Early Mesozoic subduction in the Eastern Mediterranean: Evidence from Triassic eclogite in northwest Turkey

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ABSTRACT

An eclogite forms a 40-m-long tectonic lens enveloped in serpentinite within a metabasite-phyllite-marble unit of Permian-Triassic age in northwest Turkey. The eclogite consists mainly of garnet, omphacite, glaucophane, and epidote. It is associated with other lenses of serpentinite and metagabbro. Single-grain laser probe ^{40}Ar/^{39}Ar dating of phengites from the eclogite gives ages of 203 to 208 Ma, corresponding to the Triassic-Jurassic boundary. Regional geologic considerations also suggest a latest Triassic to earliest Jurassic metamorphic age for the eclogite and the enclosing metabasite-marble-phyllite unit. The eclogite, along with serpentinite and gabbro lenses, were probably emplaced as diapirs into the metabasite-phyllite-marble unit during Late Triassic subduction. The eclogite provides evidence for the often elusive Triassic subduction history of the Paleo-Tethys in the eastern Mediterranean area.

INTRODUCTION

Late Paleozoic paleogeographic reconstructions show a wide oceanic realm in the present-day eastern Mediterranean area (e.g., Scotese and Golonka, 1979; Şengör et al., 1984; Ricou, 1996). Although there is some geologic evidence for the existence of this Paleozoic ocean—the Paleo-Tethys—in this area (e.g., Şengör et al., 1984; Stampfli et al., 1991), data for the subduction history of this Paleo-Tethys are scarce. Herein, we describe the tectonic setting, petrology, and ^{40}Ar/^{39}Ar isotopic characteristics of a Triassic eclogite from northwest Turkey interpreted to have formed during the subduction of the Paleo-Tethys. This effort constitutes, to our knowledge, the first description of an eclogite of Triassic age in the Alpide-Himalayan orogenic belt.

The eclogite occurs in the Sakarya zone, which is a paleomicroplate bounded by early Tertiary sutures (Fig. 1A, Şengör and Yılmaz, 1981). The pre-Jurassic basement of the Sakarya zone is generally made up of the Permian-Triassic subduction-accretion units of the Paleo-Tethys, collectively called as the Karakaya Complex (Tekeli, 1981; Okay et al., 1996). The Karakaya Complex is composed of a basal tectonic unit of metabasite, marble, and phyllite named the Nilüfer unit and tectonically overlying, strongly deformed but generally unmetamorphosed Triassic clastic and mafic volcanic rocks with exotic Carboniferous and Permian limestone blocks (Leven and Okay, 1996). The Nilüfer unit is interpreted as an ensimatic intra-arc to fore-arc sequence of Permian-Triassic age (Okay et al., 1996) or as a Triassic oceanic seamount (Pickett and Robertson, 1996). Lower Jurassic clastic rocks lie with pronounced unconformity over the Karakaya Complex. The Karakaya Complex represents an orogeny caused by the latest Triassic northward obduction of subduction-accretion units of the Paleo-Tethys over the late Hercynian continental basement of Laurasia (Okay et al., 1996)

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GEOLOGIC SETTING OF THE ECLOGITE

The eclogite occurs as a small tectonic lens in the Nilüfer unit east of the town of Bandırma in northwest Turkey (Fig. 1B). In this region skirting the Marmara sea, the Nilüfer unit forms a metamorphic sequence, more than 5 km thick, made up dominantly of metabasites (>80%, largely distal submarine tuffs) with intercalated minor marble and phyllite. It shows a distinct foliation, isoclinal folding and is metamorphosed in greenschist facies with actinolite or barroisite + albite + epidote + chlorite + titanite paragenesis in the metabasites. The Nilüfer unit is tectonically overlain by slightly recrystallized but strongly deformed Triassic clastic rocks with exotic Upper Permian limestone olistoliths (Leven and Okay, 1996). Undeformed Lower Jurassic conglomerates and sandstones lie unconformably over the Triassic clastic rocks north of Karacabey (Fig. 1B).

The eclogite forms a single lens, 15 m thick and 40 m long, aligned parallel to the east-northeast–trending foliation in the metabasites and is enclosed by a 2–10-m-thick envelope of antigorite serpentinite. It is massive and has a homogeneous texture. Most of the lens consists of pink garnets set on dark blue sodic amphibole and pale green omphacite. Metabasite samples collected adjacent to the eclogite show no evidence of high-pressure metamorphism but contain greenschist-facies assemblages. In the vicinity of the eclogite, there are also tectonic lenses of greenschist-facies metagabbro and antigorite serpentinite (Fig. 1C).

PETROLOGY OF THE ECLOGITE

Four samples from the eclogite lens were analyzed with a Camebax SX-50 electron microprobe. Operating conditions were 15 kV accelerating voltage, 10 or 15 nA beam current, and 10 µm beam size. The mineral assemblage in the eclogite is garnet + omphacite + glaucophane ± barroisite + epidote + quartz ± phengite + rutile. Garnet, omphacite and glaucophane make up more than 70% of the rock. Garnet forms subidioblastic crystals 2–4 mm in size with quartz, rutile, and glaucophane inclusions and is essentially almandine-grossular solid solution with minor pyrope (3–11 mol%) and spessartine (0–4 mol%) (Table 1, Fig. 2A). Sodic amphibole occurs as prismatic, lavender blue crystals as much as 4 mm in size. It has rims and patches of bluish-green barroisite but otherwise is compositionally homogeneous and plots in the glaucophane and crossite fields (Fig. 2C). Apple-green omphacite crystals as much as 2 mm long commonly occur as inclusions in glaucophane as well as in the matrix of the rock. Omphacite contains as much as 36 mol% jadeite and 15–25 mol% aegirine (Table 1, Fig. 2B). Epidote is found as aggregates of grains 0.2 mm in size. Phengite with 3.30–3.45 Si per formula unit (Fig. 2D) is present in only one sample as grains 0.4–1 mm across associated with garnet. Phengite grains show a slight rimward decrease in Si. However, the compositional variation between grains is larger than that introduced by zoning. The greenschist-facies overprint in the eclogite is charac-

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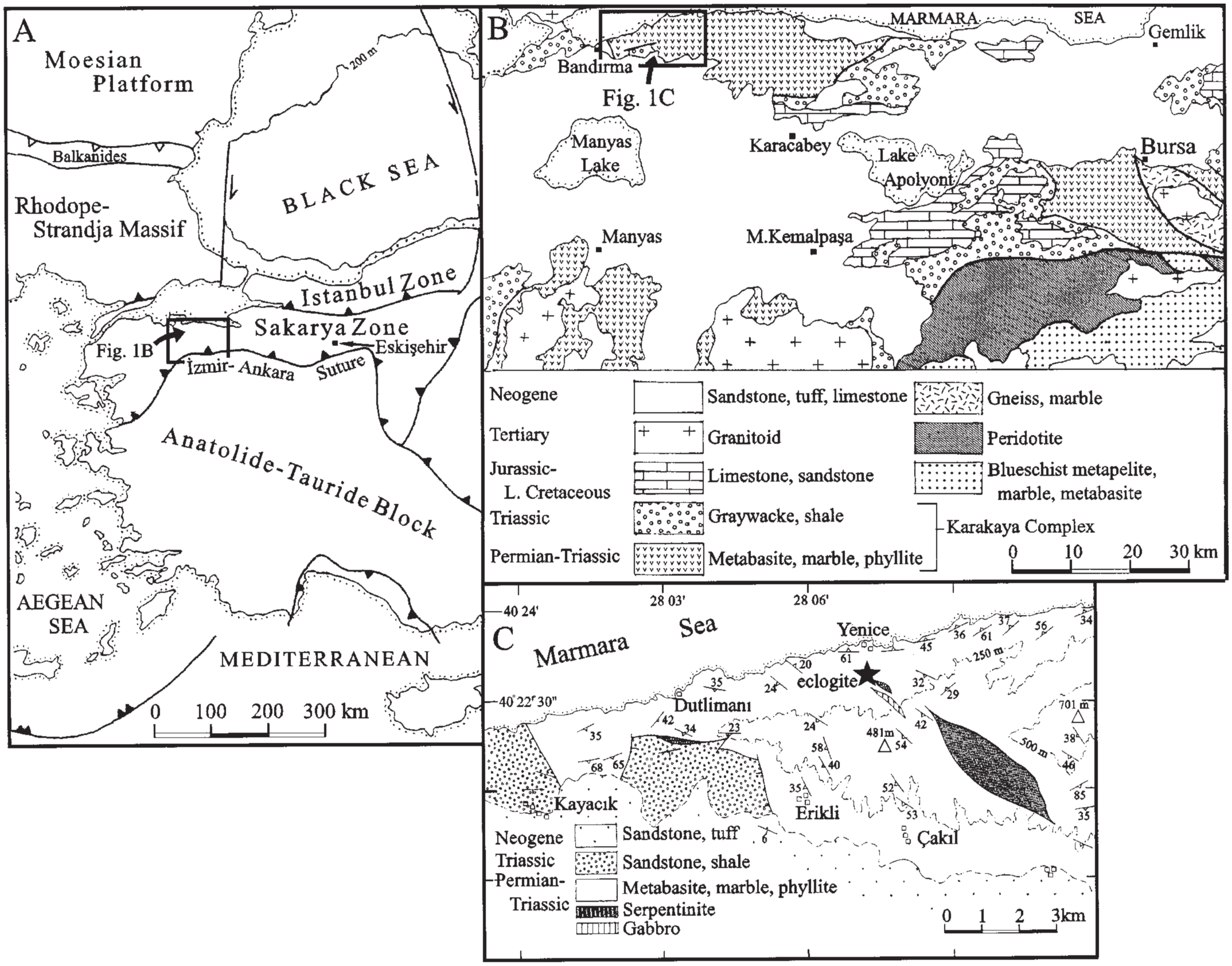

Figure 1. A: Tectonic map of western Turkey and surrounding regions (modified from Okay et al., 1996). B: Simplified geologic map of Bandırma-Bursa region in northwest Turkey. C: Geologic map of region west of Bandırma showing eclogite locality.

terized by barroisite rims around glaucophane, the development of interstitial albite, and by the partial replacement of garnet by chlorite.

Garnet-clinopyroxene Fe-Mg geothermometry of Ellis and Green (1979) indicates temperatures of 480 ± 50 °C at a pressure of 10 kbar for adjoining omphacite-garnet pairs from the eclogite samples, whereas minimum pressure of 10 kbar can be estimated from the jadeite content of the sodic pyroxene (Holland, 1990). In terms of its petrology and tectonic setting, the eclogite lens is a typical group C eclogite (Coleman et al., 1965) and is similar to the exotic eclogite blocks in the Franciscan Complex in California (e.g., Moore and Blake, 1989; Oh and Liou, 1990) and that of the Besshi district of the Sanbagawa metamorphic belt in Japan (Banno and Nakajima, 1992; Takasu et al., 1994).

^{40}Ar/^{39}Ar GEOCHRONOLOGY OF THE ECLOGITE

Two of the analyzed eclogite samples (4176C and 4176H) have been dated with step-heating and spot-fusion ^{40}Ar/^{39}Ar laser-probe methods on single grains (e.g., Dalrymple, 1989; Monié et al., 1996). The first sample contained no phengite, and a single glaucophane grain was progressively degassed by using a defocused laser beam. The glaucophane has a very low K content (<0.02 wt%, Table 1) resulting in apparent ages with relatively high experimental errors (Table A).[1] As commonly observed with sodic amphiboles, the age spectrum (Fig. 3) shows excess Ar released at the beginning of step-heating, producing meaningless apparent ages of up to 2400 Ma. Later heating increments representing about 80% of the Ar released gave a plateau date of 164 ± 17 Ma. The isochron date calculated on the same heating increments is 162 ± 7 Ma, with an initial atmospheric ^{40}Ar/^{36}Ar ratio.

Phengites from the second sample (4176H) were dated both by step-heating and spot-fusion techniques. One phengite grain about 1 mm in diameter was progressively degassed in nine heating steps and produced a good plateau of 203.1 ± 2.9 Ma for more than 90% of released Ar (Fig. 3, Table A). A similar age is indicated by the isochron plot. Another phengite grain of about 0.7 mm in diameter was analyzed by spot-fusion with a spatial resolution of about 100 µm. Ten analyses were performed on this grain. The dates cluster in a narrow range between 201 and 208 Ma with a mean value of 204 ± 3 Ma (Fig. 3). No systematic age variation across the phengite was observed, suggesting that the phengite is isotopically homogeneous. Six spot-fusion analyses were performed on a second phengite grain from this sample. Among them, four spots yielded ages that agree with the dates given above, but the two remaining spots from the rim of the grain yielded older ages of 213 and 217 Ma, probably reflecting the presence of a minor component of excess Ar. Single spot-fusion analyses on two other phengites from

[1] GSA Data Repository item 9736, Table A, Argon isotope data for the eclogites is available on request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301. E-mail: editing@geosociety.org.

TABLE 1. MINERAL COMPOSITIONS FROM THE ECLOGITE

	Garnet		Omphacite		Glaucophane		Phengite
	4176H	4176G	4176H	4176G	4176H	4176G	4176H
SiO_2	37.36	37.68	54.64	54.55	56.26	57.72	50.37
TiO_2	0.00	0.04	0.05	0.10	0.09	0.00	0.26
Al_2O_3	20.66	21.01	8.96	7.91	10.33	10.78	25.15
Cr_2O_3	0.00	0.00	0.00	0.00	0.02	0.00	0.06
FeO	29.90	30.78	9.91	10.28	12.35	10.71	3.76
MgO	2.40	2.08	6.52	6.97	9.74	10.46	3.39
MnO	0.29	0.22	0.00	0.00	0.02	0.00	0.00
CaO	8.89	9.01	11.40	12.02	1.44	0.55	0.05
Na_2O	0.07	0.00	7.74	7.65	6.69	7.46	0.45
K_2O	0.00	0.02	0.00	0.05	0.02	0.01	10.17
Total	99.57	100.84	99.22	99.53	96.95	97.69	93.67
Mineral formula on the basis of					23 oxygens and		
	12 oxygens		4 cations		15 cations		11 oxygens
Si	3.00	2.99	1.98	1.97	7.82	7.87	3.44
Al^{IV}	0.00	0.01	0.02	0.03	0.18	0.13	0.56
Al^{VI}	1.95	1.95	0.36	0.31	1.51	1.60	1.47
Ti	0.00	0.00	0.00	0.00	0.01	0.00	0.01
Cr	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe^{3+}	0.05	0.05	0.18	0.23	0.45	0.50	
Fe^{2+}	1.95	1.99	0.12	0.08	0.98	0.72	0.22
Mg	0.29	0.25	0.35	0.38	2.02	2.13	0.35
Mn	0.02	0.02	0.00	0.00	0.00	0.00	0.00
Ca	0.76	0.77	0.44	0.46	0.21	0.08	0.00
Na	0.01	0.00	0.54	0.54	1.80	1.97	0.06
K	0.00	0.00	0.00	0.00	0.00	0.00	0.89
Total	8.03	8.03	4.00	4.00	15.00	15.00	7.00

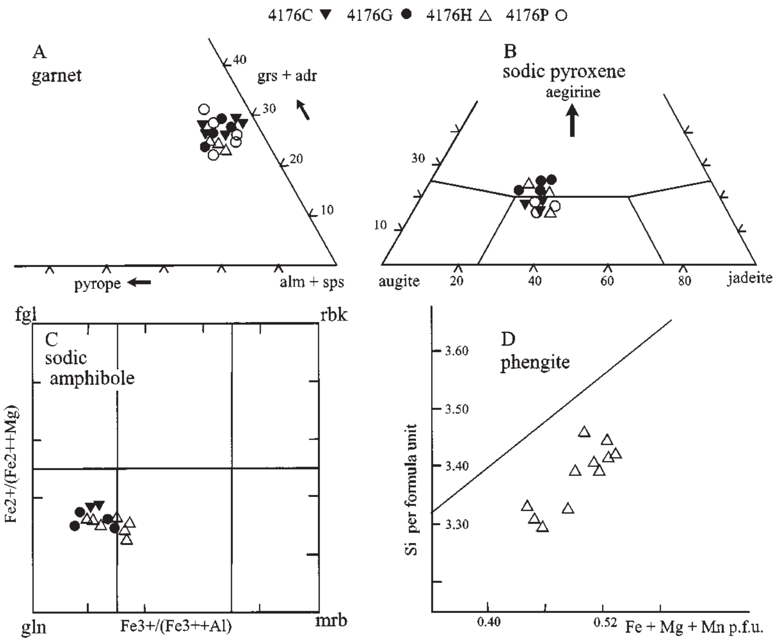

Figure 2. Mineral compositions from Triassic eclogite. A: Garnet compositions plotted on part of pyrope, almandine + spessartine (alm + sps), and grossular + andradite (grs + adr) ternary diagram. B: Sodic pyroxene compositions plotted on part of augite, jadeite, and aegirine ternary diagram. C: Sodic amphibole compositions plotted on Miyashiro diagram; gln—glaucophane, fgl—ferroglaucophane, rbk—riebeckite, mrb—magnesioriebeckite. D: Phengite compositions plotted on diagram of Si vs. Fe + Mg + Mn per formula unit (p.f.u.).

the same rock section gave ages of 207 and 205 Ma (Table A), suggesting that excess Ar cannot be considered as a major drawback in our $^{40}Ar/^{39}Ar$ study of high *P*-low *T* metamorphic rocks, probably because the nature of protoliths and the metamorphic conditions are not favorable for incorporation of excess Ar (e.g., see Li et al., 1994; Arnaud and Kelley, 1995, for counterexamples).

These phengite $^{40}Ar/^{39}Ar$ ages correspond within errors to the Triassic-Jurassic boundary (e.g., Gradstein et al., 1994). Similar $^{40}Ar/^{39}Ar$ ages ranging from 192 to 214 Ma have been reported recently from the blueschists in the Nilüfer unit from north Eskişehir, 250 km east of the studied area (Monod et al., 1996), which points to the extensive distribution of the latest Triassic high-pressure rocks in the Sakarya zone. In the absence of reliable diffusion data, the closure temperature for Ar in phengite is generally taken to be in the range of 350–400 °C. However, recent observations on Ar systematics in the white-mica group suggest that the closure temperature could be higher than 400 °C (e.g., Monié and Chopin, 1991; Kirschner et al., 1996), particularly when rocks cooled fast. Given the peak metamorphic temperatures of 480 ± 50 °C recorded by the exotic eclogite block in the Nilüfer unit, we interpret the $^{40}Ar/^{39}Ar$ phengite ages to reflect an early stage of cooling of these high-pressure rocks.

The 164 ± 17 Ma partial plateau age from the glaucophane is considerably younger than the latest Triassic ages from the phengites. The closure temperature for Ar in glaucophane is poorly known, but is likely to be close to or above that of phengite according to the ionic porosity model of Dahl (1996). Therefore, the anomalous young age of glaucophane can be best explained by the contribution from submicroscopic K-bearing inclusions that became closed systems at very low temperature. The presence of these inclusions is suggested by the difference in the Ca/K ratios evaluated from microprobe (~70) and isotopic (~50) analyses of glaucophane.

REGIONAL GEOLOGIC CONSTRAINTS ON THE AGE OF THE ECLOGITE

Two important deformational events dominated the Sakarya zone: the latest Triassic Karakaya orogeny and the early Tertiary Alpide orogeny. The Alpide orogeny was caused by the Paleocene collision of the Sakarya zone with the Anatolide-Tauride block. As the Sakarya zone belonged to the upper plate during the convergence and collision, it underwent no Alpide regional metamorphism, just a relatively weak Paleocene deformation characterized by folding and north-vergent thrusting (e.g., Saner, 1980). Therefore, it is unlikely that the eclogite was tectonically emplaced into the Sakarya basement during this early Tertiary event. Rather its emplacement must have occurred during the Karakaya orogeny responsible for regional ductile deformation and greenschist-facies metamorphism of the Nilüfer unit.

The eclogitic lens shows a greenschist-facies overprint and concordant tectonic contacts with the adjacent metabasites, which suggest that it was incorporated into the Nilüfer unit prior or during the greenschist-facies regional metamorphism. Stratigraphic constraints on the depositional age of the Nilüfer unit come from the Kozak range in northwest Turkey, where Kaya and Mostler (1992) described Middle Triassic (late Anisian–early Ladinian) conodonts from the marbles of this unit. An upper age limit on the regional metamorphism in the Nilüfer unit comes from east of Bursa, where metabasites of the Nilüfer unit are unconformably overlain by the Lower Jurassic (Sinemurian) shallow-marine clastic rocks (Altıner et al., 1991; Genç and Yılmaz, 1995). Thus, the age of regional metamorphism and ductile deformation in the Nilüfer unit is constrained to the Middle Triassic–Liassic interval (237–202 Ma). A tighter constraint on the age of the Karakaya orogeny is provided by strongly deformed but unmetamorphosed Triassic clastic rocks that lie tectonically over the Nilüfer unit. The youngest paleontological age from these rocks is late Norian (Leven and Okay, 1996), which constrains the age of deformation in the Karakaya Complex to latest Norian–Hettangian (212–203 Ma). The radiometric ages reported above are fully consistent with these stratigraphic constraints.

CONCLUSIONS

Isotopic data and regional geologic considerations indicate a latest Triassic metamorphic age for the exotic eclogitic block in the Karakaya

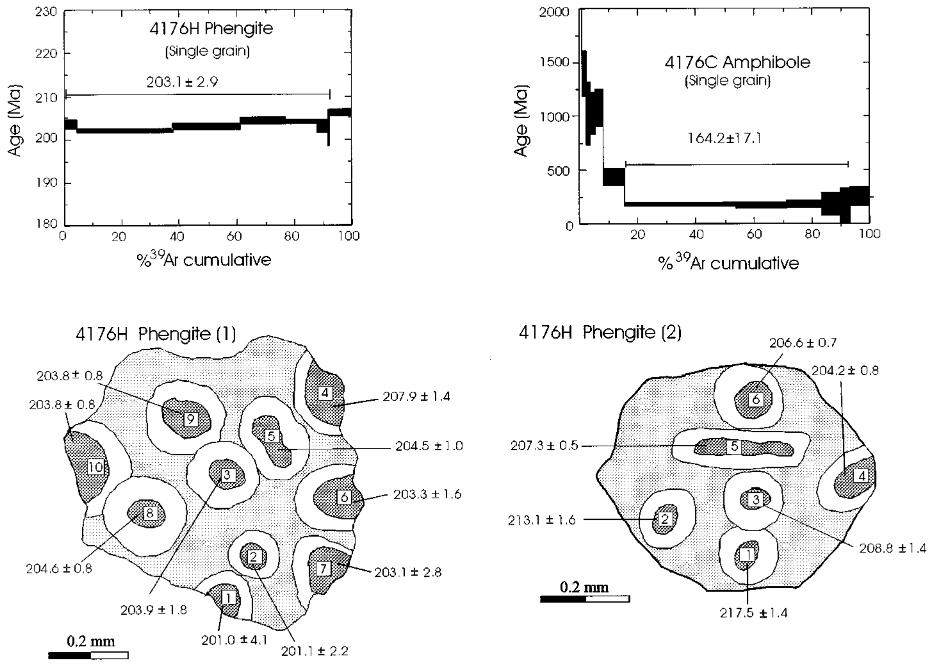

Figure 3. $^{40}Ar/^{39}Ar$ laser probe age spectra and age spot-fusion maps of phengite and glaucophane from northwest Turkey eclogite.

Complex in northwest Turkey. The association of the eclogite with lenses of serpentinite and metagabbro indicates a high *P*-low *T* metamorphism in a latest Triassic Tethyan subduction zone in the eastern Mediterranean region. The eclogite, which has a serpentinite envelope, could have been incorporated into the overlying fore-arc sequence of the Nilüfer unit as a diapir from the subduction zone. Similar situations exposing serpentinite diapirs in fore-arc sequences, locally with enclosed blueschists, are known from the Great Valley Sequence in California and from the present-day Marianna fore-arc in the western Pacific region (Maekawa et al., 1993).

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