds.), Geological and Geophysical Investigations of Continental Margins. AAPG Mem., vol. 29, pp. 189–198.
Dalziel, I.W., 1981. Back-arc extension in the Southern Andes: a review and critical reappraisal. Philos. Trans. R. Soc. Lond. A300, 319–355.
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. Geol. Mag. 138, 345–363.
Danelian, T., Robertson, A.H.F., Dimitriadis, S., 1996. Age and significance of radiolarian sediments within basic extrusives of

the marginal basin Guevgueli Ophiolite (northern Greece). Geol. Mag. 133, 127–136.

Davis, E.E., Fisher, A.T., Firth, J., 1997. Proc. Ocean Drill. Program, Initial Rep., 470 Ocean Drilling Program, College Station, TX.

Degnan, P., Robertson, A., 1994. Early Tertiary melange in the Peloponnese (Southern Greece) formed by subduction–accretion processes. Bull. Geol. Soc. Greece XXX/2, 93–107. Proc. 7th Congress, Thessaloniki.

De Graciancky, P.C. de., 1972. Récherchers géologiques dans les Taurus Lycien. [Thèse DSc.]. Université de Paris Sud, France.

Delaloye, M., Wagner, J.-J., 1984. Ophiolites and volcanic activity near the western edge of the Arabian plate. In: Dixon, J.F., Robertson, A.H.F. (Eds.), The Geological Evolution of the Eastern Mediterranean. Geol. Soc. London, Spec. Publ., vol. 17, pp. 225–233.

Delaune-Mayère, M., 1984. Evolution of a Mesozoic passive continental margin: Baer–Bassit (NW Syria). In: Dixon, J.F., Robertson, A.H.F. (Eds.), The Geological Evolution of the Eastern Mediterranean. Geol. Soc. London, Spec. Publ., vol. 17, pp. 10–11.

Demirtaşlı, E., Turhan, N., Bilgin, A.Z., Selim, M., 1984. Geology of the Bolkar Mountains. In: Tekeli, O., Göncüğlü, M.C. (Eds.), Geology of the Taurus Belt. Proc. Int. Symp. on the Geology of the Taurus Belt, Ankara, Turkey. Mineral Resources and Exploration Institute of Turkey, Ankara, pp. 12–141.

Dercourt, J., Zonenshain, L.P., Ricou, L.E., Kazmin, V.G., Le Pichon, X., Knipper, A.L., Grandjacquet, C., Sbortshhikov, I.M., Geyssant, J., Lepvrier, C., Perchersky, D.H., Boulin, J., Sibuet, J.-C., Savostin, L.A., Sorokhtin, O., Westphal, M., Bazhrnov, M.L., Lauer, J.-P., Biju-Duval, B., 1986. Geological evolution of the Tethys belt from the Atlantic to the Pamirs since the Lias. Tectonophysics 123, 241–315.

Dercourt, J., Ricou, L.E., Vrielynck, B. (Eds.), 1992. Atlas Tethys Paleoenvironmental Maps, Beicip-Franlab.

Desmurs, L., Manatschal, G., Bernoulli, D., The Steinmann trinity revisited: mantle exhumation and magmatism along an oceanic-continent transition: the Platta nappe, eastern Switzerland, D., 2001. In: Wilson, R.C.L., Whitmarsh, R.B., Taylor, B., Froitzheim, N. (Eds.), Non-Volcanic Rifting of Continental Margins: A Comparison of Evidence from Land and Sea. Spec. Pub. Geol. Soc. London 187, pp. 235–266.

Dick, H.J.B., Bullen, T., 1984. Chrominum spinel as a petrogenetic indicator in abyssal and alpine-type peridotites and spatially associated lavas. Contrib. Mineral. Petrol. 86, 54–76.

Dick, H.J.B., Natland, J.H., Miller, D.J., et al., 1999. Proc. Ocean Drill. Program: Initial Rep. Ocean Drilling Program, College Station, TX, vol. 176.

Dietrich, D., Spencer, S., 1993. Spreading-induced faulting and fracturing of oceanic crust: examples from the Sheeted Dyke Complex of the Troodos ophiolite, Cyprus. In: Prichard, H.M., Alabaster, T., Harris, N.B., Neary, C.R. (Eds.), Magmatic Processes and Plate Tectonics. Geol. Soc. London, Spec. Publ., vol. 76, pp. 121–139.

Dietrich, V.G., Gansser, A., Sommeraurer, J., Mameron, W.E., 1981. Paleogene komatiites from Gorgona Island, East Pacific—a primary magma for ocean floor basalts? Geochem. J. 15, 141–161.

Dilek, Y., 1998. Structure and tectonics of intermediate-spread oceanic crust drilled at DSDP/ODP Holes 504B and 89A, Costa Rica Rift. In: Cramp, A., MacLeod, C.J., Lee, S.V., Jones, E.W.J. (Eds.), Geological Evolution of Ocean Basins: Results from the Ocean Drilling Program. Geol. Soc. London, Spec. Publ., vol. 131, pp. 179–197.

Dilek, Y., Rowland, J.C., 1993. Evolution of a conjugate passive margin pair in the Mesozoic Antalya Complex, southern Turkey. Tectonics 11, 954–970.

Dilek, Y., Thy, P., 1998. Structure, petrology and seafloor spreading tectonics of the Kızıldağ, Ophiolite, Turkey. In: Mills, R.A., Harrison, K. (Eds.), Modern Ocean Floor Processes and the Geological Record. Geol. Soc. London, Spec. Publ., vol. 148, pp. 43–69.

Dilek, Y., Whitney, D.L., 1997. Counterclockwise P-T-t trajectory from the metamorphic sole of a Neo-Tethyan ophiolite (Turkey). Tectonophysics 280, 295–310.

Dilek, Y., Furnes, H., Skjerlie, K.P., 1997. Propagating rift tectonics of the Caledonian marginal basin: multi-stage seafloor spreading history of the Solund–Stavfjord ophiolite in western Norway. Tectonophysics 280, 213–238.

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. Geol. Soc. Amer. Bull. 111, 1192–1216.

Dilek, V., Furnes, H., Shallo, M., Mortensen, J.K., 2001. Structure, petrology and geochronology of the Albanian ophiolites and their tectonic evolution within the Neotethyan orogenic belt. J. Conf. Abstr. (EUG X1) 6, 321.

Dimitriadis, S., Asvesta, A., 1993. Sedimentation and magmatism related to the Triassic rifting and later events in the Vardar–Axios Zone. Bull. Geol. Soc. Greece 28 (2), 149–168.

Dimo, A., Vergély, P., Monie, P., 1999. Genesis of metamorphic rocks in the Albanian ophiolites. J. Conf. Abstr. 4, 406 EUG 10, Strasbourg.

Dixon, J.E., Dimitriadis, S., 1984. Metamorphosed ophiolitic rocks from the Serbo-Macedonian Massif near Lake Volvi, north–east Greece. In: Dixon, J.E., Robertson, A.H.F. (Eds.), The Geological Evolution of the Eastern Mediterranean. Geol. Soc. London, Spec. Publ., vol. 17, pp. 603–618.

Dixon, J.E., Robertson, A.H.F., 1985. Asymmetrical ridge-collapse models for genesis of arc-type magmas in ophiolites. Terra Cogn. 5, 127.

Dixon, J.E., Robertson, A.H.F., 1993. Arc signatures in Mediterranean Triassic rift basalts: a lithosphere-hosted inheritance from Hercynian subduction. Terra Abstr. 5, 424.

Dixon, J.E., Robertson, A.H.F., 1999. Are multiple plumes implicated in the Triassic break-up of the Gondwanan margin in the Eastern Mediterranean region? J. Conf. Abstr., EUG 10, 314.

Donnelly, T.W., Melson, W., Kay, R., Rogers, J.J.W., 1973. Basalts and dolerites of late Cretaceous age the central Caribbean. Initial Rep. Deep Sea Drill. Proj. 15, 989–1012.

Doutsos, R., Pe-Piper, G., Boronkay, K., Koukouvelas, I., 1993. Kinematics of the Central Hellenides. Tectonics 12 (4), 936–953.

Dvorkin, J., Nur, A., Mavko, G., Ben-Avraham, Z., 1993. Narrow subducting slabs and the origin of backarc basins. Tectonophysics 227, 63–79.

Elitok, Ö., 2001. Geochemistry and tectonic significance of the Kızıldağ ophiolite in the Beyşehir–Hoyran nappes, S.W. Turkey. 4th Internat. Symp. Eastern Mediterranean Geol., vol. 63 Suleyman Demirel University, Isparta, Turkey, p. 21. Abstract.

Erendil, M., 1984. Petrology and structure of the upper crustal units of the Kızıldağ ophiolite. In: Tekeli, O., Göncüoğlü, C.M. (Eds.), Geology of the Taurus Belt, Proceedings. Mineral Research and Exploration Institute, Turkey, pp. 269–284. Andara.

Falloon, J.T., Green, D.H., Crawford, A.J., 1987. Dredged igneous rocks from the northern termination of the Tofua magmatic arc, Tonga and adjacent Lau Basin. Aust. J. Earth Sci. 34, 487–506.

Fisk, M.R., 1990. Back-arc volcanism in the Bransfield Straits, Antartica. J. South Am. Earth Sci. 3, 91–101.

Floyd, P.A., 1993. Geochemical discrimination and petrogenesis of alkalic basalt sequences in part of the Ankara melange, central Turkey. J. Geol. Soc. London 150, 541–550.

Floyd, P.A., Yalınız, M.K., Göncüoğlü, M.C., 1998. Geochemistry and petrogenesis of intrusive and extrusive ophiolitic plagiogranites, Central Anatolian Crystalline Complex, Turkey. Lithos 42, 225–241.

Floyd, P.A., Winchester, J.A., Göncüoğlü, M.C., Yalınız, M.K., Parlak, O., 1999. Geochemical overview of relationships of metabasites from the Central Anatolian Crystalline Complex-Third International Turkish Geology Symposium Middle East Technical University, Ankara, Turkey, p. 171. Abstract.

Floyd, P.A., Göncüoğlü, M.C., Winchester, J.A., Yalınız, M.K., 2000. Geochemical character and tectonic environment of Neotethyan ophiolitic fragments and metabasites in the Central Anatolian Crystalline Complex, Turkey. In: Bozkurt, E., Winchester, J.A., Piper, J.D. (Eds.), Tectonics and Magmatism in Turkey and the Surrounding Area. Geol. Soc. London, Spec. Publ., vol. 173, pp. 183–202.

Floyd, P.A., Özgül, L., Göncüoğlü, M.C., Yalınız, M.K., Winchester, J.A., 2001. Konya HP belt metabasites: aspects of petrology and geochemistry. Fourth Internat. Turkish Geol. Symp. (ITGS IV), p. 95. Abstract.

Fourcade, E., Dercourt, J., Gunay, Y., Azema, J., Közlü, H., Bellier, J.P., Cordey, J.P., Cros, F., De Wever, P., Enay, P., Hernandez, R., Lauer, J., Vrielynck, B., 1991. Stratigraphie et paléogéographie de la marge septentrionale de la plat-forme arabe au Mesozoique (Turquie de Sud-East). Bull. Soc. Géol. Fr. 161 (1), 27–41.

Furnes, H., Skjerlie, K.P., Pederson, R.B., Anderson, T.S., Stillman, C.J., Suthren, R., Tysseland, M., Garmann, L.B., 1990. The Solund–Stravfjord Ophiolite Complex and associated rocks, west Norwegian Caledonides: geology, geochemistry and tectonic environment. Geol. Mag. 127, 209–289.

Garfunkel, Z., 1998. Constraints on the origin and history of the Eastern Mediterranean basin. Tectonophysics 298, 5–37.

Gass, I.G., 1968. Is the Troodos Massif of Cyprus a fragment of Mesozoic oceanic floor? Nature 220, 39–42.

Gass, I.G., 1990. Ophiolites and oceanic lithosphere. In: Malpas, J., Moores, E.M., Panayiotou, A., Xenophontos, C. (Eds.), Ophiolites Oceanic Crustal Analogues. Proc. Symp. 'Troodos 1987'. Cyprus Geological Survey Department, Nicosia, pp. 1–12.

Gass, I.G., Masson-Smith, D., 1963. The geology and gravity anomalies of the Troodos Massif, Cyprus. Philos. Trans. R. Soc. Lond. A255, 417–467.

Glennie, K.W., Hughes Clarke, M.W., Boef, M.W., Pilaar, M.G.H., Reinhardt, B., 1990. Inter-relationship of the Makran–Oman Mountains belts of convergence. In: Robertson, A.H.F., Searle, M.P., Ries, A.C. (Eds.), The Geology and Tectonics of the Oman Region. Geol. Soc. Spec. Publ., vol. 49, pp. 773–787.

Gnos, E., Peters, T.J., 1993. K–Ar ages of the metamorphic sole of the Semail ophiolite: implications for ophiolite cooling history. Contrib. Mineral. Petrol. 113, 325–332.

Göncüoğlü, C.M., 1990. Subophiolitic metamorphics in the Kutahya–Bolkardağ Belt, northern margin of the Menderes massif, N.W. Anatolia. Ofioliti 15, 340–345.

Göncüoğlü, C.M., Direk, K., Kozlu, H., 1996–1997. Pre-alpine and alpine terranes in Turkey: explanatory notes to the terrane map of Turkey. Ann. Geol. Pays Héll. 37, 1–3.

Göncüoğlü, C.M., Turhan, N., Şentürk, K., Ozcan, A., Üysal, S., 2000. A geotraverse acrosss NW Turkey: tectonic units of the Central Sakarya region and their tectonic evolution. In: Bozkurt, E., Winchester, J.A., Piper, J.D. (Eds.), Tectonics and Magmatism in Turkey and the Surrounding Area. Geol. Soc. London, Spec. Publ., vol. 173, pp. 139–162.

Göncüoğlü, M.C., Yalınız, M.K., Tekin, U.K., Turhan, N., 2001. Petrology of late Berriasian–late Hauterivian and Conomanian oceanic basalts within the Central Sakarya ophiolitic complex, N.W. Turkey: constraints for the evolution of the İzmir–Ankara oceanic branch of Neotethys. Fourth Internat. Turkish Geol. Symp. (ITGS IV), p. 93. Abstract.

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. Geol. Soc. Spec. Publ., vol. 17, pp. 81–96.

Haenel-Remy, S., Bébien, J., 1985. The Oreokastro ophiolite (Greek Macedonia). An important component of the Innermost Hellenic Ophiolite Belt. Ofioliti 10, 279–296.

Hall, R., 1976. Ophiolite emplacement and the evolution of the Taurus suture zone, south–east Turkey. Bull. Geol. Soc. Am. 87, 1078–1088.

Hall, R., 1984. Ophiolites: figments of ophiolitic lithosphere. In: Gass, I.G., Lippard, S.J., Shelton, A.W. (Eds.), Ophiolites and Oceanic Lithosphere. Geol. Soc. London, Spec. Publ., vol. 13, pp. 393–404.

Harland, W.B., Cox, A.V., Llewellyn, P.G., Picton, C.A.G., Smith, A.G., Watters, A.R., 1989. A Geological Time Scale Cambridge Univ. Press, New York 128 pp.

Harper, G.D., 1984. The Josephine ophiolite, northwestern California. Geol. Soc. Amer. Bull. 95, 1009–1026.

Harris, N.B.W., Kelley, S.P., Okay, A.I., 1994. Post collision magmatism and tectonics of northwestern Turkey. Contrib. Mineral. Petrol. 117, 241–252.

Hatzipanagiotou, K., Pe-Piper, G., 1995. Ophiolitic and subophiolitc metamorphic rocks of the Vatera area, southern Lesbos (Greece): petrology and geochronology. Ofioliti 20 (1), 17–29.

Hawkins, J.W., 1995. Evolution of the Lau Basin—Insights from ODP Leg 135. In: Taylor, B., Natland, J. (Eds.), Active Margins and Marginal Basins of the Western Pacific. Am. Geophys. Union Monogr., vol. 88, pp. 125–174.

Haydoutov, I., Yanev, S., 1997. The Protomoesian microcontinent of the Balkan Peninsula—a peri-Gondwanaland piece. Tectonophysics 272, 303–313.

Haymon, R.M., Fornari, D.J., Edwards, M.H., Carbotte, S., Wright, D., Macdonald, K.C., 1991. Hydrothermal vent distribution along the East Pacific Rise crest (9°09′–54′N) and its relationship to magmatic and tectonic processes on fast-spreading mid-ocean ridges. Earth Planet. Sci. Lett. 104, 513–534.

Hékinian, R., Bideau, D., Franchetaux, J., Lonsdale, P., Blum, N., 1993. Petrology of the East Pacific Rise crust and upper mantle exposed in the Hess Deep (eastern equatorial Pacific). Earth Planet. Sci. Lett. 101, 281–295.

Hirsch, F., Flexer, A., Rosenfeld, A., Yellin-Dror, A., 1995. Palinspastic and crustal setting of the Eastern Mediterranean. J. Pet. Geol. 18, 149–170.

Hoeck, V., Koller, F., Meisel, T., Onuzi, K., Gjata, K., Kneringer, E., 2002. The South Albanian ophiolites: MOR versus SSZ ophiolites. Lithos 65, 143–164, this volume.

Hopson, C.A., Coleman, R.G., Gregory, R.T., Pallister, J.S., Bailey, E.H., 1981. Geologic section through the Semail and associated rocks along a Muscat–Ibra transect, Southeastern Oman Mountains. J. Geophys. Res. 86, 227–244.

Humphris, S.E., Herzig, P.M., Miller, J., et al., 1994. TAG area, Mid-Atlantic Ridge. Proc. Ocean Drill. Program: Initial Rep., 158.

Immenhauser, A., 1996. Cretaceous sedimentary rocks on the Masirah ophiolite (Sultanate of Oman): evidence for an unusual bathymetric history. J. Geol. Soc. London 153, 539–551.

Irving, E., 1982. Fragmentation and assembly of the continents. Mid-Carboniferous to present. Geophys. Surv. 5, 299–333.

Ishii, T., 1985. Dredged samples from the Ogasawara forearc seamount of 'Ogsawara Paleoland'-forearc phiolite. In: Nasu, M. (Ed.), Formation of Active Ocean Margins. Terrapub, Tokyo, pp. 307–342.

Ivan, P., Méres, S., Hovorka, D., 1994. Oceanic crust in geological history of the Western Carpathian orogeny. Acta Geol. Hung. 37, 19–32.

Jaffey, N., Robertson, A.H.F., 2001. New sedimentological and structural data from the Ecemis Fault Zone, southern Turkey; implications for its timing and offset and the Cenozoic tectonic escape of Anatolia. J. Geol. Soc. London 18, 367–378.

Jenner, G.A., Dunning, G.R., Malpas, J., Brown, M., Brace, T., 1991. Bay of Islands and Little Port complexes, revisited: age, geochechemical and isotopic evidence confirm supra-subduction zone origin. Can. J. Earth Sci. 28, 135–162.

Jones, G., Robertson, A.H.F., 1991. Tectono-stratigraphy and evolution of the Mesozoic Pindos Ophiolite and related units, Northwestern Greece. J. Geol. Soc. London 148, 267–288.

Jones, G., Robertson, A., 1994. Rift–drift-subduction and emplacement history of the early Mesozoic Pindos ocean: evidence from the Avdella Melange, Northern Greece. Bull. Geol. Soc. Greece XXX/2, 45–58.

Jones, G., Robertson, A.H.F., Cann, J.R., 1991. Genesis and emplacement of the supra-subduction zone Pindos ophiolite, northwestern Greece. In: Peters, T.J., Nicholas, A., Coleman, R.G. (Eds.), Ophiolite Genesis and Evolution of the Oceanic Lithosphere. Kluwer Academic Publishing, Dordrecht, pp. 771–799.

Jung, G., Mussallam, K., 1985. The Sithonia ophiolite: a fossil oceanic crust. Ofioliti 10, 329–342.

Jung, G., Mussallam, K., Burgath, K., Kockel, F., Mohr, M., Raschka, H., 1980. Ulramafic and related rocks of Chalkidiki. Proc. Internat. Symp. Metals in Mafic and Ultramafic Complexes, vol. 3. Inst. Geol. Mining Research, Athens, Greece, pp. 24–42.

Juteau, T., 1970. Petrogenèse des Ophiolites des Nappes D'Antalya (Taurus Lycien Oriental). Leur liaison avec une phase d'expansion oceanique active au Trias supérieur. Mém. Sci. Terre 15, 25–288.

Juteau, T., 1980. Ophiolites of Turkey. Ofioliti 2, 199–237.

Juteau, T., Nicolas, A., Dubessy, J., Fruchard, J.C., Bouchez, J.L., 1977. Structural relationships in the Antalya ophiolite complex, Turkey: possible model for an oceanic ridge. Bull. Geol. Soc. Am. 88, 1740–1748.

Karamata, S., Majer, V., Pamić, J., 1980. Ophiolites of Yugoslavia. Tethyan Ophiolites. Ofioliti, vol. 1, pp. 105–125. Western Area.

Karson, J.A., 1998. Internal structure of oceanic lithosphere: a perspective from tectonic windows. In: Buck, W.R., Delaney, P.T., Karson, J.A., Lagabrielle, Y. (Eds.), Faulting and Magmatism at Mid-Ocean Ridges. Am. Geophys. Union, vol. 106, pp. 177–218.

Kerr, A.C., Tarney, J., Marriner, G.F., Nivia, A., Saunders, A.D., 1997. The Caribbean–Colombian Cretaceous Igneous Province: the internal anatomy of an oceanic plateau. In: Mahoney, J.J., Coffin, M.F. (Eds.), Large Igneous Provinces. Geophys. Monogr., vol. 100. Am. Geophys. Union, Washington, DC, pp. 123–144.

Kissel, C., Poisson, A., 1986. Etude paléomagnetique preliminaire des formations Néogene du bassin d'Antalya (Taurus occidentales–Turquie). C.R. Acad. Sci. Paris, 302. Ser. 11 (10), 711–716.

Koçyğit, A., 1991. An example of an accretionary forearc basin from North Central Anatolia and its implications for the history of subduction of Neo-Tethys in Turkey. Bull. Geol. Soc. Am. 103, 22–36.

Koçyğit, A., Ozkan, S., Rojay, B., 1998. Examples from the forearc basin remnants at the active margin of the Northern Neo-Tethys: developments and emplacement ages of the Anatolian Nappe. Middle East Tech. Univ. J. Pure Appl. Sci. A21, 211–283.

Koepke, J., Seidel, E., Kreuzer, H., 2002. Ophiolites on the southern Aegean Islands, Crete, Karpathos and Rhodes. Lithos 65, 183–204, this volume.

Kostopoulos, D., 1989. Geochemistry and tectonic setting of the Pindos Ophiolite, northwest Greece. Unpublished PhD thesis, University of Newcastle-upon-Tyne, UK.

Kotopouli, C.N., Hatzipanagiotou, K., Tsikouras, B., 1989. Petrographic and geochemical characteristics of the ophiolitic rocks in Northern Samothrace, Greece. Geol. Balc. 19, 61–67.

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.

Lagabrielle, Y., 1994. Ophiolites of the southwestern Alps and

the structure of the Tethyan oceanic lithosphere. Ofioliti 19, 413–434.
Lagabrielle, Y., Cannat, M., 1990. Alpine Jurassic ophiolites resemble the modern central Atlantic basement. Geology 18, 319–322.
Lagabrielle, Y., Whitechurch, H., Marcoux, J., Juteau, T., Reuber, I., Guillocheau, F., Capan, U., 1986. Obduction-related ophiolitic polymict breccias covering ophiolites of Antalya (southwestern Turkey). Geology 14, 734–737.
Lanphere, M.A., Coleman, R.G., Karamata, S., Pamić, J., 1975. Age of amphibolites associated with Alpine peridotites in the Dinaride ophiolite zone, Yugoslavia. Earth Planet. Sci. Lett. 26, 271–276.
Lapierre, H., 1972. Les formations sédimentaires et éruptives des nappes de Mamonia et leurs rélations avec le massif de Troodos (Chypre), Thèse Doctoral, Univ. Nancy, France.
Lawver, L.A., Keller, R.A., Fisk, M.R., Strelin, J.A., 1995. Bransfield Strait, Antarctic Peninsula: active extension behind a dead arc. In: Taylor, B. (Ed.), Back Arc Basins: Tectonics and Magmatism Volume. Plenum, Amsterdam, pp. 315–342.
Lawver, L.A., Sloan, B.J., Barker, D.H.N., Ghidella, M., Von Hersenn, R.P., Keller, R.A., Klinkhammer, G.P., Chin, C.S., 1996. Distributed, active extension in Bransfield Basin, Antarctic Peninsula: evidence from multibeam bathymetry. GSA Today (Geological Society of America) 6 (11), 2–6.
Lippard, S.J., Shelton, A.W., Gass, I.G., 1986. The Ophiolite of Northern Oman. Mem. Geol. Soc. Lond. 11, 178.
Lytwyn, J.N., Casey, J.F., 1993. The geochemistry and petrogenesis of volcanics and sheeted dikes from the Hatay (Kızıldağ) Ophiolite, southern Turkey: possible formation with the Troodos Ophiolite, Cyprus, along fore-arc spreading centres. Tectonophysics 232, 237–272.
Lytwyn, J.N., Casey, J.F., 1995. The geochemistry of post-kinematic mafic dike swarms and subophiolitic metabasites, Pozantı–Karsantı ophiolite, Turkey: evidence for ridge subduction. Geol. Soc. Amer. Bull. 107, 830–850.
MacLeod, C.J., Murton, B.J., 1993. Structure and tectonic evolution of the Southern Troodos Transform Fault Zone, Cyprus. In: Prichard, H.M., Alabaster, T., Harris, N.B.W., Neary, C.R. (Eds.), Magmatic Processes and Plate Tectonics. Geol. Soc. London, Spec. Publ., vol. 76, pp. 141–176.
MacLeod, C.J., Murton, B.J., 1995. On the sense of slip of the Southern Troodos transform fault zone, Cyprus. Geology 23, 257–260.
MacLeod, C.J., Célérier, B., Früh-Green, G.L., Manning, C.E., 1996. The tectonics of Hess Deep: a synthesis of drilling results from Leg 147. In: Mével, C., Gillis, K.M, Meyer, P., et al. (Eds.), Proc. Ocean Drill. Program: Sci. Results. Ocean Drilling Program, College Station, TX, pp. 461–474.
Magganas, A.C., 2002. Constraints on the petrogenesis of Evros ophiolite extrusives, NE Greece. Lithos 65, 165–182 (this volume).
Mahoney, J.J., Coffin, M.F., 1997. Large igneous provinces: continental, oceanic and planetary flood volcanism. Geophys. Monogr. 100, 438 Am. Geophys. Union (Washington, DC).
Mahoney, J.J., Storey, M., Duncan, R.A., Spencer, J.J., Pringle, M., 1993. Geochemistry and age of the Ontong Java Plateau. In: Pringle, M.S., Sager, W.W., Sliter, W.V., Stein, S. (Eds.), The Mesozoic Pacific: Geology, Tectonics and Volcanism. Geophys. Monogr., vol. 77. Am. Geophys. Union, Washington, DC, pp. 233–262.
Makris, J., Ben-Avraham, Z., Behle, A., Ginsburg, A., Giese, P., Steinmetz, L., Whitmarsh, R.B., Eleftheriou, S., 1983. Seismic refraction profiles between Cyprus and Israel and their interpretation. Geophys. J. R. Astron. Soc. 75, 575–591.
Malinverno, A., Ryan, W.B.F., 1986. Extension in the Tyrrhenian Sea and shortening of the Apennines as a result of arc migration driven by sinking of the lithosphere. Tectonics 5, 227–245.
Malpas, J., Robinson, P.T., 1990. Regional tectonics of the eastern Mediterranean ophiolites. In: Malpas, J., Moores, E.M., Panayiotou, A., Xenophontos, C. (Eds.), Ophiolites, Oceanic Crustal Analogues. Geological Survey Department, Nicosia, Cyprus, pp. 295–309.
Malpas, J., Xenophontos, C., Williams, D., 1992. The Ayia Varvara Formation of S.W. Cyprus, a product of complex collisional tectonics. Tectonophysics 212, 193–211.
Malpas, J., Calon, T., Squires, G., 1993. The development of a Late Cretaceous microplate suture zone in S.W. Cyprus. In: Prichard, H.M., Alabaster, T., Harris, N.B.W., Neary, C.R. (Eds.), Magmatic Processes and Plate Tectonics. Geol. Soc. London, Spec. Publ., vol. 76, pp. 177–196.
Manika, K., Shallo, M., Grega, D., 1997. The plutonic sequence of Shebenik ophiolitic complex. Albania: evidence for dual magmatism. Ofioliti 22, 93–99.
Marcoux, J., 1995. Initiation of the south-Neotethys margin in the Antalya nappes (SW Turkey): Late Permian and Early Mid-Triassic rifting events, late Mid Triassic oceanization. EUG Abstr. 175, p. 175.
Marcucci, M., Kodra, A., Pirdeni, A., Gjata, Th., 1994. Radiolarian assemblage in the Triassic and Jurassic cherts of Albania. Ofioliti 19, 105–115.
Mascle, J., Lohmann, G.P., Clift, P.D., et al., 1996. Proc. Ocean Drill. Program: Initial Rep., 159 College Station TX (Ocean Drilling Program).
Mercier, J., 1966. I—Etudes géologique des zones internes des Hellénides en Macédoine centrale (Grèce), II—Contribution à l'étude du métamorphisme et de l'évolution magmatiques des zones internes des Hellénides. Thèse Doct. Ès Sciences, Univ. Paris. Ann. Géol. Pays Helléniques, 20, 792.
Mercier, J., Vergely, P., Bébien, J., 1975. Les ophiolites héllenique 'obductés' au Jurassique supérieur son-elles les vestiges d'un océan tethysien ou d'une mer marginale peri-européenne? Bull. Soc. Géol. Fr. 17, 108–112.
Michard, A., Whitechurch, H., Ricou, L.E., Montigny, R., Yazgan, E., 1984. Tauric subduction (Malatya–Elaziğ provinces) and its bearing on tectonics of the Tethyan realm in Turkey. In: Dixon, J.E., Robertson, A.H.F. (Eds.), The Geological Evolution of the Eastern Mediterranean. Geol. Soc. London, Spec. Publ., vol. 17, pp. 349–360.
Monod, O., 1977. Récherches géologique dans les Taurus occidental au sud de Beyşehir (Turquie). [Thèse de Doct. Sci.,] Univ. Paris-Sud, Orsay.
Monod, O., Okay, A.I., 1999. Late Triassic Paleo-Tethyan Subduction: evidence from Triassic blueschists. European Union of Earth Sciences, 10. J. Conf. Abstr. 4, 315.

Moores, E.M., 1969. Petrology and structure of the Vourinos ophiolitic complex of northern Greece. Spec. Pap.—Geol. Soc. Am., 118.

Moores, E.M., Kellog, L.K., 1999. Eastern Mediterranean ophiolites, tectonics and mantle convection. J. Conf. Abstr., EUG 10, 406.

Moores, E.M., Vine, F.J., 1971. The Troodos Massif, Cyprus and other ophiolites as oceanic crust: evaluations and implications. Philos. Trans. R. Soc., A 268, 433–466.

Moores, E.M., Robinson, P.T., Malpas, J., Xenophontos, C., 1984. A model for the origin of the Troodos Massif, Cyprus and other mideast ophiolites. Geology 12, 500–503.

Morris, A., Robertson, A.H.F., 1993. Miocene remagnetism of carbonate platform and Antalya Complex units within the Isparta Angle, south west Turkey. Tectonophysics 220, 243–266.

Morris, A., Creer, K.M., Robertson, A.H.F., 1990. Palaeomagnetic evidence for clockwise rotations related to dextral shear along the Southern Troodos Transform Fault (Cyprus). Earth Planet. Sci. Lett. 99, 250–262.

Morris, A., Anderson, M., Al-Riyami, K., Robertson, A.H.F., Dixon, J.E., 1999. First palalaeomagnetic results from the Baer–Bassit ophiolite of N Syria. J. Conf. Abstr., EUG 10, 407.

Müntner, O., Hermann, J., 2001. The role of the lower crust and continental upper mantle during formation of non-volcanic passive continental margins: evidence from the Alps. In: Wilson, R.C.L., Whitmarsh, R.B., Taylor, B., Froitzheim, N. (Eds.), Non-Volcanic Rifting of Continental Margins: a Comparison of Evidence from Land and Sea. Spec. Pub. Geol. Soc. London 187, 267–288.

Mukasa, S.B., Ludden, J.N., 1987. Uranium–lead ages of plagiogranites from the Troodos ophiolite, Cyprus, and their tectonic significance. Geology 1, 82–828.

Mukhin, P., 1996. The metamorphosed olistostromes and turbidites of Andros Island, Greece and their tectonic significance. Geol. Mag. 133 (6), 697–711.

Murton, B.J., Peate, D.W., Aculus, R.J., Pearce, J.A., van der Laan, S., 1992. Trace-element geochemistry of volcanic rocks from Site 786 (Leg 125): the Izu–Bonin forearc. In: Pearce, J.A., Fryer, P., et al. (Eds.), Proc. Ocean Drill. Program: Sci. Results, vol. 125 ODP, College Station, TX, pp. 211–236.

Mussallam, K., 1991. Geology, geochemistry and the evolution of an oceanic lithosphere rift at Sithonia, NE Greece. In: Peters, T., Nicholas, A., Coleman, R.G. (Eds.), Ophiolite Genesis and Evolution of Oceanic Lithosphere. Kluwer Academic Publishing, Dordrecht, pp. 685–704.

Mussallam, K., Jung, D., 1986. Petrology and geotectonic significance of salic rocks preceeding ophiolites in the eastern Vardar Zone, Greece. Tschermak's Mineral. Petrogr. Mitt. 35, 217–242.

Natland, J.H., Dick, H.B.J., 1996. Melt migration through high-level gabbroic cumulates of the East Pacific Rise at Hess Deep: the origin of magma lenses and the deep crustal structure of fast-spreading ridges. In: Mével, C., Gillis, K.M., Meyer, P. (Eds.), Proc. Ocean Drill. Program: Sci. Results, vol. 147. Ocean Drilling Program, College Station, TX, pp. 21–58.

Natland, J.H., Tarney, J., 1981. Petrologic evolution of the Mariana arc and back-arc system—a synthesis of drilling results in the southern Philippine Sea. Initial Rep. Deep Sea Drill. Proj. 60, 579–599. Washington DC, US Government Printing Office.

Neubauer, F., Frisch, W., Schmerold, R., Schlöser, H., 1989. Metamorphosed and dismembered ophiolite suites in the basement units of the Eastern Alps. Tectonophysics 164, 49–62.

Nicolas, A., 1989. Structures of ophiolites and dynamics of oceanic lithosphere. Series in Petrology and Structural Geology, vol. 4. Kluwer Academic Publishing, Dordrecht, p. 367.

Nicolas, A., Boudier, F., 1999. Slow spread accretion and mantle denudation in the Mirdita ophiolite (Albania). J. Geophys. Res., 15155–15167.

Nicolas, A., Le Pichon, Z., 1980. Thrusting of young lithosphere in subduction zones with special reference to the structures in ophiolite peridotites. Earth Planet. Sci. Lett. 46, 397–406.

Nicolas, A., Boudier, F., Ildefonse, B., 1994. Evidence from the Oman ophiolite for active mantle upwelling beneath a fast-spreading ridge. Nature 370, 51–53.

Noiret, G., Montigny, R., Allegre, C.J., 1981. Is the Vourinos complex an island arc ophiolite? Earth Planet. Sci. Lett., 375–386.

Norman, T.N., 1984. The role of the Ankara Melange in the development of Anatolia (Turkey). In: Dixon, J.E., Robertson, A.H.F. (Eds.), The Geological Evolution of the Eastern Mediterranean. Geol. Soc. London, Spec. Publ., vol. 17, pp. 441–448.

Okay, A.I., 1986. High-pressure/low-temperature metamorphic rocks of Turkey. Mem. Geol. Soc. Amer. 164, 333–347.

Okay, A.I., 1989. Alpine–Himalayan Blueschists. Annu. Rev. Earth Planet. Sci. 17, 55–87.

Okay, A.I., 2000. Was the late Triassic orogeny in Turkey caused by the collision of an oceanic plateau? In: Bozkurt, E., Winchester, J.A., Piper, J.D. (Eds.), Tectonics and Magmatism in Turkey and the Surrounding Area. Geol. Soc. London, Spec. Publ., vol. 173, pp. 25–42.

Okay, A.I., Monie, P., 1997. Early Mesozoic subduction in the Eastern Mediterranean: evidence from the Triassic eclogite in northwest Turkey. Geology 25, 595–598.

Okay, A.I., Şahintürk, O., 1997. Geology of the Eastern Pontides. In: Robinson, A. (Ed.), Regional and Petroleum Geology of the Black Sea and Surrounding Region. Am. Assoc. Pet. Geol. Mem., vol. 68, pp. 291–311.

Okay, A.I., Siyako, M., Burkan, K.A., 1991. Geology and Tectonic Evolution of the Biga Peninsula, Northwest Turkey. Bull. Tech. Univ. Istanb. 44, 191–256.

Okay, A.I., Satir, M., Maluski, H., Siyako, M., Monie, P., Metzger, R., Akyuz, S., 1996. Paleo- and Neo-Tethyan events in northwest Turkey: geological and geochronological constraints. In: Yin, A., Harrison, M. (Eds.), Tectonics of Asia. Cambridge Univ. Press, pp. 420–441.

Okay, A.I., Tansel, I., Tüysüz, O., 2001. Obduction, subduction and collision as reflected in the Upper Cretaceous–Lower Tertiary sedimentary record of western Turkey. Geol. Mag. 138, 117–142.

Okrusch, M., Seidel, E., Kreuzer, H., Harre, W., 1978. Jurassic age of metamorphism at the base of the Brecovica peridotite (Yougoslavia). Earth Planet. Sci. Lett. 39, 291–297.

Önen, A.P., Hall, R., 1993. Ophiolites and related metamorphic rocks from the Kutahya region, north–west Turkey. Geol. J. 28, 399–412.

Özgül, N., 1976. Toroslarin bazi temel jeoloji ozellikleri. Turk. Jeol. Kurumu Bul. 19, 65–78.

Özgül, N., 1984. Stratigraphy and tectonic evolution of the central Taurides. In: Tekeli, O., Göncüoğlü, M.C. (Eds.), Geology of the Taurus Belt. MTA, Ankara, pp. 77–90.

Özgül, N., 1997. Stratigraphy of the tectono-stratigraphic units in the region Bozkir–Hadim–Taskent (northern central Taurides) (in Turkish). Maden Tetkik Arama Enst. Derg. 119, 113–174.

Pamić, J., 1984. Triassic magmatism of the Dinarides in Yugoslavia. Tectonophysics 109, 273–307.

Pamić, J., 1997. The northwesternmost outcrops of the Dinaridic ophiolites: a case study of Mt. Kalnik (North Croatia). Acta Geol. Hung. 40 (1), 37–56.

Pamić, J., Tomljenović, B., 2002. Ophiolites of the central and northwestern Dinarides. Lithos 65, 113–142 (this volume).

Papanikolaou, D.J., 1984. The three metamorphic belts of the Hellenides: a review and a kinematic interpretation. In: Dixon, J.E., Robertson, A.H.F. (Eds.), The Geological Evolution of the Eastern Mediterranean. Geol. Soc. London, Spec. Publ., vol. 17, pp. 551–562.

Papanikolaou, D., 1999. The Triassic ophiolites of Lesvos Island within the Cimmerian orogenic event. J. Conf. Abstr., EUG 10 (4), 315.

Parlak, O., Delaloye, M., 1999. Precise $^{40}Ar/^{39}Ar$ ages from the metamorphic sole of the Mersin ophiolite (southern Turkey). Tectonophysics 301, 145–158.

Parlak, O., Delaloye, M., Bingöl, E., 1995. Origin of sub-ophiolitic metamorphic rocks beneath the Mersin ophiolite, Southern Turkey. Ofioliti 20, 97–110.

Parlak, O., Delaloye, M., Bingöl, E., 1996a. Obduction direction of the Mersin ophiolite: structural evidence from the subophiolitic metamorphics in the central Taurus Belt, southern Turkey. Int. Geol. Rev. 38, 778–786.

Parlak, O., Delaloye, M., Bingöl, E., 1996b. Mineral chemistry of ultramafic and mafic cumulates as an indicator of the arc-related origin of the Mersin ophiolite (southern Turkey). Geol. Rundsch. 85, 647–661.

Parlak, O., Delaloye, M., Bingöl, E., 1996c. Geochemistry and mineralogy of post-metamorphic dike emplacement in the Mersin ophiolite (Southern Turkey): new age constraints from $^{40}Ar/^{39}Ar$ geochronology. Terra Nova 8, 585–592.

Parlak, O., Delaloye, M., Bingöl, E., 1997. Geochemistry of volcanic rocks in the eastern Mediterranean geology. In: Piskin, O., Erdun, M., Savaşçin, M.Y., Tarcan, M.Y. (Eds.), Proc. Int. Earth Sci. Colloq. Aegean Region, 9–14th October 1995. Döküz Eylul Univ., Izmir, pp. 441–463.

Parlak, O., Hoeck, V., Delaloye, M., 2000. Supra-subduction zone origin of the Pozantı–Karsantı ophiolite (S. Turkey) deduced from whole rock and mineral chemistry of the gabbro cumulates. In: Bozkurt, E., Winchester, J.A., Piper, J.D. (Eds.), Tectonics and Magmatism in Turkey and the Surrounding Area. Geol. Soc. London, Spec. Publ., vol. 173, pp. 219–234.

Parlak, O., Kozlu, H., Delaloye, M., Höck, V., 2001. Tectonic setting of the Yüsekova ophiolite and its relation to the Başkil magmatic arc within the southeast Anatolian orogeny. Fourth Internat. Turkish Geol. Symp., (ITGS IV). Döküz Eylul Univ., Izmir, p. 233. Abstract.

Parrot, J.-F., 1977. Assemblage ophiolitique de Baer–Bassit et termes éffusives du volcano–sedimentaire. Trav. Doc. ORSTOM 72, 333 pp.

Parson, L.M., Hawkins, J.W., 1994. Two-stage ridge propagation and the geological history of the Lau Backarc basin. Proc. Ocean Drill. Program: Sci. Results 135, 819–828.

Parson, L.M., Rothwell, R.G., MacLeod, C.J., 1994. Tectonics and sedimentation in the Lau Basin, Southwest Pacific. In: Hawkins, J.W., Parson, L.M., Allan, J.F., et al. (Eds.), Proc. Ocean Drill. Program: Sci. Results, vol. 135, pp. 9–21. College Station, TX.

Pearce, J.A., 1980. Geochemical evidence for the genesis and eruptive setting of lavas from Tethyan ophiolites. In: Panayiotou, A. (Ed.), Ophiolites: Proc. Int. Symp., Cyprus, 1979. Cyprus Geol. Survey Dept., Nicosia, pp. 261–272.

Pearce, J.A., Alabaster, T., Shelton, A.W., Searle, M.P., 1981. The Oman ophiolite as a Cretaceous arc-basin complex: evidence and implications. Philos. Trans. R. Soc. Lond., A. (Math Phys. Sci.) 300, 299–317.

Pearce, J.A., Lippard, S.J., Roberts, S., 1984. Characteristics and tectonic significance of supra-subduction zone ophiolites. In: Kokelaar, B.P., Howells, M.F. (Eds.), Marginal Basin Geology. Geol. Soc. London, Spec. Publ., vol. 16, pp. 77–89.

Pearce, J.A., van der Laan, S.R., Arculus, R.J., Murton, B.J., Ishii, T., Peate, D.W., Parkinson, U.J., 1992. Boninite and harzburgite from Leg 125 (Bonin–Mariana forearc): a case study of magma genesis during the initial stages of subduction. Proc. Ocean Drill. Program: Sci. Results 125, 623–632.

Pe-Piper, G., 1982. Geochemistry, tectonic setting and metamorphism of the mid-Triassic volcanic rocks of Greece. Tectonophysics 85, 23–272.

Pe-Piper, G., 1998. The nature of Triassic extension-related magmatism in Greece: evidence from Nd and Pb isotope geochemistry. Geol. Mag. 13, 331–348.

Perincek, D., 1979. The geology of Hazro–Korudağ–Cüngüs–Maden–Ergani–Hazar–Elaziğ–Malatya area. Spec. Publ. Geol. Soc. Turk. 33 pp.

Petterson, M.G., Babbs, T., Neal, C.R., Mahoney, J.J., Saunders, A.D., Duncan, R.A., Tolia, D., Mgu, R., Qopoto, C., Mahoa, H., Natogga, D., 1997. Geological-tectonic framework of Solomon Islands, SW Pacific: crustal accretion and growth within an intra-oceanic setting. Tectonophysics 283, 1–33.

Pickett, E.A., Allerton, S., 1998. Structural observations from the Côte D'Ivoire–Ghana transform margin. In: Mascle, J., Lohmann, G.P., Moullade, M. (Eds.), Proc. Ocean Drill. Program: Sci. Results, vol. 159, pp. 3–12.

Pickett, E.A., Robertson, A.H.F., 1996. Formation of the Late Palaeozoic–Early Mesozoic Karakaya Complex and related ophiolites in NW Turkey by Palaeotethyn subduction–accretion. J. Geol. Soc. London 153, 995–1009.

Pişkin, O., Delaloye, M., Wagner, J.-J., 1986. Guide to the Hatay geology. Ofioliti 11, 87–104.

Poisson, A., 1977. Récherches géologiques dans les Taurides occidentales, Turquie. [Thèse], Univ. Paris–Sud, Orsay, France.

Poisson, A., 1984. The extension of the Ionian trough into southwestern Turkey. In: Dixon, J.E., Robertson, A.H.F. (Eds.), Geological Evolution of the Eastern Mediterranean. Geol. Soc. London, Spec. Publ., vol. 17, pp. 241–250.

Polat, A., Casey, J.F., 1995. A structural record of the emplacement of the Pozantı–Karsantı ophiolite onto the Menderes–Taurus block in the Late Cretaceous, eastern Taurides, Turkey. J. Struct. Geol. 17, 1673–1688.

Polat, A., Casey, J.F., Kerrich, R., 1996. Geochemical characteristics of accreted material beneath the Pozantı–Karsantı ophiolite, Turkey: intra-oceanic detachment, assembly and obduction. Tectonophysics 263, 249–276.

Prela, M., Chiari, M., Marcucci, M., 2000. Jurassic radiolarian biostratigraphy of the sedimentary cover of ophiolites in the Mirdita area, Albania: new areas. Ofioliti 25, 55–62.

Rassios, A., Beccaluva, L., Bortolotti, V., Moores, E.M., 1983. The Vourinos ophiolite complex. Ofioliti 8, 275–292.

Rassios, A., Grivas, E., Konstantiopolou, G., Vacondios, I., 1994. The geometry of structures forming around the ductile–brittle transition in the Vourinos–Pindos–Othris oceanic slab. 7th Congress, Thessaloniki, 1994. Bull. Geol. Soc. Greece 30 (2), 109–121.

Remy, P., 1984. Mise en évidence d'un métamorphisme dynamothermal dans les sédiments au contact des ophiolites d'Oreokastro (Macédoine grecques). C. R. Acad. Sci., Paris 299, 27–30.

Reuber, I., 1984. Mylonitic ductile shear zones within tectonites and cumulates as evidence for an oceanic transform fault in the Antalya ophiolite, SW Turkey. In: Dixon, J.E., Robertson, A.H.F. (Eds.), The Geological Evolution of the Eastern Mediterranean. Geol. Soc. London, Spec. Publ., vol. 17, pp. 319–334.

Ricou, L.-E., Marcoux, J., Poisson, A., 1979. L'allochthonie des Bey Dağları orientaux, reconstruction palinspastique des Taurides occidentales. Bull. Soc. Géol. Fr. 21 (7), 125–134.

Ricou, L.-E., Marcoux, J., Whitechurch, H., 1984. The Mesozoic organisation of the Taurides: one or several oceanic basins. In: Dixon, J.E., Robertson, A.H.F. (Eds.), The Geological Evolution of the Eastern Mediterranean. Geol. Soc. London, Spec. Publ., vol. 17, pp. 349–360.

Rigo de Righi, M., Cortesini, A., 1964. Gravity tectonics in foothills structure belt of S.E. Turkey. Bull. Am. Assoc. Pet. Geol. 48, 1911–1937.

Robertson, A.H.F., 1977. Tertiary uplift history of the Troodos Massif, Cyprus. Bull. Geol. Soc. Am. 88, 1763–1772.

Robertson, A.H.F., 1986. Geochemistry and tectonic implications of metalliferous and volcaniclastic sedimentary rocks associated with late ophiolitic extrusives in the Hatay area, southern Turkey. Ofioliti 11, 121–140.

Robertson, A.H.F., 1990. Tectonic evolution of Cyprus. In: Malpas, J., Moores, E.M., Panayiotou, A., Xenophontos, C. (Eds.), Ophiolites Oceanic Crustal Analogues. Proc. Symp. 'Troodos 1987' Geological Survey Department, Cyprus, pp. 235–252.

Robertson, A.H.F., 1991. Origin and emplacement of an inferred Late Jurassic subduction–accretion complex, Eurboea, eastern Greece. Geol. Mag. 128, 27–41.

Robertson, A.H.F., 1993. Mesozoic–Tertiary sedimentary and tectonic evolution of Neotethyan carbonate platorms, margins and small ocean basins in the Antalya complex, S.W. Turkey. In: Frostick, L.E., Steel, R. (Eds.), Spec. Publ. Int. Assoc. Sedimentol., vol. 20, pp. 415–465.

Robertson, A.H.F., 1994. Role of the tectonic facies concept in orogenic analysis and its application to Tethys in the Eastern Mediterranean region. Earth-Sci. Rev. 37, 139–213.

Robertson, A.H.F., 1998. Mesozoic–Tertiary tectonic evolution of the Easternmost Mediterranean area; integration of marine and land evidence. In: Robertson, A.H.F., Emeis, K.C., Richter, K.-C., Camerlenghi, A. (Eds.), Proc. Ocean Drill. Program: Sci. Results, vol. 160, pp. 723–782.

Robertson, A.H.F., 2000. Mesozoic–Tertiary tectonic–sedimentary evolution of a south Tethyan oceanic basin and its margins in southern Turkey. In: Bozkurt, E., Winchester, J.A., Piper, J.D. (Eds.), Tectonics and Magmatism in Turkey and the Surrounding Area. Geol. Soc. London, Spec. Publ., vol. 173, pp. 43–82.

Robertson, A.H.F., Boyle, J.F., 1983. Tectonic setting and origin of metalliferous sediments from the Mesozoic Tethys ocean. In: Rona, P.A., et al. (Ed.), Hydrothermal Processes at Seafloor Spreading Centres. NATO Conf. Ser., Ser. IV: Mar. Sci., vol. 12, pp. 595–663.

Robertson, A., Degnan, P., 1998. Significance of modern and ancient oceanic Mn-rich hydrothermal sediments, exemplified by Jurassic Mn-cherts from southern Greece. In: Mills, R.A., Harrison, K. (Eds.), Modern Ocean Floor Processes and the Geological Record. Geol. Soc. London, Spec. Publ., vol. 148, pp. 217–240.

Robertson, A.H.F., Dixon, J.E., 1984. Introduction: aspects of the geological evolution of the Eastern Mediterranean. In: Dixon, J.E., Robertson, A.H.F. (Eds.), The Geological Evolution of the Eastern Mediterranean. Geol. Soc. London, Spec. Publ., vol. 17, pp. 1–74.

Robertson, A.H.F., Hudson, J.E., 1974. Pelagic sediments in the Cretaceous and Tertiary history of the Troodos Massif, Cyprus. In: Hsü, K.J., Jenkyns, H.C. (Eds.), Pelagic Sediments on Land and Under the Sea. Spec. Publ. Int. Assoc. Sedimentol., vol. 1, pp. 403–436.

Robertson, A.H.F., Karamata, S., 1994. The role of subduction–accretion processes in the tectonic evolution of the Mesozoic Tethys in Serbia. Tectonophysics 234, 73–94.

Robertson, A.H.F., Pickett, E.A., 2000. Palaeozoic–Early Tertiary evolution of melanges, rift and passive margin units in the Karaburun Peninsula (W Turkey) and Chios Island (Greece). In: Bozkurt, E., Winchester, J.A., Piper, J.D. (Eds.), Tectonics and Magmatism in Turkey and the Surrounding Area. Geol. Soc. London, Spec. Publ., vol. 173, pp. 42–82.

Robertson, A., Shallo, M., 2000. Mesozoic–Tertiary tectonic evolution of Albania in its regional Eastern Mediterranean context. Tectonophysics 316, 197–214.

Robertson, A.H.F., Varnavas, S.P., 1993. The origin of hydrothermal metalliferous sediments associated with the Early Mesozoic Othris and Pindos ophiolites, mainland Greece. Sediment. Geol. 83, 87–113.

Robertson, A.H.F., Waldron, J.W.F., 1990. Geochemistry and tectonic setting of Late Triassic and Late Jurassic–Early Cretaceous basaltic extrusives from the Antalya Complex, SW Turkey. Savaşçin, M.Y., Eronat, A.H. (Eds.), Proc. Internat. Earth Sciences Congress on Aegean Regions, vol. 2. Döküz Eylul Univ., Izmir, pp. 279–299.

Robertson, A.H.F., Woodcock, N.H., 1979. The Mamonia Com-

plex, S.W. Cyprus: the evolution and emplacement of a Mesozoic continental margin. Geol. Soc. Amer. Bull. 90, 651–665.
Robertson, A.H.F., Woodcock, N.H., 1981. Gödene Zone, Antalya Complex, S.W. Turkey: volcanism and sedimentation on Mesozoic marginal ocean crust. Geol. Rundsch. 70, 1177–1214.
Robertson, A.H.F., Woodcock, N.H., 1982. Sedimentary history of the south–western segment of the Mesozoic–Tertiary Antalya continental margin, south–western Turkey. Eclogae Geol. Helv. 75, 517–562.
Robertson, A.H.F., Xenophontos, C., 1993. Development of concepts concerning the Troodos ophiolite and adjacent units in Cyprus. In: Prichard, H.M., Alabaster, T., Harris, N.B., Neary, C.R. (Eds.), Magmatic Processes and Plate Tectonics. Geol. Soc. London, Spec. Publ., vol. 70, pp. 85–120.
Robertson, A.H.F., Clift, P.D., Degnan, P.J., Jones, G., 1991. Palaeogeographical and palaeotectonic evolution of the eastern Mediterranean Neotethys. Palaeoceanogr. Palaeoclimatol. Palaeoecol. 87, 289–343.
Robertson, A.H.F., Dixon, J.E., Brown, S., Collins, A., Morris, A., Pickett, E., Sharp, I., Ustaömer, T., 1996. Alternative tectonic models for the Late Palaeozoic–Early Tertiary development of Tethys in the Eastern Mediterranean region. In: Morris, A., Tarling, D.H. (Eds.), Palaeomagnestism and Tectonics of the Mediterranean Region. Geol. Soc. London, Spec. Publ., vol. 105, pp. 239–263.
Robinson, P.T., Malpas, J., 1990. The Troodos Ophiolite of Cyprus: new perspectives on its origin and emplacement. In: Malpas, J., Moores, E.M., Panayiotou, A., Xenophontos, C. (Eds.), Ophiolites: Oceanic Crustal Analogues. Cyprus Geol. Surv. Dept., Nicosia, pp. 13–36.
Robinson, P.T., Melson, W.G., O'Hearn, T., Schmincke, H.-U., 1983. Volcanic glass compositions of the Troodos ophiolite. Cyprus Geol. 11, 400–404.
Robinson, A.G., Banks, C.J., Rutherford, M.M., Hirst, J.P.P., 1995. Stratigraphic and structural development of the eastern Pontides, Turkey. J. Geol. Soc. London 152, 861–872.
Roddick, J.F., Cameron, W.E., Smith, A.G., 1979. Pero-Triassic and Jurassic Ar–Ar ages from Greek ophiolites and associated rocks. Nature 279, 788–790.
Saunders, A.D., Tarney, J., Kerr, A.C., Kent, R.W., 1996. The formation and fate of large oceanic igneous provinces. Lithos 37, 81–95.
Schmincke, H.U., Bednarz, U., 1990. Pillow, sheet flows and breccia flow volcanoes and volcano-tectonic hydrothermal cycles in the extrusives series of the northeastern Troodos ophiolite, Cyprus. In: Malpas, J., Moores, E.M., Panayiotou, A., Xenophontos, C. (Eds.), Ophiolites: Oceanic Crustal Analogues. Cyprus Geol. Surv. Dept., Nicosia, pp. 207–221.
Schunemann, M., 1985. Contributions of the geology, geochemistry and tectonics of the Chortiatis Series metamorphic calc-alkaline suite, Chalkidiki, northern Greece, PhD Thesis, Univ. Hamburg, 165.
Searle, M.P., Cox, J., 1999. Tectonic setting, origin and obduction of the Oman ophiolite. Geol. Soc. Amer. Bull. 111, 104–122.
Searle, M.P., Malpas, J., 1980. The structure and metamorphism of sub-ophiolitic metamorphic rocks in the Oman Mountains. J. Geol. Soc. London 139, 235–248.
Searle, R.C., Thomas, M.V., Jones, E.J.W., 1994. Morphology and tectonics of the Romanche transform and its environs. Mar. Geophys. Res.
Searle, R.C., Patriat, P., Mevel, C., Tamaki, C. FUJI Scientific Team, 1998. TOBI sidescan imager and magnetics of the Southwest Indian Ridge III: detailed history and tectonic style of seafloor spreading and detachment faulting. EOS Trans. Am. Geophys. Union Fall.
Şengör, A.M.C., Yılmaz, Y., 1981. Tethyan evolution of Turkey: a plate tectonic approach. Tectonophysics 75, 81–241.
Şengör, A.M.C., Yılmaz, Y., Ketin, I., 1980. Remnants of a pre-Late Jurassic ocean in northern Turkey: fragments of Permian–Triassic Paleo-Tethys? Geol Soc. Amer. Bull. 91, 599–609.
Şengör, A.M.C., Yılmaz, Y., Süngürlü, O., 1984. Tectonics of the Mediterranean Cimmerides: nature and evolution of the western termination of Palaeo-Tethys. In: Dixon, J.E., Robertson, A.H.F. (Eds.), The Geological Evolution of the Eastern Mediterranean. Geol. Soc. London, Spec. Publ., vol. 17, pp. 77–112.
Shallo, M., Kodra, A., Gjata, K., 1990. Geotectonics of the Albanian ophiolites. In: Malpas, J., Moores, E.M., Panayiotou, A., Xenophontos, C. (Eds.), Ophiolites Oceanic Crustal Analogues. Proc. Symp, 'Troodos 87' Geol. Surv. Dept., Cyprus, pp. 265–270.
Shallo, M., Turku, I., Manika, K., Marto, A., 1996. Genesis and geotectonic setting of the Albanian ophiolites. Sci. Rep. Tirana, Albania, 270 pp. (in Albanian).
Sharaskin, A.Y., Putchin, I.K., Zlobin, S.K., Kolesov, G.M., 1983. Two ophiolite sequences from the basement of the Northern Tonga Arc. Ofioliti 8, 411–438.
Sharp, I.R., 1994. The evolution of Neotethyan ocean basins. The sedimentary, tectonic and magmatic evolution of the Pelagonian and Axios (Vardar) zones, Macedonia, NE Greece. Unpubl. PhD thesis, Univ. of Edinburgh.
Sharp, I., Robertson, A., 1994. Late Jurassic–Lower Cretaceous oceanic crust and sediments of the Eastern Almopias zone, NW Macedonia (Greece); Implications for the evolution of the Eastern 'internal' Hellenides. Bull. Geol. Soc. Greece XXX/1, 47–61.
Simonian, K.O., Gass, I.G., 1978. Arakapas fault belt, Cyprus: a fossil transform fault. Geol. Soc. Amer. Bull. 89, 1220–1230.
Smith, A.G., 1993. Tectonic significance of the Hellenic–Dinaric ophiolites. In: Prichard, H.M., Alabaster, T., Harris, N.B.W., Neary, C.R. (Eds.), Magmatic Processes and Plate Tectonics. Geol. Soc. London, Spec. Publ., vol. 76, pp. 213–243.
Smith, A.G., 1999. Gondwana: its shape, size and position from Cambrian to Triassic times. J. Afr. Earth Sci. 28, 71–97.
Smith, A.G., Spray, J.G., 1984. A half-ridge transform model for the Hellenic–Dinaric ophiolites. In: Dixon, J.E., Robertson, A.H.F. (Eds.), The Geological Evolution of the Eastern Mediterranean. Geol. Soc. London, Spec. Publ., vol. 17, pp. 589–603.
Smith, A.G., Hynes, A.J., Menzies, M., Nisbet, E.G., Price, I., Welland, M.J., Ferrière, J., 1975. The stratigraphy of the Othris Mountains, Eastern Central Greece: a deformed Mesozoic Continental Margin Sequence. Eclogae Geol. Helv. 68, 463–481.
Smith, A.G., Woodcock, N.H., Naylor, M.A., 1979. The structural evolution of the Mesozoic continental margin, Othris Mountains, Greece. J. Geol. Soc. London 136, 589–603.

Spadea, P., Espinosa, A., Orrego, A., 1989. High-Mg extrusive rocks from the Romeral zone ophiolites in the southwestern Colombian Andes. Chem. Geol. 77, 303–321.

Spray, J.G., Roddick, J.C., 1980. Petrology and $^{40}Ar/^{39}Ar$ geochronology of some Hellenic sub-ophiolitic metamorphic rocks. Contrib. Mineral. Petrol. 72, 4–5.

Spray, J.G., Roddick, J.C., 1981. Evidence of Upper Cretaceous transform metamorphism in West Cyprus. Earth Planet. Sci. Lett. 55, 72–75.

Spray, J.G., Bébien, J., Rex, D.C., Roddick, J.C., 1984. Age constraints on the igneous and metamorphic evolution of the Hellenic–Dinaric ophiolites. In: Dixon, J.E., Robertson, A.H.F. (Eds.), Geological Evolution of the Eastern Mediterranean. Geol. Soc. London, Spec. Publ., vol. 17, pp. 619–627.

Stais, A., Ferrière, J., 1991. Nouvelles données sur la paléogéographie Mésozoique du domaine Vardarien: Les bassins d'Almopias et des Péonias (Macédoine, Hellénides internes septentrionales). Bull. Geol. Soc. Greece XXV/1, 491–507.

Stampfli, G., 1996. The Intra-Alpine terrain: a Paleotethyan remnant in the Alpine Variscides. Eclogae Geol. Helv. 89, 13–42.

Stampfli, G., 2000. Tethyan oceans. In: Bozkurt, E., Winchester, J.A., Piper, J.D. (Eds.), Tectonics and Magmatism in Turkey and the Surrounding Area. Geol. Soc. London, Spec. Publ., vol. 173, pp. 1–23.

Stampfli, G., Marcoux, J., Baud, A., 1991. Tethyan margins in space and time. Palaeogeogr. Palaeoclimatol. Palaeoecol. 87, 373–410.

Stampfli, G., Mosar, J., De Bono, A., Vavassis, I., 1998. Late Palaeozoic, early Mesozoic plate tectonics of the western Tethys. 8th Int. Congr. Geol. Soc. Greece. Bull. Geol. Soc. Greece, vol. 32, pp. 113–120.

Stampfli, G., Mosar, J., Faure, P., Pillevuit, A., Vannay, J.-C., 2000. Permo-Mesozoic evolution of the western Tethys real: the Neotethys East Mediterranean basin connection. In: Ziegler, P., Cavazza, W., Robertson, A.H.F., Crasquin-Soleau, S. (Eds.), Peri-Tethys Memoir, vol. 6. Mem. Mus. Hist. Nat., Paris, pp. 51–108.

Stern, R.J., Bloomer, S.H., 1992. Subduction zone infancy: examples from the Eocene Izu–Bonin–Mariana and Jurassic California Arcs. Geol. Soc. Amer. Bull. 104, 1621–1626.

Swarbrick, R.E., 1980. The Mamonia complex of S.W. Cyprus: a Mesozoic continental margin and its relationship with the Troodos Complex. In: Panayiotou, A. (Ed.), Ophiolites, Proc. Int. Ophiolite Symp., 1979. Cyprus Geol. Surv. Dept., Nicosia, pp. 86–92.

Swarbrick, R.E., Robertson, A.H.F., 1980. Revised stratigraphy of the Mesozoic rocks of Southern Cyprus. Geol. Mag. 117, 547–563.

Tankut, A., 1990. Geochemical implications for tectonic setting of the ophiolitic rocks from the ophiolitic melange belt of the Ankara Melange. Miner. Res. Expl. Bull., Ankara 110, 17–28.

Tappin, D.R., Ballance, P.F., 1994. Contributions to the sedimentary geology of Eua Island, Kingdom of Tonga: reworking in an oceanic forearc. In: Stevenson, A.J., Herzer, R.J., Ballance, P.F. (Eds.), Geology and Resources of Island Arcs—Tonag–Lau–Fiji Region. SOPAC Tech. Bull., vol. 8, pp. 1–20.

Taylor, B., 1992. Rifting and the volcanic–tectonic evolution of the Izu–Bonin–Mariana arc. In: Taylor, B., Fujioka, K., et al. (Eds.), Proc. Ocean Drill. Program: Sci. Results, vol. 126 Ocean Drilling Program, College Station, TX, pp. 652–672.

Tekeli, O., 1981. Subduction complex of pre-Jurassic age, northern Anatolia, Turkey. Geology 9, 68–72.

Tekeli, O., Erendil, M., 1986. Geology and petrology of the Kızıldağ, ophiolite (Hatay). Bull. Miner. Res. Explor. Inst. Turk. 21, 21–37 (MTA).

Tekeli, O., Aksay, A., Urgun, B.M., İslik, A., 1984. Geology of the Aladağ Mountains. In: Tekeli, O., Goncüöğlü, M.C. (Eds.), Geology of the Taurus Belt. Proc. Internat. Symp., Turkey, 1983. MTA, Ankara, pp. 143–158.

Thuizat, R., Montigny, R., Çakir, U., Juteau, T., 1978. K–Ar investigations of two Turkish ophiolites. In: Zartman, R.E. (Ed.), Short Papers of the 4th International Conference Geochronology, Isotope Geology. Geol. Surv. Amer. Open-File Rep. 78-701, 430–432.

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 Planet. Sci. Lett. 52, 302–310.

Tsikouras, B., Hatzipanagiotou, K., 1998a. Two alternative solutions for the development of a marginal basin in NE Greece. Ofioliti 23 (2), 83–92.

Tsikouras, B., Hatzipanagiotou, K., 1998b. Petrogenetic evolution of an ophiolite fragment in an ensialic marginal basin, northern Aegean (Samothraki Island, Greece). Eur. J. Mineral. 10, 551–567.

Tucholke, B.E., Lin, J., Kleinrock, M.C., Tivey, M.A., Reed, T.B., Goff, J., Jaroslow, G.E., 1997. Segmentation and crustal structure of the western Mid-Atlantic Ridge flank, 25°25′–27°10′N and 0–29 m.y. J. Geophys. Res. 102 (10), 10203–10223.

Tüysüz, O., 1990. Tectonic evolution of a part of the Tethyside orogenic collage, the Kargı Massif, Northern Turkey. Tectonics 9, 141–160.

Ustaömer, T., 1999. Pre-Jurassic crustal extension, basin formation and associated magmatism at a consuming margin, Yusufeli–Artvin, Eastern Pontides, NE Turkey. J. Conf. Abstr., EUG 10, 316.

Ustaömer, T., Robertson, A.H.F., 1993. A Late Palaeozoic–Early Mesozoic Marginal Basin along the active southern continental margin of Eurasia: evidence from the Central Pontides (Turkey and adjacent Regions). Geol. J. 28, 219–238.

Ustaömer, T., Robertson, A.H.F., 1994. Late Palaeozoic marginal basin and subduction–accretion: evidence from the Palaeotethyan Küre Complex, Central Pontides, N. Turkey. J. Geol. Soc. London 151, 291–305.

Ustaömer, T., Robertson, A.H.F., 1997. Tectonic–sedimentary evolution of the north Tethyan margin in the Central Pontides of northern Turkey. In: Robinson, A.G. (Ed.), Regional and Petroleum Geology of the Black Sea and Surrounding Region. AAPG Mem., vol. 68, pp. 255–290.

Ustaömer, T., Robertson, A.H.F., 1999. Geochemical models used to test alternative plate tectonic models for pre-Upper Jurassic (Palaletethyan) units in the Central Pontides, N Turkey. Geol. J. 34, 25–53.

Varga, R.J., Moores, E.M., 1985. Spreading structure of the Troodos ophiolite, Cyprus. Geology 13, 846–850.

Vergély, P., Dimo, A., Monie, P., 1998. Datation des semelles métmorphiques ophiolitiques d'Albanie par la méthode $^{40}Ar/^{39}Ar$: conséquences sur le méchanisme de leur mise en place. C.R. Acad. Sci. Paris 326, 717–722.

Waldron, J.W.F., 1984. Evolution of carbonate platforms on a margin of the Neotethys ocean: Isparta angle, south–western Turkey. Eclogae Geol. Helv. 77, 553–581.

Whitechurch, H., 1977. Les roches métamorphiques infraperiditotiques du Baer–Bassit (NW Syrien), temoins de l'écaillage intraoceanique téthysien. Etude pétrologique et structurale. Thèse, Université de Nancy, France, 194 pp.

Whitechurch, H., Juteau, T., Montigny, R., 1984. Role of the Eastern Mediterranean ophiolites (Turkey, Syria, Cyprus) in the history of Neo-Tethys. In: Dixon, J.E., Robertson, A.H.F. (Eds.), The Geological Evolution of the Eastern Mediterranean. Geol. Soc. London, Spec. Publ., vol. 17, pp. 301–318.

Whitmarsh, R.B., Sawyer, D.S., Klaus, A., Masson, D.G., (Eds.), 1996. Proc. Ocean Drill. Program: Sci. Results 152, Ocean Drilling Program, College Station, TX, vol. 149.

Whitmarsh, R.B., Minshull, T.A., Russell, S.M., Dean, S.M., Louden, K.E., Chain, D., 2001. The role of syn-rift magmatism in the rift-to-drift evolution of the west Iberia continental margin: geophysical observations. In: Wilson, R.C.L., Whitmarsh, R.B., Taylor, B., Froitzheim, N. (Eds.), Non-Volcanic Rifting of Continental Margins: a Comparison of Evidence from Land and Sea. Spec. Pub. Geol. Soc. London 187, pp. 107–124.

Woodcock, N.H., Robertson, A.H.F., 1977. Origins of some ophiolite-related rocks of the "Tethyan" belt. Geology 5, 373–379.

Yalınız, M.K., Göncüoğlü, M.C., 1998. General geological characteristics and distribution of the Central Anatolian Ophiolites. Yer Bilim. Derg. 20, 19–30.

Yalınız, M.K., Floyd, P.A., Göncüoğlü, M.C., 1996. Supra-subduction zone ophiolites of Central Anatolia: geochemical evidence from the Sarikaraman Ophiolite, Aksary, Turkey. Min. Mag. 60, 697–710.

Yazgan, E., Chessex, R., 1991. Geology and tectonic evolution of Southeastern Taurus in the region of Malatya. Turk. Assoc. Petrol. Geol. Bull. 3, 1–42.

Yılmaz, P.O., 1984. Fossil and K–Ar data for the age of the Antalya Complex, S.W. Turkey. In: Dixon, J.E., Robertson, A.H.F. (Eds.), The Geological Evolution of the Eastern Mediterranean. Geol. Soc. London, Spec. Publ., vol. 17, pp. 335–348.

Yılmaz, Y., 1991. Allochthonous terranes in the Tethyan Middle East: Anatolia and the surrounding regions. In: Dewey, J.F., Gass, I.G., Curry, G.B., Harris, N.B.W., Şengör, A.M.C. (Eds.), Allochthonous Terranes. Cambridge Univ. Press, pp. 155–168.

Yılmaz, Y., 1993. New evidence and model on the evolution of the southeast Anatolian orogen. Geol. Soc. Amer. Bull. 105, 251–271.

Yılmaz, P.O., Maxwell, J.C., 1982. K–Ar investigations from the Antalya complex ophiolites, SW Turkey. Ofioliti 2, 27–538.

Yılmaz, Y., Şengör, A.M.C., 1985. Palaeo-Tethyan ophiolites in northern Turkey: petrology and tectonic setting. Ofioliti 10, 485–504.

Yılmaz, Y., Tüysüz, O., Yığıtbaş, E., Genç, S.C., Şengör, A.M.C., 1997. Geology and tectonic evolution of the Pontides. In: Robinson, A.G. (Ed.), Regional and Petroleum geology of the Black Sea and surrounding region. Am. Assoc. Pet. Geol. Mem., vol. 68, pp. 183–226.

Yığıtbaş, E., Kerrich, R., Yılmaz, Y., Xia, Q., Elmas, A., 2001. Pre-Cambrian ophiolites in the basement of Istanbul–Zonguldak unit (N.W. Turkey) and its tectonic significance. Fourth Internat. Turkish Geol. Symp. (ITGS IV), p. 116. Abstract.

Zachariadou, S., Dimitriadis, S., 1995. Aspects of the tectono-magmatic evolution of the Late Jurassic Guevgueli Complex, Macedonia, Greece. Spec. Publ. Geol. Soc. Greece 4, 143–147.

Zeck, H.P., Ünlü, T., 1988. Alpine ophiolite onduction before 110 Ma ago, Taurus belt, eastern central Turkey. Tectonophysics 145, 55–56.