Geological Society, London, Special Publications

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Geological Society, London, Special Publications 2000; v. 173; p. 183-202
doi:10.1144/GSL.SP.2000.173.01.09

Geochemical character and tectonic environment of Neotethyan ophiolitic fragments and metabasites in the Central Anatolian Crystalline Complex, Turkey

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Abstract: The Central Anatolian Crystalline Complex (CACC) or Kırşehir Block is part of the metamorphosed leading edge of the Tauride–Anatolide Carbonate Platform. It contains oceanic remnants derived from the Neotethys Ocean (İzmir–Ankara–Erzincan branch) which separate it from the Sakarya microcontinent. Two tectonic units are distinguished: an amphibolite facies Mesozoic 'basement', dominated by platform marbles, over which is thrust a younger fragmented Upper Cretaceous ophiolite sequence. Three metabasite horizons were sampled to reconstruct the development of the oceanic components: (1) fragmented Upper Cretaceous (90–85 Ma) stratiform ophiolitic members comprising gabbros, sheeted dykes, basalt lavas and pelagic sediments thrust over all other units; (2) a tectonised admixture of basite, ultramafic and felsic blocks in an ophiolitic mélange (Upper Cretaceous matrix) thrust over the basement metamorphic rocks; and (3) amphibolites concordant with 'basement' marbles and minor pelagics of the largely (?)Triassic Kaleboynu Formation in the lower part of the carbonate platform.

Metabasalts and metagabbros from isolated fragments of the stratiform ophiolites form geochemically coherent groups and indicate the influence of a subduction component during their development. It is considered that the suprasubduction zone ophiolites record the association of a tholeiitic arc and an adjacent back-arc basin with more mid-ocean ridge basalt (MORB)-like compositions.

Metabasite blocks within the tectonised ophiolitic mélange slice are MORB like, together with minor ocean island basalt (OIB) and island arc basalts, and may be tectonically related to ophiolitic units within the accretionary wedge of the Ankara Mélange.

Concordant amphibolites of the Kaleboynu Formation are largely OIB types and reflect an early ensialic rifting stage of the Tauride–Anatolide Carbonate Platform. Small ocean basins also developed at this time, as recorded by the presence of MORB and associated pelagics.

The CACC block, together with parts of the Ankara Mélange, are considered to represent oceanic lithosphere (comprising both early spreading centre and latter subduction-influenced crust) and continental carbonate platform that were subsequently ejected from an accretionary–subduction complex on collision with the Sakarya microcontinent.

The Neotethyan area of the eastern Mediterranean records the development of a series of narrow oceanic seaways and microcontinent fragments that resulted from the fragmentation of the Gondwana margin during the Mesozoic (Robertson & Dixon 1984). Rifting of the northern margin of Gondwana, and the subsequent development and destruction of ocean floor, is documented by diverse tectonolithological associations and accompanying basaltic volcanism (Şengör & Yılmaz 1981; Robertson & Dixon 1984; Robertson *et al.* 1991). The Neotethys, initially generated during the Late Triassic, survived in small seaways up to Late Cretaceous time, when convergence of Africa and Eurasia largely closed this segment via northwards subduction under the Pontide active margin of Eurasia (Livermore & Smith 1984; Yılmaz *et al.* 1997).

The Turkish sector of Neotethys is characterized by two major east–west belts of ophiolitic fragments (Fig. 1, inset) that mark the presence of ancient suture zones and document the destruction of former ocean basins (Juteau

From: BOZKURT, E., WINCHESTER, J. A. & PIPER, J. D. A. (eds) *Tectonics and Magmatism in Turkey and the Surrounding Area.* Geological Society, London, Special Publications, **173**, 183–202. 1-86239-064-9/00/$15.00

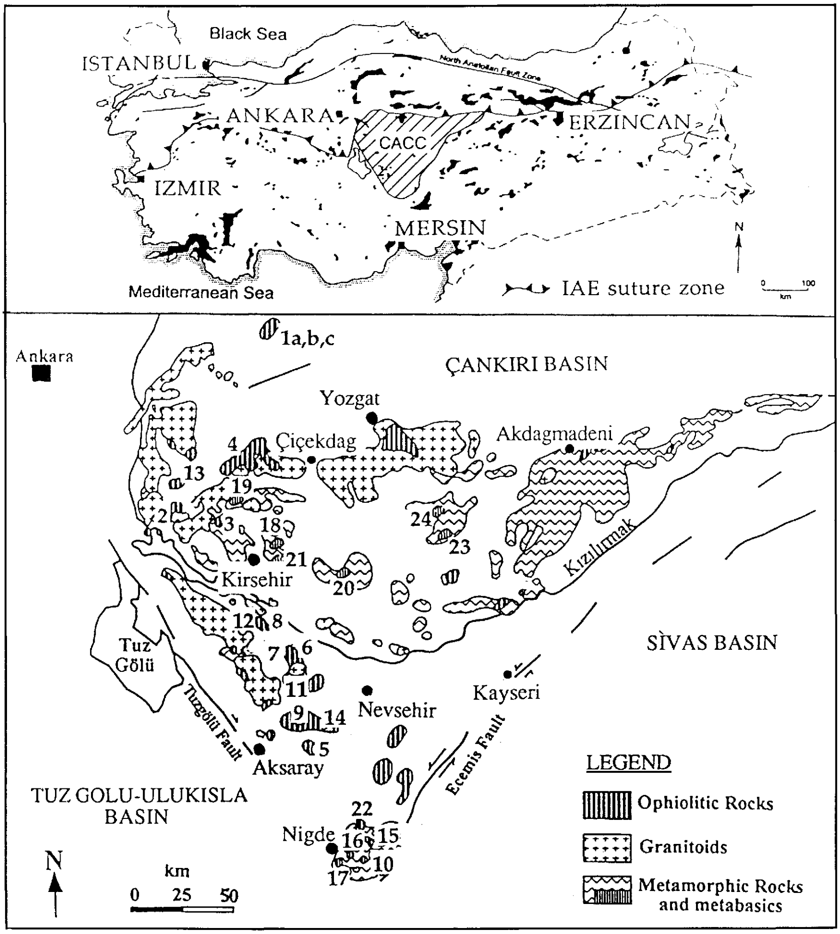


Fig. 1. Lithological sketch map of the CACC or Kırşehir Block (largely after surveying by Göncüoğlu *et al.* 1991; Yalınız & Göncüoğlu 1998) showing the location of the main SSZ ophiolitic fragments and the major metabasite bodies within the metamorphic basement. Inset shows Tethyan ophiolitic belts [after Juteau (1980)] and the location of the CACC in Turkey. The main sampling areas covered by this paper are shown by numbers and refer to the following localities: for Stratiform SSZ ophiolites – 4, Çiçekdağ Ophiolite; 6, Sarıkaraman Ophiolite: for isolated ophiolitic remnants – 1, Çankırı Basin (a, Ayvatlı; b, Alişeyhli; c, İneğazılı); 2, Kaman–Hirfanlı Dam; 3, Kurançalı; 5, Mamasin Dam; 7, Bozkır Dam; 8, Devedamı; 9, Alayhanı; 11, Yalıntaş; 12, Karataş; 13, Geyral; 14, Keskin; 15, Dokuzlar; 22, Aktaş Dam: for metamorphosed ophiolitic mélange – 10, Aşigediği; 18, Çimeli; 19, Köşker Yaylası; 20, Ayrıdağ: for the Kaleboynu Formation – 16, Söğütlütepe; 17, Göbettepe; 21, Kervansaray Dağı; 23, Çomakdağ; 24, Karaveli.

1980; Şengör & Yılmaz 1981). Each belt is considered to represent a separate Neotethyan ocean: (1) a northerly belt composed mainly of ophiolitic mélange (part of the 'Ankara Mélange') is representative of the İzmir–Ankara–Erzincan Ocean, located between the Sakarya microcontinent fragment and the leading edge of the Tauride–Anatolide Platform (TAP); and (2) a southern branch called either the Southern Neotethys Ocean (Şengör & Yılmaz 1981) or the Péri–Arabic Belt (Ricou 1971), which includes well-documented bodies such as Troodos, Mersin, Pozantı–Karsantı, and Hatay. The latter ocean strand separated the main body of the Gondwana continent from the rifted TAP to the north and was formed in a suprasubduction zone setting (Pearce *et al.* 1984) rather than at a major ocean-spreading centre.

Isolated, allochthonous metabasite bodies of possible ophiolitic affinity (termed the Central Anatolian Ophiolites; Göncüoğlu *et al.* 1991) are exposed in the triangular Central Anatolian

Crystalline Complex (CACC) or Kırşehir Block (Fig. 1), and are less well known than the Southern Neotethyan ophiolites. They are of particular interest to Neotethyan development in that they are considered to have been thrust southwards out of the İzmir–Ankara–Erzincan Ocean during closure (Şengör & Yılmaz 1981; Göncüoğlu *et al.* 1991), and preserve both spreading ridge and suprasubduction zone generated oceanic crust.

The Central Anatolian Crystalline Complex (CACC)

The CACC is situated north of the TAP proper and south of the İzmir–Ankara–Erzincan Suture (Fig. 1). A belt of glaucophanitic ophiolites situated around the southern margin of the CACC has been interpreted as an additional oceanic seaway (the Inner Tauride Belt; Görür *et al.* 1984) which once separated the CACC from the TAP. However, others considered that the CACC originally represented the northern passive margin of the TAP (Özgül 1976) and that the Inner Tauride ophiolites were also derived from the İzmir–Ankara–Erzincan Ocean to the north (Göncüoğlu 1986).

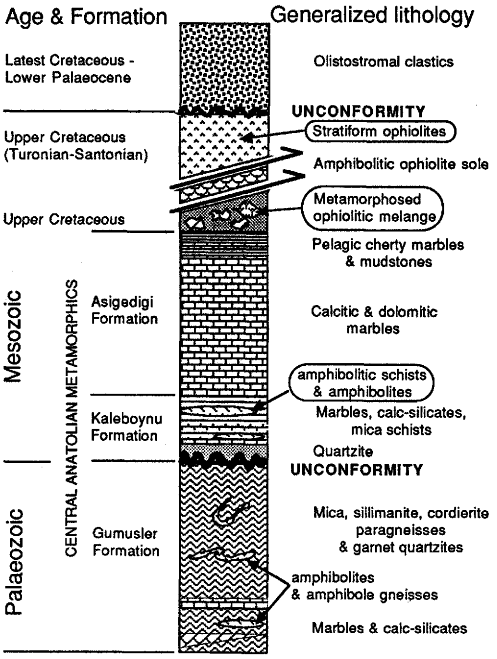


Fig. 2. Generalized stratigraphic column (not to scale) for the CACC (Göncüoğlu *et al.* 1991). The relative positions of the units sampled for the geochemical review are enclosed in envelopes: stratiform ophiolites, metamorphosed ophiolitic mélange and Kaleboynu Formation amphibolites.

Apart from a cover of uppermost Cretaceous–Miocene volcanic and sedimentary rocks, the CACC (Fig. 1) comprises three fundamental lithological units (Göncüoğlu *et al.* 1991): (1) a mainly amphibolite facies metamorphic basement dominated by marble with subordinate pelitic to psammitic schists, gneisses and metabasites (the Central Anatolian Metamorphics); (2) fragmented ophiolitic remnants of pillow lavas, dykes and gabbros with minor ultramafic rocks and plagiogranites; and (3) two sets of granitoid rocks. Generalized stratigraphic relationships within the CACC are shown in Fig. 2 (not to scale).

The abundance of marbles with a carbonate-platform affinity in the basement suggests that it is the metamorphosed equivalent of the TAP. Due to recrystallization, precursor ages from fauna in the marbles are difficult to determine, but largely range in age from Triassic to Early Cretaceous, although some have suggested a Late Palaeozoic age (Silurian–Devonian) for the lower parts of the complex (e.g. Koçak & Leake 1994; Fig. 2). The regional metamorphism is generally considered to be pre-mid-Cretaceous (Göncüoğlu 1982). Two sets of acid plutonics are recognized: an early, but post-metamorphic, group of syncollisional (95 ± 11 Ma) and post-collisional granites (76–71 Ma; Rb–Sr whole rock) and a later group of cross-cutting syenites (71–70 Ma; Rb–Sr, K–Ar) (Ataman 1972; Göncüoğlu 1986; Göncüoğlu & Türeli 1993; Erler & Göncüoğlu 1996; Göncüoğlu *et al.* 1997). These are important markers relative to the formation age of the ophiolitic fragments in the CACC (see below) and demonstrate that, during collision, melting of continental crust both preceded suprasubduction-type ophiolite crust formation and postdated its subsequent obduction.

Metabasites and ophiolites

Pertinent to this overview are two tectonically separate magmatic groups: (1) metabasite bodies within the basement (Central Anatolian Metamorphics), as well as blocks from a separate ophiolitic mélange unit; and (2) massive stratiform ophiolites, together with various isolated remnants of suspected ophiolitic parentage.

Metabasites were sampled from the Kaleboynu Formation (that may, in part, be Triassic in age) and the structurally higher ophiolitic mélange unit (matrix of possible Late Cretaceous age; Fig. 2). In the Kaleboynu Formation, the metabasites comprise multiple, relatively thin, concordant bodies often intimately associated with minor metapelites and highly siliceous sediments, representing pelagics and cherts, respectively. This is typical of the basement around Niğde (Fig. 1) which exhibits a high proportion of contorted marble with infolds of metabasites and metasediments. In contrast, various metabasite, meta-ultramafic and metafelsic rocks have been sampled from the metamorphosed ophiolitic mélange unit, where all three lithologies commonly occur as boudins, together with marble blocks derived from the Aşığediği Formation below, in a sheared metapelitic or calc-pelite matrix. This is a common occurrence in the northern part of the CACC around Kırşehir, where a relatively high proportion of metamagmatic lithologies are present in the tectonic mélange.

The other main set of basaltic rocks in the CACC are represented by variously fragmented ophiolites thrust/obducted over the basement (Fig. 2). These are low-grade greenschist facies, stratiform sequences of pillowed and massive metabasalts with sheeted dykes and associated gabbros (Yalınız *et al.* 1996). Plagiogranites developed throughout the plutonic and volcanic portions of the ophiolite are common (Göncüoğlu & Türeli 1993; Floyd *et al.* 1998). The largest ophiolites are the Sarıkaraman and Çiçekdağ Ophiolites (Fig. 1), which exhibit a typical suprasubduction zone (SSZ) chemistry (Yalınız *et al.* 1996; Yalınız & Göncüoğlu 1998). Scattered throughout the CACC are tectonically isolated remnants of pillow lavas or gabbros (both with dykes) that may also have an ophiolitic parentage. Based on the faunal content of pelagic sediments covering the volcanic portion of the massive stratiform ophiolites, formation ages are generally Middle Turonian–Early Santonian (90–85 Ma; Yalınız & Göncüoğlu 1998). These oceanic segments were short lived (5–10 Ma), as deep slicing and obduction over the metamorphic basement was rapidly followed by the intrusion of the late granitoids that cut the ophiolites at around *c.* 76–71 Ma (e.g. the Terlemez Monzogranite intrudes the Sarıkaraman Ophiolite; Floyd *et al.* 1998).

Objectives and comparisons

The main objectives of this paper are to: (1) review the chemical features of the metabasites within the CACC metamorphic basement and the fragmented stratiform ophiolites obducted over it; and (2) compare the basaltic compositions with reference units to determine their affinities and aid discrimination of their geotectonic environment. The chemical features of minor metafelsic and meta-ultramafic bodies in the basement will also be briefly discussed to decide whether they might be equivalent to ophiolitic plagiogranites and (mantle) cumulates, respectively.

In the light of current tectonic models, which suggest that the basement metabasites were derived from the İzmir–Ankara–Erzincan Ocean, comparisons will be made with metabasalts from the Ankara ophiolitic Mélange (Çapan & Floyd 1985; Floyd 1993). In a similar manner, those CACC obducted ophiolites with suprasubduction features (e.g. Sarıkaraman Ophiolite; Yalınız *et al.* 1996) will provide a chemical template for other isolated metabasic units with suspected ophiolitic affinities; e.g., pillow lavas in the Çankırı Basin and tectonically isolated gabbro bodies with associated dykes.

Determination of chemical affinity is relatively straightforward, although direct regional comparisons suffer from two problems: (1) that many of the carbonate sequences (marble) in the basement have not been dated and hence the age of associated volcanism is unknown; and (2) structural relationships are often complex and the assignment of metabasites to a particular basement formation has previously been based on apparently similar lithological associations. A broad comparison can be made with the carbonate platform of the TAP, but this features few volcanic rocks away from its northern edge. Thus, at best, this review, offers possible correlations and discriminations based on the data available and a model that emphasizes the chemical differences between the basement metabasites (possibly Late Triassic and/or broadly Jurassic–Early Cretaceous) and the later stratiform ophiolites, well documented as Late Cretaceous.

In summary, the following sampled units and groups of lithologies are chemically characterized and compared in this paper: (1) ophiolitic plagiogranites and basement metafelsic blocks (from the metamorphosed ophiolitic mélange); (2) basement meta-ultramafic rocks (from the Kaleboynu Formation and the metamorphosed ophiolitic mélange); (3) basement metabasites (from the Kaleboynu Formation and the metamorphosed ophiolitic mélange); and (4) stratiform ophiolites (the Sarıkaraman and Çiçekdağ Ophiolites), together with tectonically isolated remnants thought to have an ophiolitic parentage or affinity.

Petrographic summary of basic compositions

Stratiform ophiolites and tectonically isolated remnants

The Sarıkaraman and Çiçekdağ Ophiolites are the best representatives of fragmented stratiform bodies in the CACC; the former has already been described by Yalınız *et al.* (1996).

The volcanic portion of the Çiçekdağ Ophiolite has many features in common with the Sarıkaraman Ophiolite, exhibiting both massive and pillowed basalts cut by various feeder dykes, all of which have undergone low-grade greenschist or pumpellyite facies metamorphism. The Çiçekdağ sheeted dyke complex comprises aphyric and plagioclase–phyric metabasalts and dolerites with any minor interstitial glass replaced by chlorite. Carbonate, chlorite, quartz and minor epidote are common replacement minerals. The lavas may be aphyric, or exhibit a number of phenocryst assemblages, including olivine, plagioclase, plagioclase–clinopyroxene, all of which may be set in a variably quenched matrix of serrated plagioclase microlites, variolitic fans of crystallites and an opaque, originally glassy, matrix. Secondary assemblages are typically actinolite, chlorite or chlorite–smectite, carbonate, epidote and rarer pumpellyite. Interiors of pillow lavas and massive flows are coarser grained and generally holocrystalline, whereas the margins are glassy and often develop spherulites. Pillow breccias show similar textures and petrography. No systematic petrographic changes have yet been noted with stratigraphic height in the lava sequence, except that the upper basalts tend to be generally aphyric. Feeder dykes to the lavas are dominated by aphyric and plagioclase–phyric basalts and are commonly altered with variable proportions of epidote, actinolite, carbonate and chlorite.

The isolated outcrops of metagabbro and dykes seen at the Bozkır Dam Quarry and the Aktaş Dam and nearby Dokuzlar sites (locations 7, 22 and 15, respectively in Fig. 1) are also of assumed ophiolitic parentage. In each case, a variety of massive and tectonised metagabbros are exposed, cut by both basaltic and plagiogranite dykes. The gabbros have been variably amphibolitized and range from examples showing relict subophitic clinopyroxene and plagioclase surrounded by amphibole, to foliated hornblende–plagioclase amphibolites and massive granular-textured quartz-bearing amphibolites with rare pyroxene relicts. The basaltic dykes are generally plagioclase–phyric and variably altered.

Other tectonically isolated remnants include outcrops of pillow lavas, such as those which form a local basement to Tertiary basin-fill sediments in the Çankırı Basin (location 1 in Fig. 1). The pillow lavas, which are often highly altered by carbonate and chlorite, are represented by aphyric and plagioclase ± clinopyroxene–phyric metabasalts.

Basement metabasites

Although the metabasites are mainly amphibolites, some larger bodies retain relict textures and mineralogy indicating that they were originally gabbros or dolerites. While this is invariably true of the boudins found in the metamorphosed ophiolitic mélange unit, it is not seen in the concordant Kaleboynu Formation amphibolites. Throughout the basement, metamorphism was broadly amphibolite facies, although the variable colour of the hornblende (pale green, brownish green and blue-green) implies a range of conditions within this facies (e.g. Miyashiro 1973). The association of migmatitic sillimanite + garnet-bearing gneisses with amphibolites in the south of the CACC implies peak metamorphic conditions of 600–700°C at 4 kbar for the lowermost Gümüşler Formation (Koçak & Leake 1994).

Metabasite blocks from the Upper Cretaceous ophiolitic mélange (Fig. 2) range from coarse-grained amphibolites with strongly pleochroic hornblende (yellow to brownish green), granular plagioclase and minor quartz, to hornblende–quartz schists. Some coarser varieties of clear gabbroic parentage retain relict magmatic clinopyroxene and exhibit a granoblastic mosaic of sieve-textured clinopyroxene with plagioclase, quartz and abundant titanite. Progressive amphibolitization produced various hornblende schists, some with relict clinopyroxene, and abundant sphene which appears characteristic for this group of metabasites. Concordant Kaleboynu Formation metabasites from the Niğde area (Fig. 1) are dominated by fine-grained amphibolites or hornblende schists, and are characterized by variable secondary carbonate and epidote, probably resulting from penetration of these thin bodies by late circulating fluids from the adjacent marbles.

Analytical methods and alteration effects

Representative metabasaltic lavas were collected from the Çiçekdağ Ophiolite (Table 1) and tectonically isolated (presumed ophiolitic) gabbro bodies and pillow lava sequences (Table 2) for comparison with the Sarıkaraman Ophiolite [previously described by Yalınız *et al.* (1996)]. A suite of basement metabasites represented by foliated and massive amphibolites (Table 3), together with minor metafelsic and meta-ultramafic rocks, were collected from the Kaleboynu Formation and ophiolitic mélange. All were analysed for major and selected trace elements on an ARL 8420 X-ray fluorescence (XRF) spectrometer (Department of Earth Sciences, University of Keele), calibrated against both international and internal Keele standards of appropriate composition. Details of methods, accuracy and precision are given in Floyd & Castillo (1992).

The metabasite samples show varying degrees of low-grade mineralogical alteration (within the pumpellyite to amphibolite facies) and as such can be expected to have suffered selected element mobility, especially involving the large-ion lithophile (LIL) elements (e.g. Hart *et al.* 1974; Humphris & Thompson 1978; Thompson 1991). LIL element (e.g. K, Na, Rb, Ba, Sr) abundances are often highly variable, together with most major elements and ratios (e.g. FeO*/MgO), and are unreliable as indicators of petrogenetic relationships or tectonic discrimination. This is particularly true for the volcanic sequence of ophiolites where mineralogical and chemical alteration by submarine hydrothermal processes are well known (e.g. Gass & Smewing 1973; Pearce & Cann 1973; Spooner & Fyfe 1973; Smewing & Potts 1976). However, characteristic magmatic interelement relationships are often maintained by those elements that are considered relatively immobile during alteration, such as high field strength (HFS) elements and the rare earth elements (REE) (e.g. Pearce & Cann 1973; Smith & Smith 1976; Floyd & Winchester 1978). Under some circumstances, such as the extensive carbonatization of metabasites, the REE and HFS elements can also be mobilized and/or abundances diluted (e.g. Hynes 1980; Humphris 1984; Rice-Birchall & Floyd 1988), although this appears only to have seriously affected the meta-ultramafic rocks (see below).

Geochemistry of plagiogranites and basement metafelsics

Trondjemites and rhyolites (plagiogranite suite) of the Sarıkaraman Ophiolite associated with the gabbros and basalts, respectively, have compositions typical of other plagiogranites worldwide (Floyd *et al.* 1998). Both sets of plagiogranites from the stratiform Sarıkaraman and Çiçekdağ Ophiolites have typically low and uniform Nb values (Fig. 3). This feature distinguishes them from the late post-collisional granitoids (that cut the ophiolites) which display Zr/Nb ratios of *c.* 10. Various felsic or feldspar porphyry dykes that cut isolated pillow lava sequences and gabbro remnants also have similar chemical features to the plagiogranites. This suggests that they are also part of the plagiogranite suite and that their basic hosts represent tectonically isolated ophiolite remnants.

On the other hand, variably foliated metafelsic bodies within the basement (blocks from the metamorphosed ophiolitic mélange) have similar Zr/Nb ratios to the late granitoids, but tend to be less evolved (Fig. 3). Although these metafelsic rocks generally have low HFS element abundances they do not appear to belong to an earlier basement plagiogranite suite, but have features more akin to post-collisional, or possibly arc-related, 'granites' which commonly have Zr/Nb > 10 (Leat *et al.* 1986). It is suggested that the metafelsic rocks are not comagmatic with the associated basement metabasites but probably represent independent acid melts generated by crustal melting within an arc, or during continent collision, prior to incorporation in the ophiolitic mélange.

Geochemistry of meta-ultramafic bodies

Large boudins within segments of highly deformed ophiolitic mélange have many of the features typical of 'knockers' (Karig 1980). High MgO, Ni and Cr contents, together with a serpentine–talc–carbonate mineralogy, indicate an ultramafic parentage. However, most have suffered variable Ca and Sr metasomatism relative to fresh ultramafic compositions (Fig. 4), reflecting the mobility of these elements in the surrounding carbonate-rich mélange matrix during shearing. On the basis of their Ni and Cr contents (Floyd *et al.* 1993), the meta-ultramafic rocks comprise two separate groups, some of which have a clear ophiolitic affinity, while others represent cumulates associated with continental intrusive gabbro bodies. The low Ni and

Table 1. *Representative chemical analyses of basaltic lavas from the Sarıkaraman and Çiçekdağ Ophiolites*

	Sarıkaraman ophiolite basaltic lavas										Çiçekdağ ophiolite basaltic lavas									
Sample number	P-3	P-10	P-12	P-14	P-15	P-16	P-17	P-18	P-19	M-19	C-6	C-9	C-10A	C-10B	C-11	C-13	C-16	C-17	C-18	C-19
Major oxides (wt%) by XRF spectrometry																				
SiO_2	53.26	55.27	38.62	50.53	64.25	56.43	47.65	50.33	55.58	47.01	53.12	53.72	51.59	57.12	47.36	54.01	45.45	51.19	49.99	40.67
TiO_2	0.86	1.36	0.78	0.70	0.91	0.63	1.03	0.69	0.62	1.50	1.39	0.44	1.20	1.08	0.76	1.21	1.06	1.32	0.66	0.84
Al_2O_3	16.07	12.57	14.28	13.05	11.58	11.67	16.17	14.58	12.17	15.32	16.63	13.43	15.91	14.21	14.03	16.66	17.93	14.87	15.74	12.18
Fe_2O_3t	10.32	13.37	8.61	8.38	8.18	7.52	9.07	7.59	5.80	13.30	12.31	9.85	15.39	12.47	12.10	12.09	11.44	12.42	9.11	8.75
MnO	0.09	0.26	0.41	0.34	0.07	0.29	0.11	0.24	0.24	0.32	0.26	0.18	0.20	0.16	0.21	0.13	0.18	0.14	0.13	0.10
MgO	3.68	7.93	13.66	13.89	4.02	12.30	9.49	10.89	8.75	5.53	3.90	8.96	5.43	3.25	6.64	4.00	6.88	3.97	5.74	1.65
CaO	12.10	4.03	9.25	3.36	8.14	2.71	5.09	5.34	6.41	5.73	7.55	5.92	2.53	2.82	5.65	1.60	12.21	4.76	6.33	16.50
Na_2O	0.01	0.01	2.33	1.16	0.01	1.20	4.09	3.04	2.98	3.95	3.69	5.05	5.73	7.09	7.14	8.64	2.41	4.20	2.46	6.67
K_2O	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.43	0.09	0.17	0.07	0.08	0.20	0.37	0.04	0.18	0.09
P_2O_5	0.06	0.08	0.05	0.05	0.07	0.05	0.10	0.05	0.04	0.10	0.06	0.04	0.08	0.09	0.05	0.08	0.04	0.13	0.06	0.19
LOI	3.16	4.99	11.83	8.51	2.75	7.18	6.92	7.52	7.45	7.37	0.81	2.51	1.55	1.35	5.75	1.01	1.88	6.92	9.44	12.68
Total	99.62	99.88	99.83	99.98	99.99	99.99	99.73	100.28	100.05	100.14	100.15	100.19	99.78	99.71	99.77	99.63	99.85	99.96	99.84	100.32
Trace elements (ppm) by XRF spectrometry																				
Ba	12	7	5	14	9	7	11	20	5	8	73	36	25	76	47	182	53	17	55	24
Ce	10	1	3	3	10	9	1	2	10	8	3	1	10	3	1	6	3	5	2	2
Cl	50	54	46	86	59	54	58	107	72	44	226	1	5	5	3	5	4	2	3	1
Cr	116	49	487	460	116	452	204	311	359	24	21	345	24	9	254	38	127	27	110	242
Cu	14	18	9	10	10	3	7	8	16	32	89	162	161	170	74	50	68	45	109	37
Ga	17	15	10	12	16	10	15	12	9	17	20	10	13	18	15	13	19	20	12	8
La	1	1	1	1	2	1	1	1	1	1	3	3	1	1	2	2	1	4	1	1
Nb	2	3	1	1	2	1	1	1	1	3	2	1	2	2	2	2	4	2	1	2
Nd	19	8	13	11	11	7	8	14	5	11	5	7	15	1	7	11	9	16	3	6
Ni	35	18	186	164	46	187	76	115	124	14	7	55	17	18	70	12	54	16	50	85
Pb	10	6	6	6	8	7	4	6	2	7	75	9	9	4	15	6	30	2	5	12
Rb	3	5	4	3	4	3	3	3	3	4	17	2	2	5	3	6	6	3	8	2
S	65	72	70	76	70	82	75	80	85	88	210	1	2	19	10	9	3	23	12	48
Sr	325	103	76	34	192	27	78	99	75	31	190	92	66	134	108	124	737	41	34	106
V	327	442	219	262	258	217	260	245	164	528	301	281	576	648	433	385	356	451	332	251
Y	25	25	17	11	20	11	25	17	12	26	25	12	23	28	17	26	34	31	17	22
Zn	23	186	115	137	24	108	49	111	78	202	195	68	80	135	130	52	75	115	72	82
Zr	54	71	57	53	58	50	70	53	48	76	48	20	43	47	32	66	77	80	37	52

Table 2. *Representative chemical analyses of metamorphosed gabbros and basaltic pillow lavas from tectonically isolated ophiolitic fragments*

	Aktaş Dam gabbros							Aktaş Dam dykes			Çankırı Basin lavas							Çankırı Basin dykes		
Sample number	AK-1	AK-2	AK-3	AK-4	AK-5	AK-12	AK-13	AK-6	AK-7	AK-8	AY-5	AY-8	AY-9	AY-11	AY-18	AY-19	AY-20	AY-6	AY-10	AY-21
Major oxides (wt%) by XRF spectrometry																				
SiO_2	51.10	50.50	49.44	48.24	49.91	48.45	52.77	49.33	51.65	48.77	45.47	49.65	50.46	54.89	53.00	47.62	47.43	52.16	54.71	50.05
TiO_2	0.25	0.16	0.46	0.44	0.46	0.42	0.59	0.47	0.74	0.51	1.65	1.28	0.96	1.27	0.58	1.54	1.27	1.40	1.03	1.06
Al_2O_3	21.30	14.65	12.74	15.33	13.60	11.23	18.81	14.22	18.20	11.91	16.94	17.13	17.68	15.73	19.77	16.52	15.73	16.01	15.74	17.90
$Fe_2O_3{}^t$	5.76	5.92	9.76	9.89	9.43	8.99	7.36	10.40	12.18	17.19	11.86	9.60	10.30	4.54	13.65	12.88	13.07	7.46	9.22	8.75
MnO	0.13	0.11	0.18	0.17	0.15	0.15	0.14	0.18	0.18	0.23	0.21	0.25	0.16	0.15	0.11	0.22	0.20	0.13	0.28	0.22
MgO	5.10	11.60	13.89	9.95	12.22	15.64	4.75	11.28	5.28	11.95	6.39	5.42	4.18	4.38	1.69	4.37	5.29	3.40	3.50	5.82
CaO	12.08	14.82	10.84	13.68	10.62	12.00	10.55	11.72	9.70	12.15	1.96	4.78	6.16	4.31	4.49	7.55	5.44	4.01	5.17	4.70
Na_2O	2.11	0.78	1.30	0.94	1.53	1.09	3.53	1.76	3.67	1.44	5.74	5.70	6.14	5.99	4.69	4.10	5.32	6.94	6.66	5.38
K_2O	0.85	0.29	0.17	0.37	0.18	0.12	0.19	0.22	0.11	0.20	0.03	0.09	0.02	0.05	7.12	0.17	0.03	0.04	0.03	0.02
P_2O_5	0.01	0.01	0.03	0.02	0.03	0.03	0.43	0.04	0.08	0.01	0.12	0.15	0.12	0.16	0.25	0.14	0.16	0.17	0.16	0.14
LOI	1.01	1.14	0.97	1.25	1.54	1.37	0.78	1.25	0.42	0.53	4.63	3.28	4.14	2.70	4.19	5.98	5.73	2.67	5.47	5.46
Total	99.70	99.98	99.78	100.28	99.67	99.49	99.90	99.75	100.43	99.88	100.33	99.59	99.62	99.93	100.43	100.38	100.27	99.72	100.48	99.97
Trace elements (ppm) by XRF spectrometry																				
Ba	58	38	49	67	35	21	52	13	38	15	68	48	41	63	31	116	33	47	38	52
Ce	1	2	2	2	2	1	1	12	1	1	3	15	11	17	4	2	8	3	12	2
Cl	1	2	109	44	86	142	287	65	97	93	3	4	2	3	31	2	3	2	3	4
Cr	154	291	971	448	721	1443	167	647	35	699	1	19	38	20	42	13	62	1	59	123
Cu	12	22	29	40	45	41	36	23	48	22	18	95	15	31	79	54	20	20	14	40
Ga	17	10	13	10	12	11	18	13	17	14	17	17	14	14	20	17	14	18	14	15
La	1	2	2	1	2	1	5	2	3	1	2	2	3	2	1	1	1	1	4	2
Nb	3	3	1	2	2	2	3	2	3	3	5	5	4	5	4	3	5	6	6	5
Nd	11	6	2	1	3	2	6	18	1	4	6	15	11	17	6	8	10	11	17	4
Ni	30	107	266	55	207	241	33	191	15	172	11	18	24	13	22	8	33	9	27	45
Pb	20	16	6	10	9	1	3	11	7	11	2	2	5	5	9	6	7	5	5	3
Rb	31	10	7	16	5	8	8	5	2	3	1	3	2	1	1	3	1	1	1	1
S	1	2	2	1	41	3	4	3	2	1	2	27	3	1	6	17	1	2	2	2
Sr	163	79	165	92	84	56	215	94	187	64	66	149	138	126	345	170	72	77	88	104
V	119	116	248	303	244	229	116	247	257	344	420	356	246	308	295	420	351	368	219	252
Y	14	8	14	11	15	11	21	15	23	16	18	29	22	29	19	19	26	29	22	18
Zn	52	37	72	61	70	59	55	65	84	93	148	108	111	101	82	112	104	87	64	104
Zr	15	13	23	15	26	20	40	24	33	21	54	89	66	91	61	36	90	100	90	80

Table 3. *Representative chemical analyses of metabasites (massive and foliated amphibolites) in different segments of the CACC metamorphic basement*

	Metamorphosed ophiolitic mélange										Kaleboynu Formation									
Sample number	CM-9	CM-10	CM-11	CM-15	AD-1	AD-3	AD-5	ED-3	ED-4	ED-5	GT-8	GT-11	GT-14	GT-17	CO-2	CO-4	CO-5	KV-1	KV-2	KV-3
Major oxides (wt%) by XRF spectrometry																				
Sio$_2$	51.47	47.01	49.96	45.12	52.35	51.56	52.72	55.69	54.36	50.01	44.70	48.38	44.24	48.73	48.19	45.63	53.26	46.19	52.29	52.34
TiO$_2$	0.50	0.91	1.44	1.09	1.00	0.86	1.29	1.53	1.51	1.68	3.43	0.97	1.53	1.57	2.68	0.86	0.93	0.60	0.86	1.00
Al$_2$O$_3$	14.80	17.40	15.38	13.98	16.93	15.69	14.35	14.18	15.17	15.56	12.62	15.50	12.02	12.05	13.77	13.04	14.19	15.81	11.26	11.41
Fe$_2$O$_3$^{t}	8.65	8.90	12.21	13.08	9.65	9.25	9.80	12.31	12.59	13.39	15.32	8.05	13.27	12.85	16.26	6.65	6.97	12.05	7.31	6.94
MnO	0.17	0.17	0.18	0.21	0.17	0.17	0.20	0.16	0.18	0.20	0.16	0.19	0.27	0.23	0.20	0.11	0.11	0.20	0.21	0.18
MgO	8.82	7.03	6.32	9.84	4.14	5.67	6.09	4.12	4.34	5.67	10.17	6.68	10.05	8.37	6.00	4.19	3.67	7.43	5.60	6.21
CaO	9.96	12.31	9.20	11.14	9.20	9.82	9.29	7.78	8.37	8.68	9.00	11.48	12.67	11.11	9.10	21.06	16.55	13.62	17.49	17.06
Na$_2$O	4.21	3.98	4.47	2.23	4.99	4.68	3.84	3.47	2.93	3.23	2.73	3.90	1.85	2.72	3.17	1.55	1.30	1.85	2.32	2.18
K$_2$O	0.25	0.32	0.36	0.34	0.35	0.42	0.36	0.22	0.55	0.45	0.14	1.87	1.51	0.79	0.49	2.10	1.89	0.58	1.49	2.04
P$_2$O$_5$	0.08	1.64	0.08	0.01	0.27	0.24	0.24	0.14	0.11	0.14	0.41	0.13	0.23	0.29	0.28	0.15	0.15	0.10	0.16	0.20
LOI	0.93	0.58	0.64	2.84	1.35	1.50	1.55	0.28	0.39	0.73	1.59	3.15	2.74	1.29	0.23	4.68	1.51	0.94	1.51	1.03
Total	99.84	100.25	100.24	99.88	100.40	99.86	99.73	99.88	100.50	99.74	100.27	100.30	100.38	100.00	100.37	100.02	100.53	99.37	100.50	100.59
Trace elements (ppm) by XRF spectrometry																				
Ba	39	74	175	155	68	99	70	27	35	52	31	200	223	71	48	185	198	81	262	304
Ce	3	1	9	10	42	17	28	5	8	3	73	20	15	4	18	50	47	6	37	38
Cl	2	23	2	61	15	3	127	65	146	57	4	2	1	1	2	204	2	19	158	3
Cr	477	233	75	123	173	263	321	181	149	150	1129	357	513	486	248	193	240	184	324	319
Cu	62	20	194	17	112	93	70	38	53	52	33	68	54	63	29	22	15	123	24	66
Ga	14	17	16	13	18	17	14	18	19	20	22	15	17	16	19	18	19	15	16	13
La	2	1	1	1	15	14	11	2	2	4	26	4	5	7	6	23	33	3	14	26
Nb	2	3	4	6	9	9	21	5	4	6	38	8	21	23	7	22	29	3	16	24
Nd	8	12	13	16	28	12	24	11	17	10	40	17	14	7	15	28	22	10	25	22
Ni	112	61	34	80	35	56	106	31	21	31	244	104	305	276	64	60	65	35	121	129
Pb	7	22	18	16	10	8	10	5	8	6	12	1313	14	15	4	17	11	9	14	18
Rb	3	4	4	7	9	12	11	9	19	15	3	45	38	13	11	78	62	18	52	69
S	2	1	26	2	5	5	4	18	2	20	2	172	3	1	16	17	5	5	17	14
Sr	163	786	247	360	546	315	273	82	75	50	175	258	199	243	161	974	735	335	313	350
V	236	259	370	438	234	227	226	448	410	412	378	170	193	215	479	81	93	311	113	109
Y	15	25	30	31	25	21	29	35	37	41	27	20	19	20	58	27	29	14	27	27
Zn	58	75	80	83	84	65	89	80	91	106	122	172	121	107	135	94	109	78	112	90
Zr	24	41	85	85	105	92	119	88	93	108	204	77	89	89	173	148	179	23	118	147

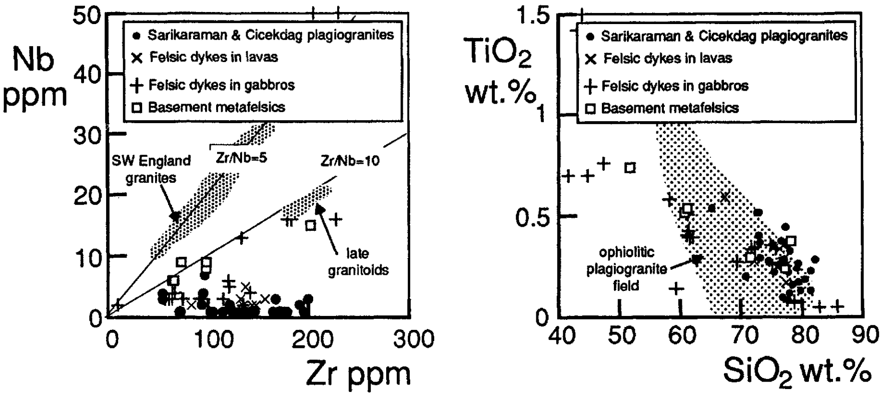


Fig. 3. Nb v. Zr and TiO_2 v. SiO_2 diagrams for various felsic rocks from the CACC: Sarıkaraman and Çiçekdağ ophiolitic plagiogranites [some data from Floyd *et al.* (1998)], metafelsics from the metamorphic basement, and late cross-cutting granitoids. Ophiolitic plagiogranites with very low and uniform Nb values are distinguishable from both basement metafelsics and the late granitoids. Ophiolitic plagiogranite field from Gerlach *et al.* (1981 and refs cited therein); data for southwest England granite field (high-level, post-collisional granites) from Exley *et al.* (1983).

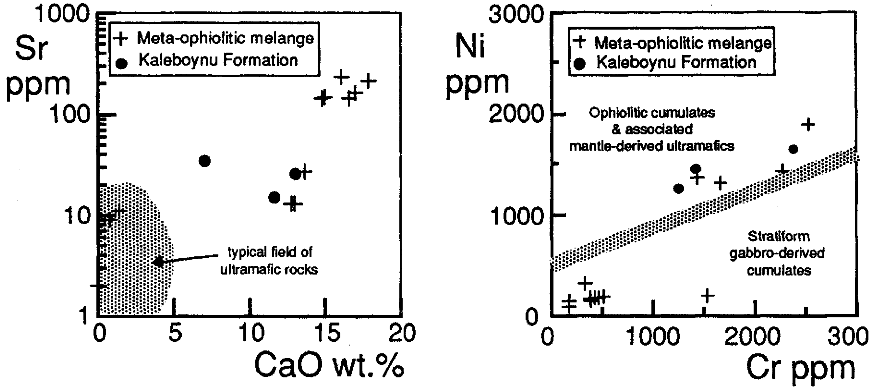


Fig. 4. Sr v. CaO and Ni v. Cr diagrams for meta-ultramafic bodies within the metamorphic basement complex of the CACC. Two chemical groups of meta-ultramafic rocks are probably present, some of which have subsequently been metasomatically enriched in Sr and Ca. Generalized ultramafic field from literature.

Cr values are not a consequence of metasomatic dilution as the Ca contents are variable throughout this group. The presence of ophiolitic ultramafics is to be expected as many of the associated metabasite blocks have mid-ocean ridge basalt (MORB) chemical characteristics (see below), both of which imply an oceanic regime. The low-Ni + Cr group, on the other hand, has chemical affinities with typical stratiform gabbros and might represent early gabbros intruded in a rifted continental setting prior to major ocean development.

Geochemistry of stratiform ophiolites

The Sarıkaraman Ophiolite has previously been shown to be a fragmented stratiform body with a volcanic section exhibiting typical suprasubduction zone (SSZ) characteristics similar to other Neotethyan ophiolites (Yalınız *et al.* 1996). The Çiçekdağ Ophiolite (location 4 in Fig. 1), of which the volcanic section also makes up the dominant exposed portion, has similar chemical features to the Sarıkaraman Ophiolite, with low, depleted incompatible element contents

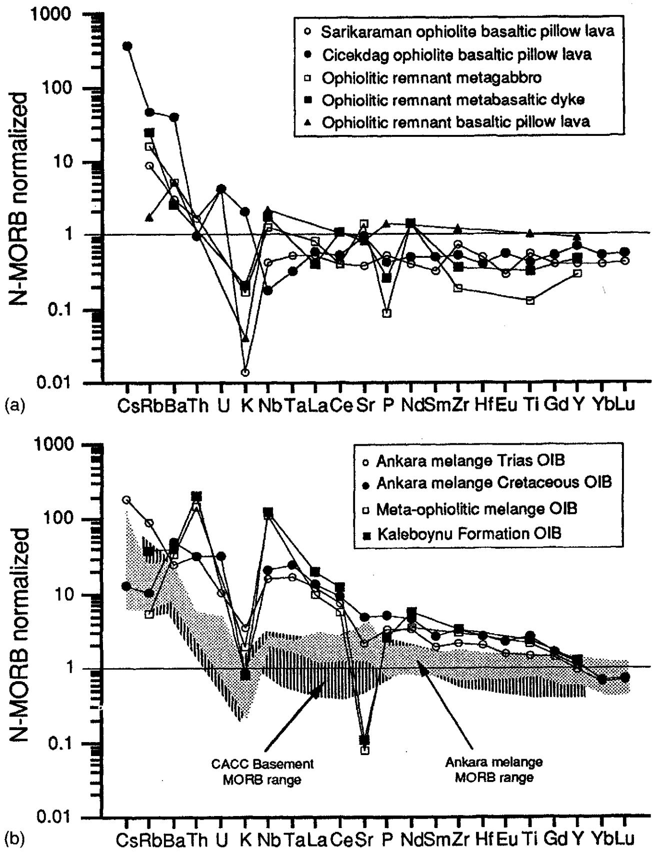


Fig. 5. (**a**) Representative multi-element patterns for Sarıkaraman and Çiçekdağ ophiolite pillow lavas (obducted stratiform ophiolites with suprasubduction zone features) compared with isolated remnants (gabbros with dykes, pillow lava sequences) of suspected ophiolitic affinity. (**b**) Normalized multi-element comparison between MORB and OIB in the CACC and Ankara Mélange. Sarıkaraman data from Yalınız *et al.* (1996), Ankara Mélange data from Floyd (1993). Normalization factors after Sun & McDonough (1989).

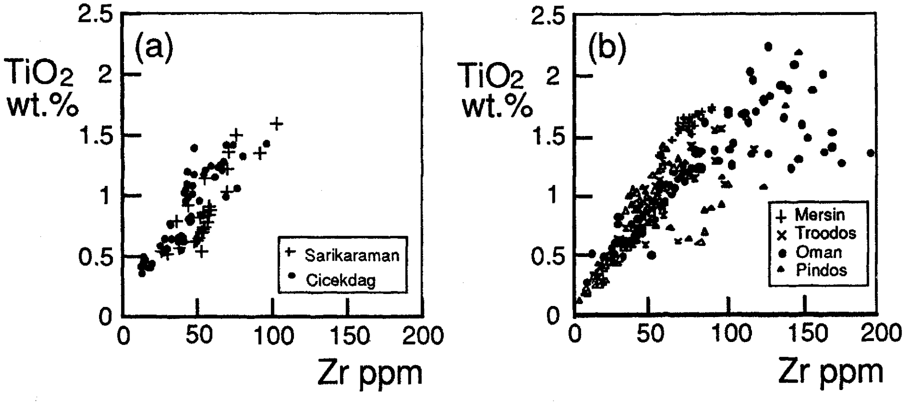
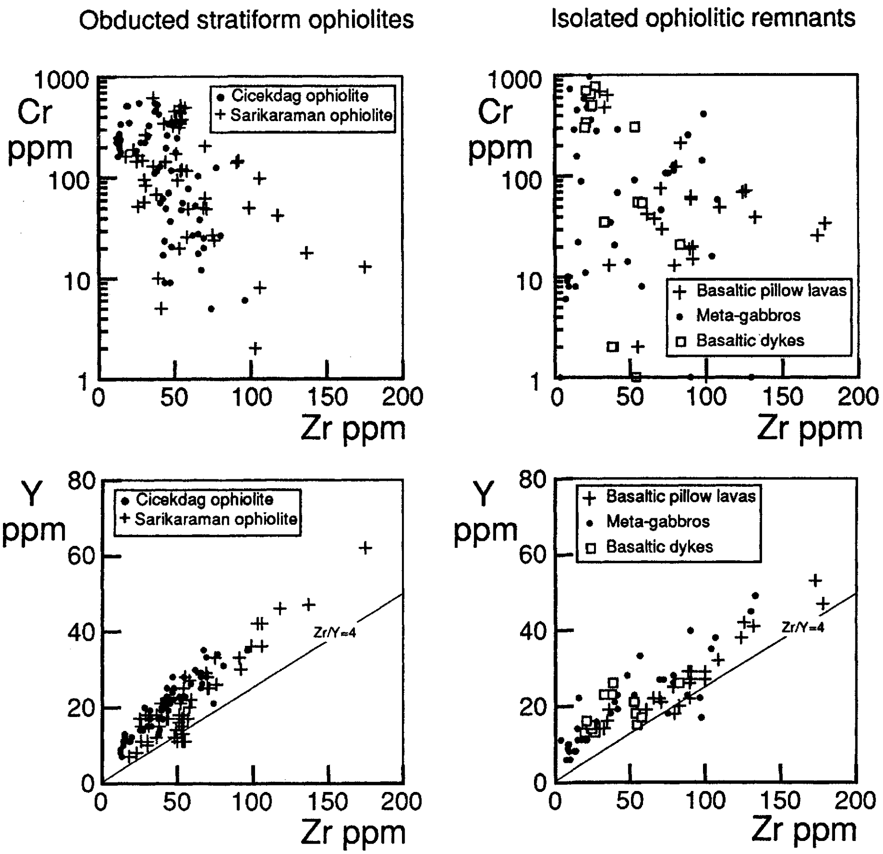


Fig. 6. TiO_2 v. Zr diagrams comparing basaltic lavas from the Sarıkaraman and Çiçekdağ Ophiolites of the CACC with other Neotethyan ophiolites with suprasubduction zone features. Data: Sarıkaraman (Yalınız *et al.* 1996); Mersin (Parlak 1996); Oman (Alabaster *et al.* 1982); Pindos (Valsami 1990); Troodos (Pearce 1975; Smewing & Potts 1976).


Obducted stratiform ophiolites

Isolated ophiolitic remnants

Fig. 7. Cr v. Zr and Y v. Zr diagrams comparing data for obducted stratiform ophiolites and tectonically isolated remnants represented by pillow lava sequences and gabbros with dykes, found within and adjacent to the CACC. The Çankırı Basin metabasalts define a similar trend to the pillow lavas of the ophiolites, but at a slightly higher ratio approaching Zr/Y = 4. Sarıkaraman data from Yalınız *et al.* (1996).

relative to MORB (Fig. 5) that reinforces their SSZ affinities. Both of these CACC stratiform ophiolites have features that can be directly compared with other ophiolites from the Neotethyan zone (e.g. Pindos, Mersin, Troodos, Oman). As seen in Fig. 6, they closely match the variation (in terms of TiO_2 and Zr) shown by the Pindos Ophiolite, but lack the degree of extensive chemical evolution shown by Mersin (highly evolved, but restricted in composition) or the range of Oman (to tholeiitic andesites).

Further evidence for the broad chemical overlap in composition between the two ophiolites is shown in Fig. 7, where the range in composition is largely a function of mafic ± plagioclase fractionation (decreasing Cr, with covariant and increasing Zr and Y). Although there is a dominant subduction-related signature similar to island-arc basalts (IAB) rather than MORB in terms of V v. TiO_2 distributions (Fig. 8), some metabasalts from both ophiolites spill over into the MORB field. On comparison with island-arc–back-arc basin pairs from the western Pacific (Woodhead *et al.* 1993), the more MORB-like components of the ophiolites appear to have back-arc characteristics with very low V/Ti ratios (Fig. 8). As many of these basalts are stratigraphically uppermost in the ophiolite lava sequence, the apparent change in chemical designation might suggest a transition to a back-arc environment.

Differences between the ophiolites are essentially restricted to the Çiçekdağ metabasalt lavas and dykes, showing a more limited range of Zr and Y contents (less fractionated), and lacking the special group of Sarıkaraman lavas characterized by uniform Zr values (50–60 ppm Zr) and variable Y contents (Fig. 7). However, as the formation ages and basalt chemistries are generally similar, they are considered to be

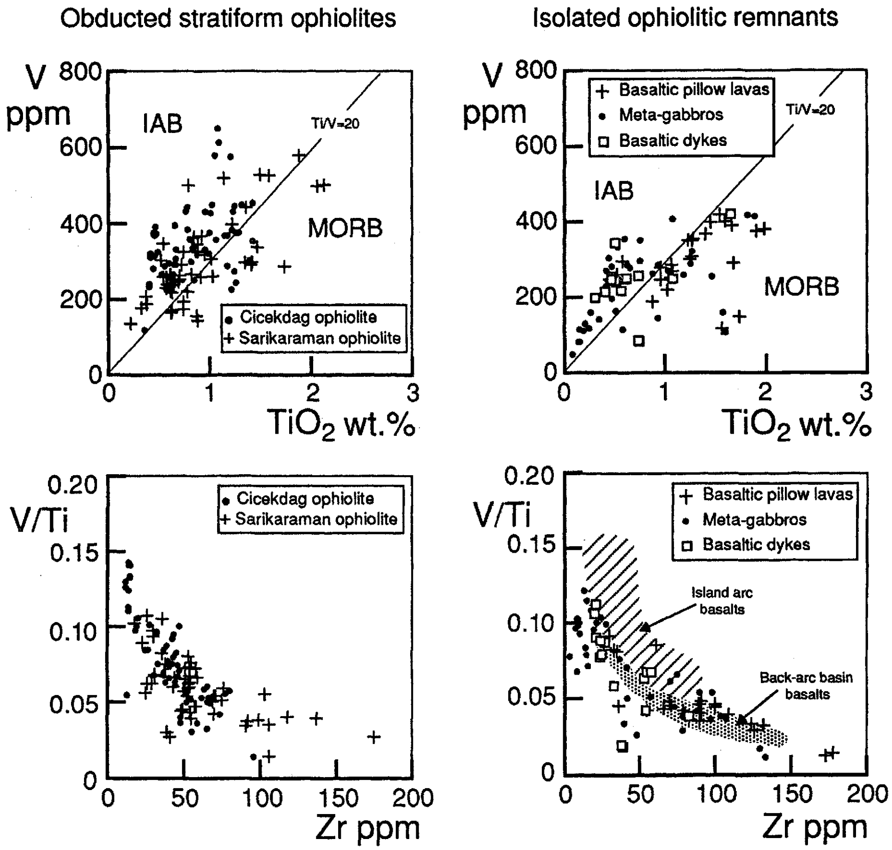


Fig. 8. V v. TiO_2 and V/Ti v. Zr diagrams comparing data for obducted stratiform ophiolites and tectonically isolated remnants represented by pillow lava sequences and gabbros with dykes, found within and adjacent to the CACC. The stratiform ophiolites show a dominant subduction-related signature (IAB field), although some late lavas and dykes (including the Çankırı metabasalts) have a more MORB-like affinity akin to back-arc basin basalts. Sarıkaraman data from Yalınız *et al.* (1996). IAB, island-arc basalts; MORB, mid-ocean ridge basalts; OIB, ocean island basalts; BABB, back-arc basin basalts. Ratios and fields in the V v. TiO_2 diagrams from Shervais (1982); IAB and BABB fields in the V/Ti v. Zr diagrams compiled from Woodhead *et al.* (1993).

different slices of the same obducted ophiolitic sheet.

Structurally isolated outcrops with suspected ophiolitic affinities have been grouped lithologically into pillow lavas, metagabbros and cross-cutting metabasaltic dykes, and plotted on companion diagrams for comparison with the stratiform ophiolites. As seen in Figs 5 and 7, the metagabbros and dykes have similar SSZ-type features to the massive ophiolites and may have originally been part of the same obducted sheet. However, basaltic pillow lavas and associated dykes from the Çankırı Basin generally form a different trend, with higher Zr/Y ratios (*c*. 4) and a MORB-like affinity. These chemical distinctions are emphasized in Fig. 8, where the pillow lavas predominantly have MORB-like compositions similar to those of back-arc basins, whereas the metagabbros and dykes are akin to IAB. These features alone are not sufficient to relate the Çankırı Basin lavas to the stratiform ophiolites, although they mirror the chemistry of the uppermost basalt lavas (with high Zr contents) of the Sarıkaraman Ophiolite (Fig. 8). However, evidence of an ophiolitic link is suggested by the composition of cross-cutting quartz–feldspar porphyry dykes (see above) which are similar to the Sarıkaraman and Çiçekdağ plagiogranites rather than late granitoids. It is therefore possible that the Çankırı Basin may have been floored by ophiolitic lavas of largely back-arc derivation. Support for this suggestion is provided by the association of the pillow lavas with bedded basic volcaniclastics, the latter of which are often a significant feature of the back-arc and forearc environments (Garcia 1978).

Geochemistry of basement metabasites

On the basis of current geotectonic models, the amphibolite facies metabasites are compared with the low-grade metabasalts of the Ankara Mélange which have been shown to be dominated by alkalic basalts of ocean island basalt (OIB) character, together with minor normal- and enriched-type MORBs (Figs 5 and 9) (Çapan & Floyd 1985; Floyd 1993). On the basis of stable Nb/Y ratios (Winchester & Floyd 1977), metabasites from the metamorphosed ophiolitic mélange are predominantly tholeiitic in character, whereas those from the Kaleboynu Formation are dominantly alkalic basalts. This latter group can be directly compared chemically with OIB from the Ankara Mélange with similar normalized patterns (Fig. 5) and Zr/Y of *c.* 8 (Fig. 9). However, although a chemical correspondence is indicated, no correlation is necessarily implied between the Karakaya Nappe of the Ankara Mélange (being a Sakarya unit) and the Kaleboynu Formation (a Tauride unit). In a similar fashion, the tholeiitic basalts largely have MORB-like features that mirror similar rocks in the Ankara Mélange with both depleted and enriched compositions (Figs 5 and 9).

One significant chemical feature to emerge from the basement metabasites is the presence of some clasts with an IAB chemistry exhibiting low TiO_2 and high V/Ti ratios (Fig. 10). The association of the three eruptive settings, represented by IAB–MORB–OIB, is discussed below.

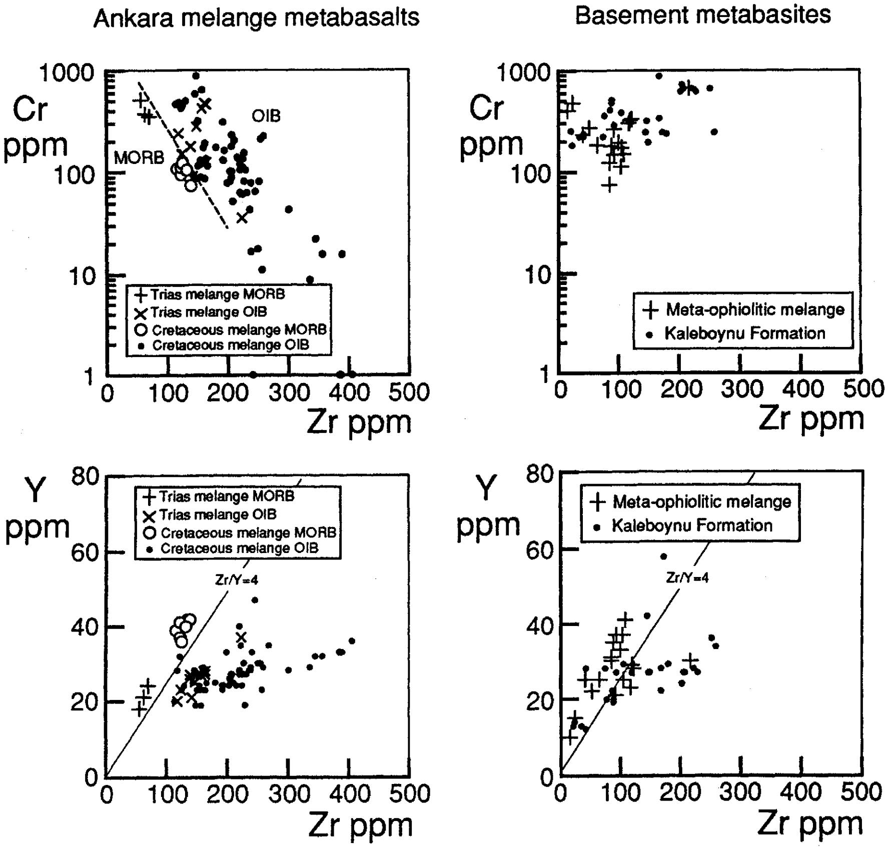
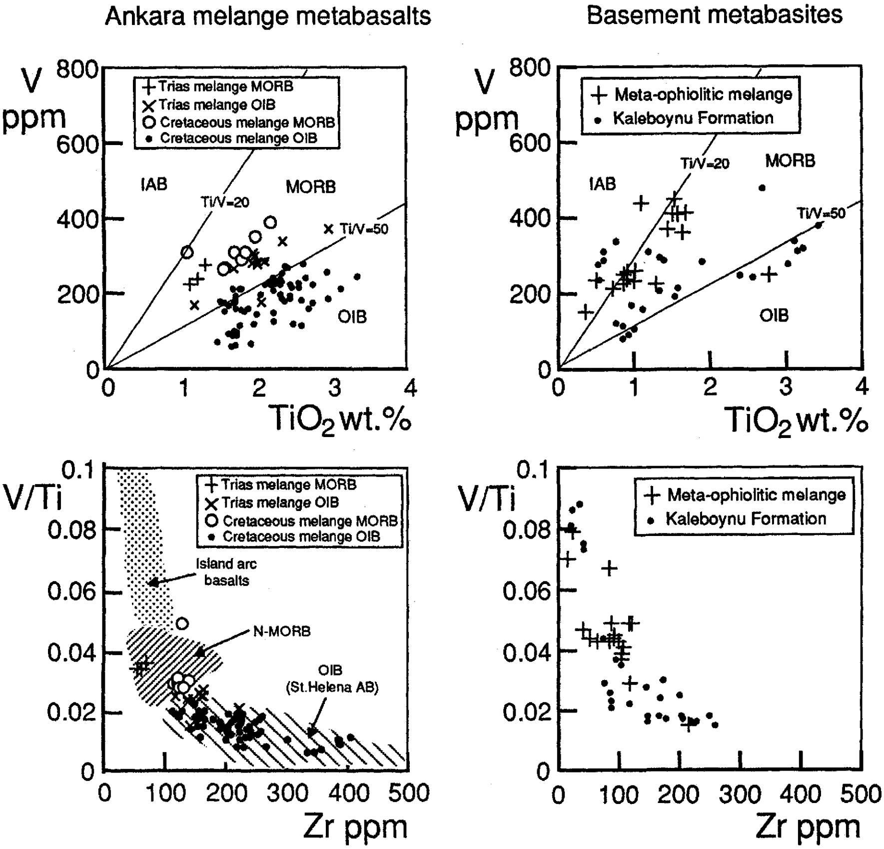


Fig. 9. Cr v. Zr and Y v. Zr diagrams comparing data for MORB-type and OIB-type pillow lava blocks within the Ankara Mélange with similar chemical groupings within the metabasites of the meta-ophiolitic mélange and Kaleboynu Formation. A ratio of Zr/Y = 4 discriminates two chemical suites within the Kaleboynu Formation: one MORB and the other with a similar chemistry to the Ankara Mélange Kılıçlar suite (Floyd 1993), with Zr/Y *c.* 8.


Ankara melange metabasalts

Basement metabasites

Fig. 10. V v. TiO_2 and V/Ti v. Zr diagrams comparing data for pillow lava blocks within the Ankara Mélange [data from Floyd (1993)] with similar chemical groupings within the metabasites of the meta-ophiolitic mélange and Kaleboynu Formation. Note the lack of subduction-related basaltic types relative to MORB and OIB in the Ankara Mélange. Fields in the V v. TiO_2 diagram from Shervais (1982); IAB from Woodhead *et al.* (1993); N-MORB from Floyd & Castillo (1992); representative OIB are alkali basalts (AB) from St Helena, from Chaffey *et al.* (1989).

Interpretation of geochemical features

This section summarizes the main geochemical characteristics of the stratiform ophiolites and basement metabasites, and interprets the magmatic associations in the light of their tectonic designations.

Stratiform ophiolites and tectonically isolated remnants

Main features. (1) The large obducted sheets of stratiform ophiolites (the Sarıkaraman and Çiçekdağ Ophiolites) have similar and overlapping basaltic compositions, with SSZ features similar to Neotethyan ophiolites of the eastern Mediterranean. (2) Both ophiolites have similar plagiogranite suites that differ chemically from late cross-cutting granitoids and syenitoids. (3) Isolated remnants of gabbroic bodies with basaltic and felsic dykes are chemically related to the main SSZ ophiolites. (4) Pillow lava sequences from the Çankırı Basin are chemically distinct from those in the stratiform ophiolites and display a more MORB-like affinity similar to back-arc basin basalts. These features are also shown by some lavas and dykes high in the ophiolite stratigraphic sequence.

The presence of a sheeted dyke complex indicates that the CACC stratiform ophiolites were generated in an extensional oceanic regime. Comparison with back-arc basin–island arc pairs suggests that the bulk of the SSZ ophiolite lavas have an island-arc character, whereas the (later) MORB-like lavas are more akin to back-arc basalts. As all the basaltic lavas are submarine, there is little evidence for the development of a major (subaerial) arc edifice, although the chemistry suggests the ophiolites represent a transition to, or an association with, a more back-arc-type environment just prior to obduction. The main evidence for the existence of a back-arc, however, is furnished by the separate Çankırı Basin pillow lavas which are also associated with volcaniclastic activity that might be expected in this setting. It is likely that the SSZ ophiolites and the Çankırı Basin basalts represent uncoupled or different obducted slices of oceanic crust from a broad arc-type setting.

Faunal evidence indicates that the SSZ-type ophiolites were generated during the Late Cretaceous (*c.* 90–85 Ma) and probably obducted soon afterwards, prior to late granitoid intrusion (*c.* 76–71 Ma). The main feature to emerge is that the SSZ-type ophiolites rapidly developed under the influence of a short-lived subduction zone and were subsequently obducted within 10 Ma or less.

Basement metamagmatic bodies

Main features. (1) Deformed metafelsic bodies in the ophiolitic mélange have enhanced HFS element abundances and high Zr/Nb ratios dissimilar to ophiolitic plagiogranites. (2) Boudinaged meta-ultramafic bodies are often Ca–Sr metasomatized by the adjacent carbonate-rich matrix. They appear to comprise two types with variable MgO + Ni + Cr contents, reflecting different origins: ultramafic rocks typically associated with ophiolite sequences and (possibly) cumulates related to continental stratiform gabbros. (3) Boudinaged ophiolitic mélange amphibolites ('knockers') are dominated by tholeiites with MORB-like features (both normal and slightly enriched types), although some minor OIB and IAB types are also present. (4) Kaleboynu Formation amphibolites, conformable with massive platform carbonates, are dominated by within-plate alkalic basalts of OIB type.

Although there is chemical correspondence between the basaltic components of the basement (ophiolitic mélange and Kaleboynu Formation) and units of the Ankara Mélange of broadly the same age, the main differences are in the proportion of MORB and OIB types, and the presence of IAB in the former. The features displayed by the ophiolitic mélange can be reconciled in a subduction–accretion setting where seamount structures, standing above the ocean floor, will be largely scraped off and accreted, whereas the ocean floor is more likely to be subducted. Thus, the dominant OIB in Cretaceous ophiolitic units of the Ankara Mélange represents the scraped off and accreted relicts of alkalic seamounts (Floyd 1993), whereas the CACC ophiolitic mélange MORB and IAB represents initially subducted ocean floor, together with remnants of the adjacent arc, respectively. The close association of these three different basaltic components derived from the island arc, the ocean floor and ocean islands/seamounts are a feature of mélanges in forearc settings (Bloomer 1983; Johnson & Fryer 1990; Macpherson *et al.* 1990). Although this scenario could well reflect the association of metabasite clasts in the ophiolitic mélange, the origin of the OIB in the Kaleboynu Formation is unlikely to be seamount-derived as in the Ankara Mélange. The conformable relationship of many of the thin Kaleboynu Formation amphibolites with the surrounding marbles indicates that they were probably intrusive sheets and/or basic volcaniclastic accumulations in shallow rifted basins. Like the Ankara Mélange OIB, the Kaleboynu Formation OIB are alkalic basalts of within-plate character; only in the latter case does the geological situation suggest a different environmental setting – rifted carbonate platform relative to that of a seamount. That rifting had reached the stage of small basins floored with ocean crust in some cases is suggested by the presence of MORB compositions within the Kaleboynu Formation metabasites.

Overall, the chemistry of the different magmatic lithologies in the deformed crystalline basement (ophiolitic mélange and Kaleboynu Formation) suggests the admixture at different stages of what was originally major ocean, island-arc and rifted continent margin, environments. The oceanic setting is indicated by MORB-type compositions typical of spreading centres with scattered OIB-type seamounts dominated by alkalic basalts. This type of ocean floor is distinct from the SSZ characteristics of the later stratiform ophiolites. On subduction, the seamounts were fragmented and incorporated into the forearc accretionary prism. A few basaltic (as well as felsic) clasts within the ophiolitic mélange were derived from the overriding active island arc. The continental margin is represented by the metamorphosed TAP carbonate platform with associated within-plate alkalic basalts (Kaleboynu Formation OIB). The association of minor MORB in this predominantly continental setting suggests the development of small rifted submarine basins partly floored by ocean crust.

Tectonic model

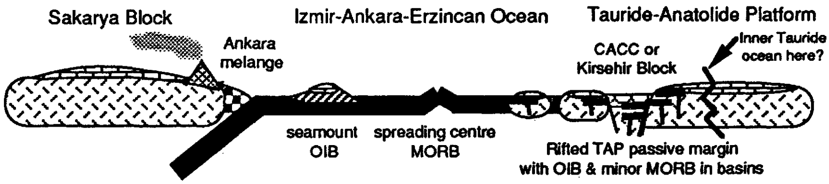
On the basis of the above geochemical characterization, two features are clear: (1) the stratiform ophiolites with SSZ features are distinct from the metabasites in the underlying basement; and (2) both the ophiolitic mélange metabasite blocks and the concordant Kaleboynu Formation amphibolites have their corresponding chemical counterparts in different segments of the Ankara Mélange. The actual age of the basement metabasites is still a problem. Part of the Kaleboynu Formation is probably Triassic and similar in age to the Upper Karakaya Nappe ('metamorphic block mélange') of the Ankara Mélange (Koçyiğit 1991), although it is recognized that they belong to different crustal blocks – the Taurides and Sakarya unit, respectively. On the other hand, the basement ophiolitic mélange is probably equivalent to the Anatolian Nappe ('ophiolitic mélange') of Middle–Late Cretaceous age.

In many disrupted ophiolitic sequences, a metabasite block-bearing mélange tectonically underlies an ophiolite nappe with its attendant thrust-bound metamorphic sole (Parkinson 1996; Parlak 1996), and a genetic relation can often be demonstrated between the blocks and the ophiolite. A similar tectonic stacking sequence is indicated here for the CACC (Fig. 2), although the N-MORB-dominated ophiolitic mélange blocks appear to be chemically unrelated to the SSZ-type ophiolites. In the model below, however, a relationship between the two magmatic groups is based on the premise that the MORB-type blocks are representative of an original (and older) oceanic crust on which the later SSZ-type ophiolites developed.

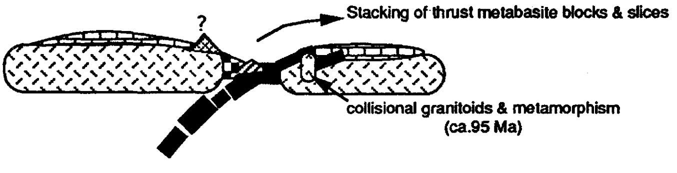
The following tectonic model (illustrated in Fig. 11) is based on the geochemical interpretation of the data above and attempts to integrate the CACC into a broad model for the development of the Neotethys Ocean (e.g. Robertson *et al.* 1991; Yılmaz *et al.* 1997). A number of stages are envisaged:

- The northern margin of Gondwanaland rifted in the Late Triassic with the eventual development of small ocean basins. The association of volcanic rocks and carbonates of Triassic age indicate that the marginal platforms were being subjected to an extensional regime at this time. The concordant OIB-type metabasites (mainly alkali basalts) of the

(a) Late Triassic - Jurassic - early Cretaceous: rifting of TAP margin and northwards migration



(b) Mid-Cretaceous: closure of majority of I-A-E Ocean



(c) Late Cretaceous (Turonian-Santonian): formation and obduction of SSZ ophiolites

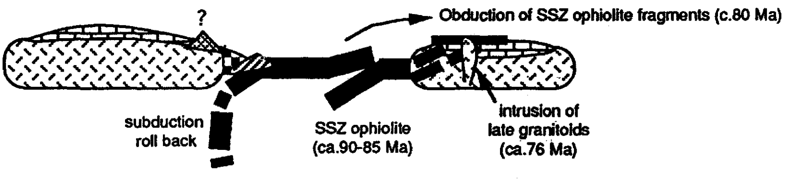


Fig. 11. Cartoon illustrating the closure of the İzmir–Ankara–Erzincan (I–A–E) Ocean by the collision of the CACC with the Sakarya microcontinental block during the Late Cretaceous. The original eruptive settings of various ophiolitic bodies (SSZ) and metabasites (MORB, OIB) now found in the CACC are exhibited.

Kaleboynu Formation are evidence for within-plate rifting, although the presence of MORB indicates that continental crust attenuation had been sufficient to generate some true ocean floor during the Triassic.

- By the Early Jurassic and throughout the Cretaceous, as the Neotethys Ocean gradually widened, a progression of microcontinental slices (Sakarya, Kırşehir–CACC), that had been rifted off Gondwanaland, migrated northwards towards Eurasia (Fig. 11a). According to Özgül (1976), the CACC remained attached to the carbonate TAP, although Görür *et al.* (1984) think that these two blocks were separated by another seaway, the Inner Tauride Ocean (Fig. 11a). The CACC block lagged behind the Sakarya Block and became separated from it by the İzmir–Ankara–Erzincan oceanic strand. Most of this ocean was subducted under the southern active margin of the Sakarya microcontinent, so that evidence for its existence is now largely found in tectonic mélanges. Taken together, metabasaltic blocks in segments of the Ankara Mélange and the basement ophiolitic mélange record the existence of MORB, OIB and minor IAB compositions, typical of forearc accretionary wedges. MORB compositions represent the subducting ocean crust, whereas the alkali basalts were derived either from volcanic seamounts developed on the ocean floor and/or earlier rift-related ensialic environments. The huge rafts of platform carbonate seen in part of the Ankara Mélange suggest that much of the alkalic basalt could be associated with the original Trias rifting, although OIB pillow lavas intimately associated with Cretaceous pelagic limestones indicate a true seamount construct (Floyd 1993). The minor IAB and subduction-related metafelsic blocks were probably derived by tectonic erosion of the subduction zone hanging wall or intersection of deep-arc faults.
- As the CACC block approached the Sakarya subduction zone, the intervening ocean crust was largely subducted, whereas the seamount constructs and rafted carbonate platforms were mainly accreted into the trench mélange. By the mid-Cretaceous, the leading promontories of the CACC carbonate platform collided with the Sakarya microcontinent. Deeply subducted material, metamorphosed to amphibolite facies, was then buoyantly disgorged and obducted southwards over the CACC margin (Fig. 11b). The higher grade material (amphibolite facies) is now represented by the Central Anatolian Metamorphics of the CACC, whereas the lower grades (pumpellyite and greenschist facies) are found in the Ankara Mélange. Southward stacking of the contents of the subduction zone took place before the emplacement of post-collisional granitoids at *c.* 95 Ma (Fig. 11b).
- Due to the irregular margin of the advancing CACC microcontinent after initial collision, small segments of oceanic crust remained that had not yet been subducted. It was in these remnants that the Late Cretaceous (90–85 Ma) SSZ-type ophiolites would develop (Fig. 11c). It is speculated that, on initial collision, subduction zone roll-back occurred, thereby inducing extension in the remaining ocean crust and the development of a new subduction zone (Fig. 11c). Another possibility is that asymmetric collapse of any remaining spreading ridge in the oceanic segment engendered a subduction zone (e.g. Clift & Dixon 1998). Either way, an incipient arc developed with a limited degree of back-arc spreading – environments which are now represented by the SSZ ophiolites and the Çankırı Basin pillow lavas, respectively. This phase lasted between 5 and 10 Ma.
- Further compression produced slicing and imbrication of the SSZ oceanic lithosphere and the eventual obduction of ophiolitic fragments over the CACC metamorphic basement (Fig. 11c). The whole sequence was then intruded by late granitoids at *c.* 76 Ma.

In conclusion, the CACC and the Ankara Mélange are considered to represent variably tectonized and subducted oceanic lithosphere and continental carbonate platform that were subsequently ejected from an accretionary–subduction complex on collision with the Sakarya microcontinent.

Funding for this collaborative project was provided by NATO (grant CRG 960549) and the Scientific and Research Council of Turkey (TÜBİTAK) (code no: YDABÇAG-85) grant to whom thanks are due. Analytical data production was greatly helped by the expertise of D. W. Emley and M. Aikin at the Department of Earth Sciences, University of Keele, UK. We acknowledge the helpful and expert comments of P. Clift and M. Delaloye.

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