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Metabasite Blocks from the Koçyaka HP-LT Metamorphic Rocks, Konya, Central Anatolia: Geochemical Evidence for an Arc-Back-Arc Pair?

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Abstract: The Kütahya-Bolkardağ Belt, situated on the northern margin of the Tauride-Anatolide Platform, includes slices of HP/LT metamorphic rocks adjacent to allochthonous ophiolitic fragments. The Koçyaka Metamorphic Complex is one such thrust slice and is located to the northeast of Konya. The local tectonostratigraphic succession consists of Upper Cretaceous calcareous metasediments overlain respectively by the Altınekin and Akçasar mélanges of ophiolitic character. Both mélanges contain metabasites (pillow lavas and amphibolites) overprinted with HP-LT glaucophanitic assemblages and later low-grade facies associations. The geodynamic significance of the ophiolites prior to dismemberment (as oceanic crust) is in dispute, being either interpreted as a separate Neotethyan oceanic strand or derived from the İzmir-Ankara-Erzincan ocean to the north.

Geochemical comparisons suggest that the metasediments are largely admixtures of pelagic and calcareous sediments typical of the ocean floor. The metabasite blocks in both mélanges are incompatible element-depleted, plagioclase-clinopyroxene phyric tholeiites and appear to form a coherent magmatic group. Although the metabasalts have affinities to N-MORB, their range of composition is more typical of a back-arc basin environment. Geochemical comparison, tectonic juxtaposition and similarity of age to the stratiform supra-subduction zone (SSZ) ophiolites of the Central Anatolian Crystalline Complex (CACC) suggest that the Konya metabasite blocks (with back-arc affinity) and the SSZ ophiolites (with arc affinity) could represent an arc–back-arc pair. If this is the case, it removes the need for a separate "Inner Tauride Ocean" between the CACC and the Tauride-Anatolide Platform, both units being initially derived from the northern İzmir-Ankara-Erzincan ocean.

Key Words: metabasite, geochemistry, HP-LT rocks, central Anatolia, back-arc

Koçyaka (Konya-Orta Anadolu) Yüksek Basınç-Düşük Sıcaklık Metamorfitleri İçindeki Metabazit Bloklarının Jeokimyası: Yay-Yayardı İkilisine İlişkin Jeokimyasal Kanıtlar

Özet: Torit-Anatolit platformunun kuzey kenarında yeralan Kütahya-Bolkardağ Kuşağı, allokton ofiyolit parçaları yanında Yüksek Basınç-Düşük Sıcaklık (YB-DS) metamorfizması geçirmiş tektonik dilimler içerir. Bu dilimlerden biri olan Koçyaka Metamorfik Karmaşığı Konya'nın kuzeydoğusunda yüzeylenir. Birim, Üst Kretase karbonatlı metasedimenter kayalar üzerinde yeralan ofiyolitli karışık özelliğindeki Altınekin ve Akcaşar melanjlarından oluşan bir tektonostratigrafik dizilim sunar. Her iki melanjda da düşük dereceli metamorfizma ile üzerlenmiş YB-DS metamorfizması ürünü glokofanlı topluluklar içeren ve yastık lav ve amfibolitden oluşan metabazik kayalar yeralır. Ofiyolitik kayaların parçalanma öncesindeki jeodinamik konumları hakkında farklı görüşler vardır. Bu görüşlerden ilkine göre bu kayalar kuzeydeki İzmir-Ankara-Erzincan Neotetis okyanus kolundan türemiştir. Diğer görüşe göre ise bu okyanusal kabuk parçaları farklı bir Neotetis okyanus koluna aittir.

Jeokimyasal karşılaştırmalar, melanjların metasedimanter kayalarının okyanus tabanı çökelleri için tipik olan pelajik ve karbonatlı çökellerinin karışmasından oluştuğunu gösterir. Her iki melanj içinde yeralan metabazik blokları, plajiyoklas-klinopiroksen fenokristalli olup uyumsuz elementlerce tüketilmiştir ve bütünselliği olan bir magmatik grup içinde yeralırlar. Bu metabazik kayalar genelde Normal Okyanus Sırtı Bazalt'lara (N-MORB) benzerlikler sunmakla birlikte birleşimsel konakları yayardı havza ortamı için daha tipiktir. Orta Anadolu Kristalen Kompleksinde (OAKK) yer alan stratiform dalma-batma zonu üstü (SSZ) ofiyolitleri ile oluşum, tektonik yerleşme yaşlarının benzerlikleri ve jeokimyasal deneştirmeler dikkate alındığında, Konya'daki yayardı özellikli metabazitlerle OAKK'daki yay özellikli SSZ tipi ofiyolitlerin bir yay-yayardı ikilisini temsil edebileceği düşünülmektedir. Eğer bu karşılaştırma geçerli ise, her iki birim de İzmir-Ankara-Erzincan Okyanusundan türemiş olabilirler. Bu durum, OAKK ile Torid-Anatolit Platformu arasında ayrı bir "İç Toros Okyanusu" nun varlığını gereksiz kılar.

Anahtar Sözcükler: Metabazik, Jeokimya, YB-DC kayaçları, orta Anadolu, yayardı

Introduction

Mesozoic rifting and fragmentation of the northern margin of Gondwana led to the development of Neotethyan oceanic lithosphere that is now recorded as numerous ophiolitic segments throughout Turkey (e.g., Şengör & Yılmaz 1981; Robertson & Dixon 1984). The multistrand Neotethys ocean was generated over a period from the late Triassic to the Late Cretaceous, when convergence between Africa and Eurasia largely closed the seaway via northern subduction (e.g., Yılmaz *et al.* 1997). Two major Neotethyan oceanic seaways are recognised between Eurasia and Gondwana: (a) a northern segment comprising two ocean strands – the Intra-Pontide Ocean and the İzmir-Ankara-Erzincan (I-A-E) Ocean just to the south, and (b) a southern segment – the Southern Neotethyan Ocean (Şengör & Yılmaz 1981) – that includes well-known ophiolites, such as Troodos and Hatay.

The I-A-E Ocean was situated between the rifted Sakarya microcontinent and the leading edge of the Tauride-Anatolide Platform (TAP) and is now largely represented by ophiolitic fragments along the Kütahya-Bolkardağ Belt and in the composite "Ankara Mélange", as well as segmented stratiform ophiolites thrust over the Central Anatolian Crystalline Complex (CACC) to the south (Özgül 1976; Göncüoğlu *et al.* 1991; Yalınız *et al.* 2000a). The CACC or Kırşehir Block (Figure 1), composed of a marble-dominated metamorphic basement, is considered to represent the northern passive margin of the Mesozoic TAP (Göncüoğlu *et al.* 1991).

High pressure-low temperature (HP-LT) metamorphic rocks of alpine age occur widely in the Aegean area (Okrusch *et al.* 1978; Candan *et al.* 1997; Dilek & Whitney 1997) and western Turkey (for localities see Okay 1986). The most prominent belt with HP-LT metamorphic rocks in Turkey is found in northwest and central Anatolia, extending from the Biga Peninsula to the northeast of Kayseri. Although the existence of HP-LT metamorphic rocks in this belt (e.g., Tavşanlı Zone of Okay 1984) has been known for over thirty years (e.g., Kaaden 1966), the first detailed study on the northwestern sector was published by Okay (1984).

Of significance to this study, and situated at the southern margin of the CACC (Figure 1), is a localised segment of high pressure–low temperature glaucophanitic ophiolites that have been interpreted

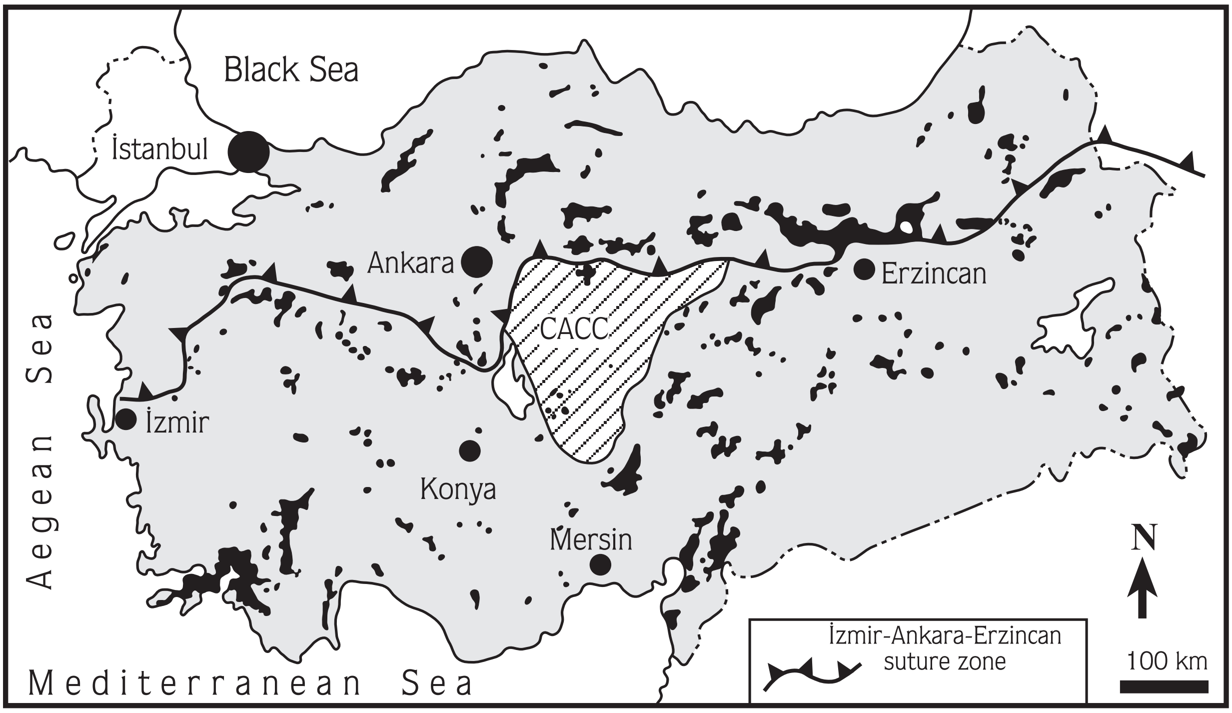

Figure 1. Distribution of Tethyan ophiolitic bodies in Turkey (after Juteau 1980) and the position of the İzmir-Ankara-Erzincan (I-A-E) suture zone. The Konya area of this study is located to the southwest of the Central Anatolian Crystalline Complex (CACC).

(Görür *et al.* 1984) as an additional Neotethyan seaway – the Inner Tauride Belt – that once separated the CACC from the TAP. In this model the CACC represents a separate continental fragment or block and not part of the leading edge of the TAP.

Objectives

The "Inner Tauride Belt" is clearly ophiolitic in character and being representative of oceanic lithosphere is important in terms of its geotectonic significance for central Turkey, and essentially how and where it was developed. In essence, was this segment of ophiolitic crust a completely separate oceanic strand (e.g., Görür *et al.* 1984, 1991) or initially derived from the İzmir-Ankara-Erzincan Ocean and then thrust southwards (Göncüoğlu *et al.* 1991)?

This paper outlines the petrography and geochemistry of glaucophanitic metabasites within the Koçyaka Metamorphic Complex in a little known area to the NE of Konya, central Anatolia, and attempts to determine their characteristics and possible eruptive environment in the regional context. Comparison with new geochemical work (Yalınız *et al.* 1996, 2000b; Floyd *et al.* 2000) on the stratiform ophiolites of the CACC (derived from the I-A-E Ocean) is considered significant and how they might be related to the Inner Tauride ophiolites of similar age. However, the ideas presented here are considered preliminary in that only a small segment of the Inner Tauride ophiolites has been sampled and geochemically evaluated.

Local Geological Setting

The allochthonous units of the Kütahya-Bolkardağ Belt– that represents the northern margin sequences of the Tauride-Anatolide Platform in NW and central Anatolia– include numerous slices that have more or less similar stratigraphic successions, but differ in the type and grade of metamorphism. The most complete slices have a low-grade metamorphic basement of pre-Triassic age, unconformably overlain by Mesozoic platform carbonates and Upper Cretaceous to Lower Palaeocene ophiolite-bearing mélanges, which are finally overlain tectonically by ophiolites.

The sampled Koçyaka Metamorphic Complex is one of these slices (Figure 2) and in the Konya area consists in its lower part of pelagic carbonates. It is underlain by Middle Triassic–Lower Cretaceous neritic carbonates and overlain by mélanges with blocks of ophiolitic affinity. The whole sequence has undergone high-pressure glaucophanitic metamorphism (Karaman 1983; Özcan *et al.* 1990; Özgül 1998).

The local tectonostratigraphy consists of three units in ascending order (Figure 3):

Midos Tepe Formation

In terms of protolith (based on overall chemical composition, relict bedding features and textures), the lower part of this c. 550-m-thick succession is composed of thin-bedded pelagic carbonates with some very thin turbiditic bands and radiolarites, whereas towards the upper part, chert and turbiditic intercalations increase. The uppermost section of the Midos Tepe Formation is represented by calciturbidite, calcarenite, chert and an alternation of argillaceous limestone and pelites that represents the transition to the overlying mélange. The calciturbidites in the upper part of the succession are rich in volcanogenic clasts and contain very fine, dark blue needles of Na-amphiboles. The unit is interpreted as a continental-slope to ocean-floor sequence and assigned a mid-Cretaceous age (Özcan *et al.* 1990).

Altınekin Mélange

The basal portion is composed of an alternation of well-foliated metacalciturbidites and olistostromal metaclastics. Olistoliths and detritus of basic volcanic rocks (now blueschist, metabasalt, amphibolite), serpentinite, magnesian schist, with metachert bands and marble, are found both in the metacalciturbidite-dominated lower, and clastic-dominated upper, parts. The sizes of the blocks increase towards the upper part of the succession. The unit is characterised by the dominance of a calcpelite matrix with approximately E–W-trending and N-dipping foliation planes. The Altınekin mélange has an apparent thickness of approximately 1500 m, and shows lateral and vertical gradational contacts with the overlying Akçasar mélange.

Akçasar Mélange

This unit is dominated by coarser-grained clastic rocks (Figure 3) that generally exhibit block–block-type contacts. It contains megaclasts of metapillow basalt, chromitite, metaultramafic (dominantly serpentinite),

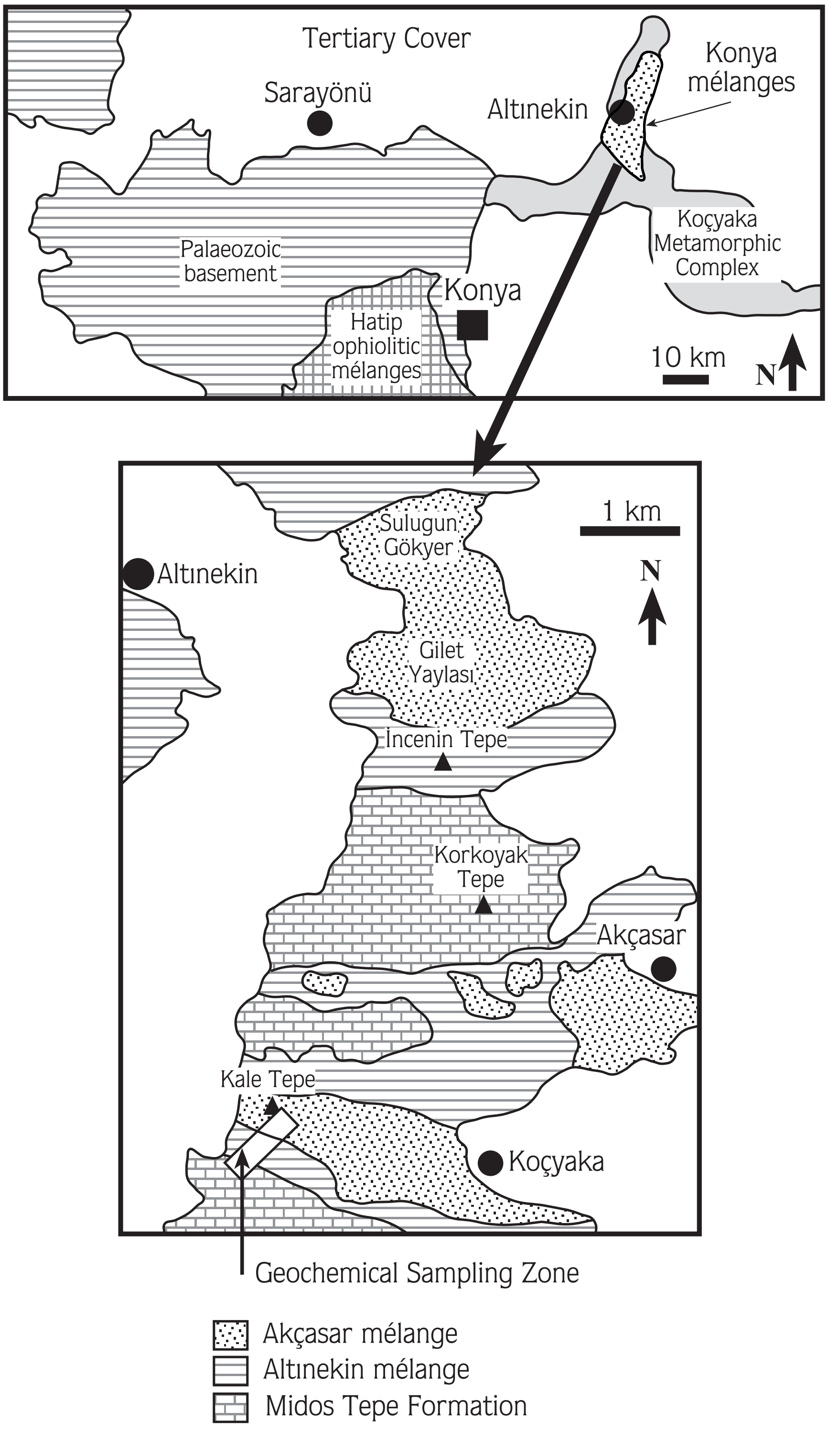

Figure 2. Outline geology around Konya showing the extent of the Koçyaka Metamorphic Complex and the detailed distribution of the Midos Tepe Formation and the mélange units (after Özgül 1998).

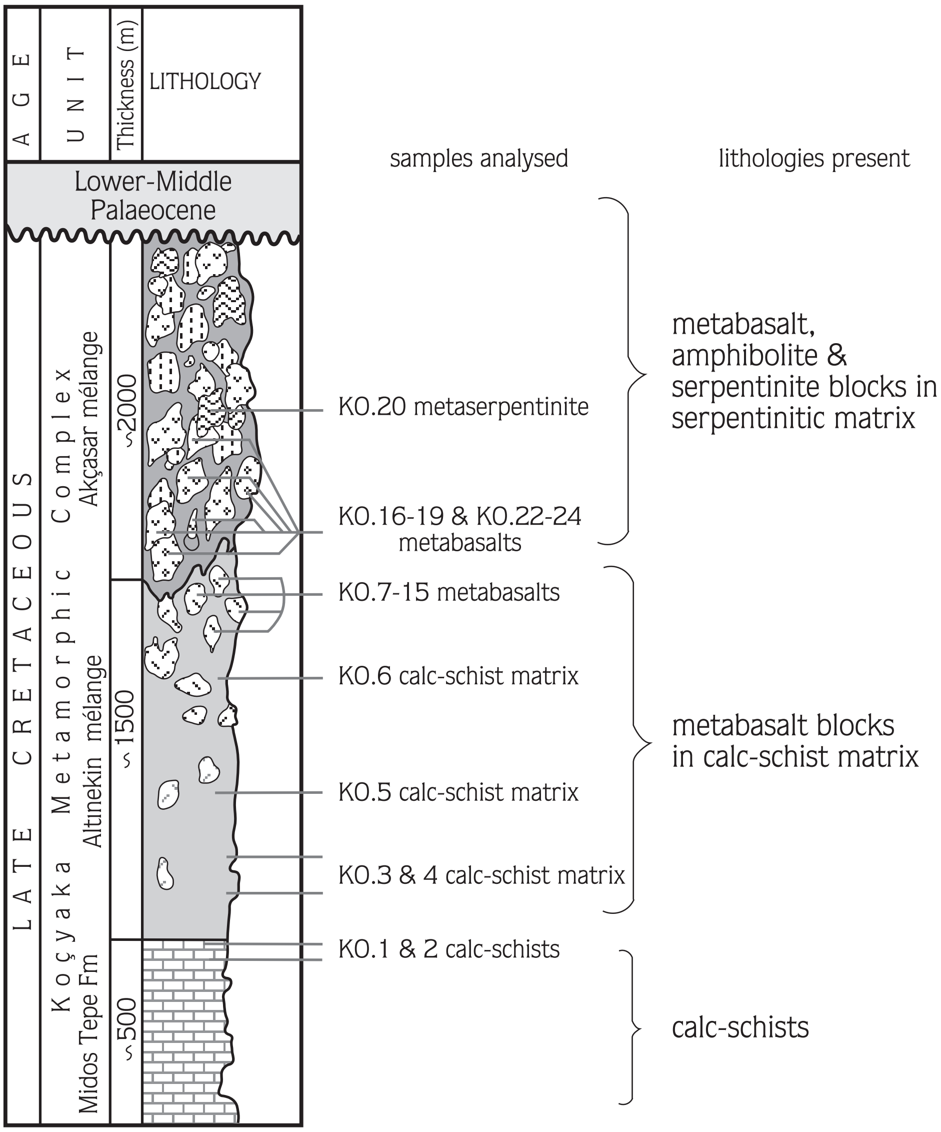

Figure 3. Tectonostratigraphy of the Koçyaka Metamorphic Complex in the Konya area (after Özgül 1998) showing the relative positions of the samples collected for geochemical analysis.

metapyroclastic, and amphibolite with occasional minor bands and lenses of olistostromal metarenite/metarudite and metacalciturbidite between the blocks.

Although penetrative foliation has affected some of the knockers, others (metapillow basalt, chromitite, metavolcanoclastics, amphibolite and marble) have preserved their original textures. In the uppermost part of this unit there are huge blocks or klippe-like bodies of garnet-chromitite and chromite-bearing peridotites, with a subophiolitic metamorphic sole. The Akçasar mélange has an apparent thickness of over 2000 m.

The transitional boundary between the Midos Tepe Formation and Altınekin mélange indicate that the latter is an exotic block-bearing olistostrome (displaying allolistostrome features; Raymond 1984) rather than a totally tectonic mélange generated in a subduction-accretion complex. The local existence of turbiditic units also supports that submarine sliding and turbidite currents probably played a part in the deposition of the two-mélange units. The large volume of ophiolitic knockers of variable size and shape in the Koçyaka Metamorphic Complex also suggests incorporation by largely sedimentary processes into the matrix prior to any subsequent deformation.

On the basis of regional correlation a Cenomanian–pre-Thanetian formation age has been assigned for the Koçyaka Metamorphic Complex (Özcan *et al.* 1990). The Upper Palaeocene, continental Kartal Formation unconformably covers the complex (Göncüoğlu *et al.* 1997).

Petrographic Summary

As the main thrust of this paper concerns the geochemical composition of the metabasites only, a brief introduction to their principle metamorphic assemblages will be given. The main assemblage of mélange metabasites is composed of Na-pyroxene-glaucophane-lawsonite (Özgül & Göncüoğlu 1999), and broadly similar to that in the olistostrome blocks and the calc-turbidite part of the Midos Tepe Formation. Relicts of magmatic minerals are occasionally preserved in some of the larger blocks of pillow lavas and enable an approximation of the original mineralogical composition to be derived, e.g., plagioclase-phyric basalt. Some coarser-grained metagabbro blocks, with relict igneous textures in the Altınekin mélange, exhibit primary augites that are totally uralitised by pale-green amphibole, which in turn are rimmed by blue/blue-green acicular Na-amphiboles. Plagioclase is partly or completely replaced by lawsonite.

Almost all the rock units of the Koçyaka Metamorphic Complex also show the effects of a later metamorphic stage. The late-stage association albite-actinolite-epidote is common in the metabasites, whereas epidote and albite porphyroblasts, with numerous actinolite inclusions, are found in volcanogenic and calcareous matrix materials.

The broad range of primary and secondary mineral assemblages and textures indicate disequilibrium conditions for all lithologies. However, common to all the rock groups is the presence of HP-LT metamorphic mineral phases and a late metamorphic overprint characterised by higher temperatures. These features may be caused by zero-strain static recrystallisation and replacements during incipient metamorphism followed by high-strain penetrative deformation during progressive HP-LT metamorphism (e.g., Okay 1989). The main and late-stage metamorphic assemblages are typical of the blueschist facies and glaucophanic greenschist facies respectively, as defined by Bucher & Frey (1994).

Sampling and Analytical Methods

The location of the geochemical sampling traverse is shown in Figure 2 and includes eight calc-schist metasediments (3 from the Midos Tepe Formation and 5 from the matrix of the Altınekin mélange) and sixteen metabasites from megablocks within the Altınekin and Akçasar mélanges. The metabasites included both recognisable basaltic pillow lavas and massive amphibolites, some of which may have originally represented dykes, sills or thick basalt flows. The relative tectonic position of the samples is shown diagrammatically in Figure 3. Analytical data for the samples are presented in Tables 1 and 2 (metasediments and metabasites, respectively), with additional trace element data, including REE, in Table 3.

All samples were analysed for major and selected trace elements on an ARL 8420 X-Ray Fluorescence spectrometer (School of Earth Sciences & Geography, 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). Additional trace elements, including the REE, were analysed at the University of Pais Vasco, Spain, following procedures published by Gonzalez Montero & Bea (1998).

Alteration Effects

The metabasite samples have undergone mineralogical alteration within the blueschist 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 ophiolite volcanic sequence where mineralogical and chemical alterations by submarine hydrothermal processes are well known (e.g., Gass & Smewing 1973;

Table 1. Calc-schist metasediments from the Konya area.

Field group	Midos Tepe Formation			Altınekin mélange matrix				
Sample no.	KO-1A	KO-1B	KO-2B	KO-3	KO-4A	KO-4B	KO-5	KO-6
Major oxides (wt.%)								
SiO_2	26.22	19.81	19.62	31.82	49.01	51.05	29.06	52.35
TiO_2	0.33	0.24	0.25	0.33	0.68	1.79	0.38	0.72
Al_2O_3	8.08	4.83	5.26	8.81	12.89	11.62	9.47	15.07
Fe_2O_3t	2.94	3.17	3.30	3.08	8.48	11.96	3.61	7.14
MnO	0.07	0.10	0.08	0.07	0.17	0.11	0.07	0.26
MgO	2.73	4.71	4.70	3.06	7.28	3.53	3.38	6.35
CaO	24.61	43.51	34.59	26.26	8.33	6.82	26.28	5.84
Na_2O	3.38	0.86	2.33	3.74	1.02	3.14	3.79	1.51
K_2O	0.31	0.61	0.11	0.36	1.79	0.01	0.42	2.79
P_2O_5	0.08	0.09	0.07	0.09	0.09	0.20	0.10	0.15
LOI	31.86	22.25	29.55	22.49	10.14	10.36	23.19	8.06
Total	100.61	100.18	99.86	100.11	99.88	100.59	99.75	100.24
Trace elements (ppm)								
Ba	69	45	18	42	234	200	54	316
Ce	2	25	5	8	9	18	17	55
Cl	1	1	61	12	2	2	51	4
Co	15					35		
Cr	99	84	142	79	288	308	94	262
Cu	39	32	37	32	57	59	32	58
Ga	6	8	7	7	16	16	9	17
La	1	7	1	9	1	2	14	22
Li	22					66		
Nb	4	8	5	7	10	10	8	12
Nd	11	17	9	11	13	16	14	28
Ni	62	69	85	59	236	237	68	198
Pb	6	12	77	15	6	10	14	14
Rb	17	11	3	11	72	62	13	101
S	46	3	41	1	2	5	21	2
Sr	636	611	603	621	206	209	633	83
V	38	73	52	68	195	195	72	187
Y	10	28	14	25	19	21	25	24
Zn	40	56	55	51	111	120	56	95
Zr	31	73	37	67	94	105	75	126

Pearce & Cann 1973; Spooner & Fyfe 1973; Smewing & Potts 1976), although in this case such initial alteration has been overprinted by high pressure blueschist metamorphism. The presence of abundant amphibole in both the pillow lavas and the amphibolites is reflected in the relatively high LOI contents. 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 carbonatisation of metabasites, the REE and HFS elements can also be mobilised and/or abundances diluted (e.g., Hynes 1980; Humphris 1984; Rice-Birchall & Floyd 1988), although this appears only to have seriously affected two high-CaO metabasite samples (KO-19 & KO-22, Table 2).

Table 2. Metabasites from the Konya area.

Field group	Blocks within the Altınekin mélange									Blocks within the Akçasar mélange						
Sample no.	KO-7	KO-8	KO-9	KO-10	KO-11	KO-12	KO-13	KO-14	KO-15	KO-16	KO-17	KO-18	KO-19	KO-22	KO-23	KO-24
Major oxides (wt.%)																
SiO_2	53.93	53.26	53.42	50.74	48.30	51.97	51.33	47.24	53.82	33.94	51.77	52.67	43.49	33.91	52.52	49.98
TiO_2	1.66	1.15	0.84	1.37	3.16	1.71	2.06	0.90	1.38	1.16	1.25	1.04	1.21	1.08	1.25	1.25
Al_2O_3	13.06	13.66	13.42	17.84	13.55	14.31	14.19	13.61	12.73	21.60	16.36	15.31	13.65	21.43	12.72	15.74
Fe_2O_3t	11.51	12.07	10.24	9.66	10.41	12.01	12.29	7.60	13.80	11.11	10.26	10.82	8.58	11.58	11.35	10.72
MnO	0.22	0.23	0.20	0.18	0.24	0.22	0.23	0.12	0.23	0.34	0.16	0.17	0.23	0.22	0.14	0.12
MgO	5.67	7.28	6.26	5.29	10.21	5.77	5.89	6.83	6.75	10.79	5.00	5.41	9.55	10.72	5.00	5.08
CaO	4.68	4.05	5.60	6.28	5.12	4.00	4.38	10.30	2.56	12.52	6.99	6.62	18.39	13.07	8.93	8.91
Na_2O	5.80	4.62	4.52	4.89	4.35	6.15	6.10	5.14	6.08	0.14	4.94	5.12	1.50	0.19	7.00	5.00
K_2O	0.14	0.48	0.91	0.58	0.09	0.61	0.56	0.69	0.58	0.01	1.02	0.86	0.01	0.01	0.15	0.33
P_2O_5	0.15	0.12	0.14	0.10	0.47	0.18	0.32	0.20	0.11	0.41	0.08	0.09	0.08	0.01	0.14	0.19
LOI	3.21	3.11	4.57	3.10	3.88	2.79	3.01	7.31	2.29	7.59	2.08	1.85	3.78	7.55	1.00	2.62
Total	100.03	100.03	100.12	100.03	99.78	99.72	100.36	99.94	100.33	99.61	99.91	99.96	100.47	99.77	100.20	99.94
Trace elements (ppm)																
Ba	37	89	147	99	30	74	90	74	84	3	129	100	19	8	29	83
Ce	22	1	2	17	68	34	37	20	2	35	20	9	16	15	13	7
Cl	3	2	3	1	1	1	1	1	2	2	2	2	2	12	2	1
Co			36		53								37			
Cr	156	95	84	129	534	170	188	529	68	311	66	60	91	292	34	77
Cu	28	62	69	56	72	53	54	57	62	86	60	50	113	51	16	66
Ga	14	13	14	17	14	14	16	12	16	17	17	16	11	13	16	16
La	1	2	2	2	17	5	2	3	5	2	2	2	3	2	2	4
Li			74		83								35			
Nb	16	3	3	3	57	15	18	17	11	15	5	4	6	3	3	3
Nd	21	8	2	20	37	27	28	20	9	22	24	13	18	19	19	6
Ni	50	58	52	44	332	56	69	133	63	200	32	31	63	137	12	51
Pb	4	5	2	7	2	3	4	6	1	12	4	3	3	5	11	5
Rb	4	14	25	12	3	16	16	18	18	1	25	22	2	1	8	8
S	5	4	6	2	3	2	2	2	5	10	29	5	11	2	2	10
Sr	48	48	100	175	20	65	65	164	25	260	115	95	63	29	130	142
V	344	357	325	349	206	341	347	214	337	275	374	352	237	210	384	367
Y	37	26	21	36	34	42	51	19	27	42	34	28	39	24	28	35
Zn	87	90	77	74	103	100	103	62	115	144	79	86	50	107	35	74
Zr	109	66	54	85	209	105	132	56	102	110	77	66	102	61	76	78

Table 3. Additional trace element and REE data.

Sample no.	KO-1A	KO-4B	KO-9	KO-11	KO-19
Trace elements (ppm)					
Cs	0.64	3.88	1.39	0.15	0.19
Hf	0.97	1.44	0.12	4.42	0.77
Sc	7.74	26.77	40.87	23.61	38.16
Ta	0.81	0.87	0.17	4.35	0.36
Th	6.38	5.31	0.3	5.12	0.37
U	1.16	0.98	0.17	1.24	0.49
Rare Earth Elements (ppm)					
La	20.93	10.75	2.63	31.05	4.58
Ce	39.79	22.10	7.53	62.07	13.05
Pr	4.56	2.75	1.22	7.60	2.06
Nd	16.84	11.23	6.18	31.41	11.19
Sm	3.41	2.50	2.02	7.12	3.79
Eu	0.92	0.64	0.75	1.96	1.37
Gd	3.32	2.59	2.62	6.79	4.63
Tb	0.56	0.44	0.48	1.05	0.86
Dy	3.89	3.04	3.21	6.30	6.07
Ho	0.90	0.68	0.71	1.27	1.27
Er	2.49	1.90	1.86	3.27	3.58
Tm	0.39	0.30	0.27	0.49	0.58
Yb	2.12	1.88	1.56	2.84	3.42
Lu	0.27	0.28	0.20	0.37	0.53

1A = Midos Tepe Formation metasediment
4B = Altınekin mélange matrix
9 & 11 = Altınekin mélange metabasite
19 = Akçasar mélange metabaslite

The metasediments are particularly calcareous as reflected by the generally high CaO, Sr and LOI (largely CO_2) contents, and as such cause dilution of other trace-element contents. In so far as many of the metasediments may represent mechanical mixtures of pelite and limestone, absolute trace-element abundances reflect varying degrees of mixing of the two main components.

Metasediment Geochemical Variation

Geochemically the analysed calc-schists represent a range of compositions from low-CaO pelites to high-CaO limestones and dolostones. Both the Midos Tepe Formation and the Altınekin mélange matrix calc-schists show this feature and it is reasonable to suppose that they represent the same type or range of sedimentary material. In terms of both major oxides and trace elements (illustrated in Figures 4 and 5, respectively) both sediment groups can be matched with typical oceanic pelagic and carbonate sediments. The chemical comparison suggests that the Midos Tepe Formation could, therefore, be characteristic of pelagic sediments found above the volcanic section of the ocean floor, whereas the Altınekin mélange matrix originally represented the sediment infilling or horizons associated with and around pillow lava sequences. The range in composition displayed now, however, appears to represent the mixing between pelagic and calcareous end-members (Figure 4). In view of the internal shearing observed in the metasediments, much of the mixing could be a mechanical feature engendered during subduction and accretion, rather than original compositional differences of ocean-floor sediments.

Metabasite Geochemical Variation

The megaclasts from both the Altınekin and Akçasar mélange units are dominated by tholeiitic compositions, although one sample (KO-11) from the former unit has high Nb/Y (1.6) and Zr/Y (6.1) ratios typical of alkalic basalts (Winchester & Floyd 1977). In general, the meta-tholeiites are characterised by low incompatible element contents and Zr/Y ratios of 2–3, as well as highly variable LIL element abundances caused by secondary alteration. As seen in Figure 6 the tholeiitic metabasites from both mélange units appear to form a single co-magmatic suite. This suggests that these particular samples were derived, in genetic terms, from the same or closed associated volcanic segment of oceanic crust. The linear covariance for Zr and Y (Y vs Zr, Figure 6) indicates that this suite was related by predominantly plagioclase-olivine fractionation, although the decrease in TiO_2 (TiO_2 vs Zr, Figure 6) suggests that Fe-Ti oxide fractionation was also operative for some samples.

Normalised patterns for the metabasites (Figure 7) show distinct differences between the tholeiites and the alkalic basalt sample; the latter being characterised by typical elemental enrichment features in both normalised diagrams. One of the meta-tholeiitic REE patterns shows a very slight light REE depletion, whereas the other is marginal humped in aspect. Both patterns fall within the range typical of MORB, but due to the marginal light REE depletion, they only have a general affinity to N-type MORB. Their N-MORB character is more clearly shown in the multi-element normalised pattern with both stable LIL and HFS elements straddling the unity line. Of the stable elements, the apparently large negative Hf anomaly is an analytical feature, whereas the small Th enrichment is a

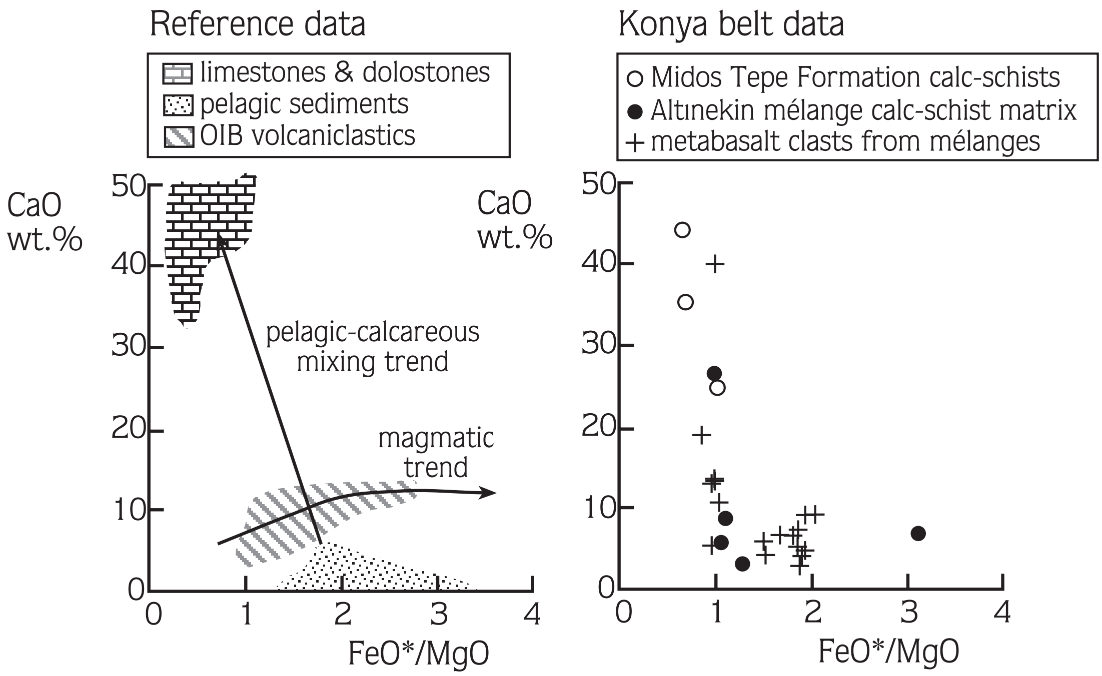

Figure 4. Distribution of Konya metasediments and mélange metabasites in terms of CaO and FeO*/MgO ratio. The metasediments appear to represent a mixing trend between oceanic carbonate and pelagic sediments. Reference data from literature: OIB volcaniclastics (Lees *et al.* 1992) and oceanic sediments (Wang *et al.* 1986; Karpoff 1992).

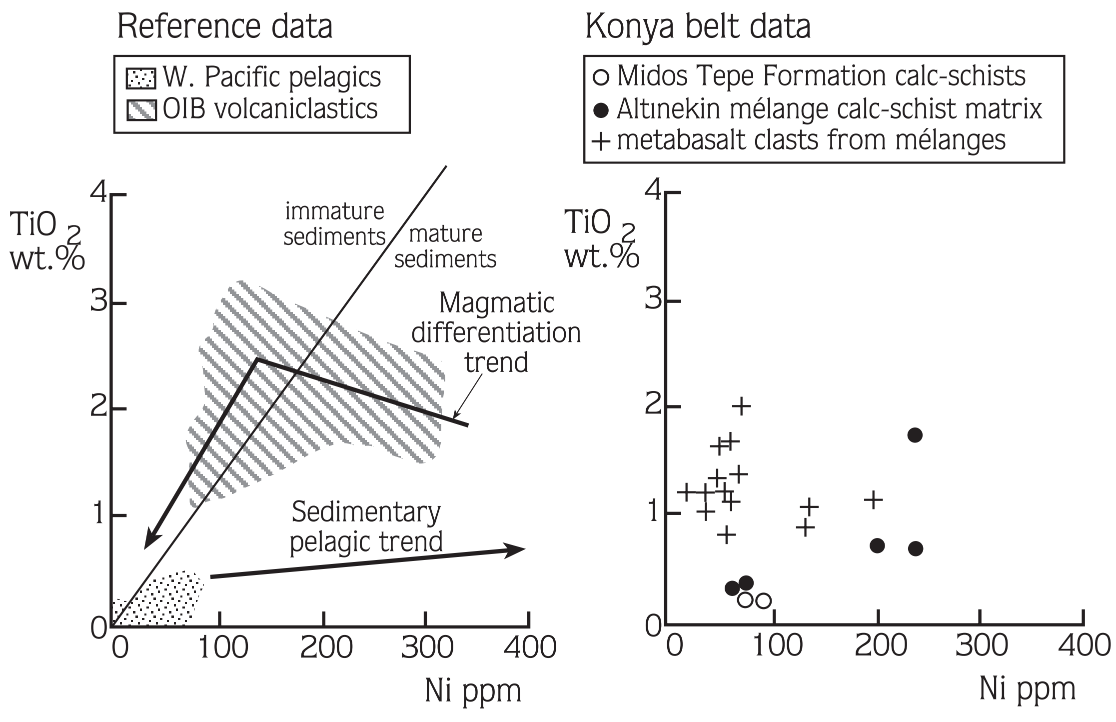

Figure 5. Distribution of Konya metasediments and mélange metabasites in terms of TiO_2 and Ni relative to pelagic and magmatic trends. The diagonal line divides mature sediments from immature (e.g., greywackes) (from Floyd *et al.* 1990).

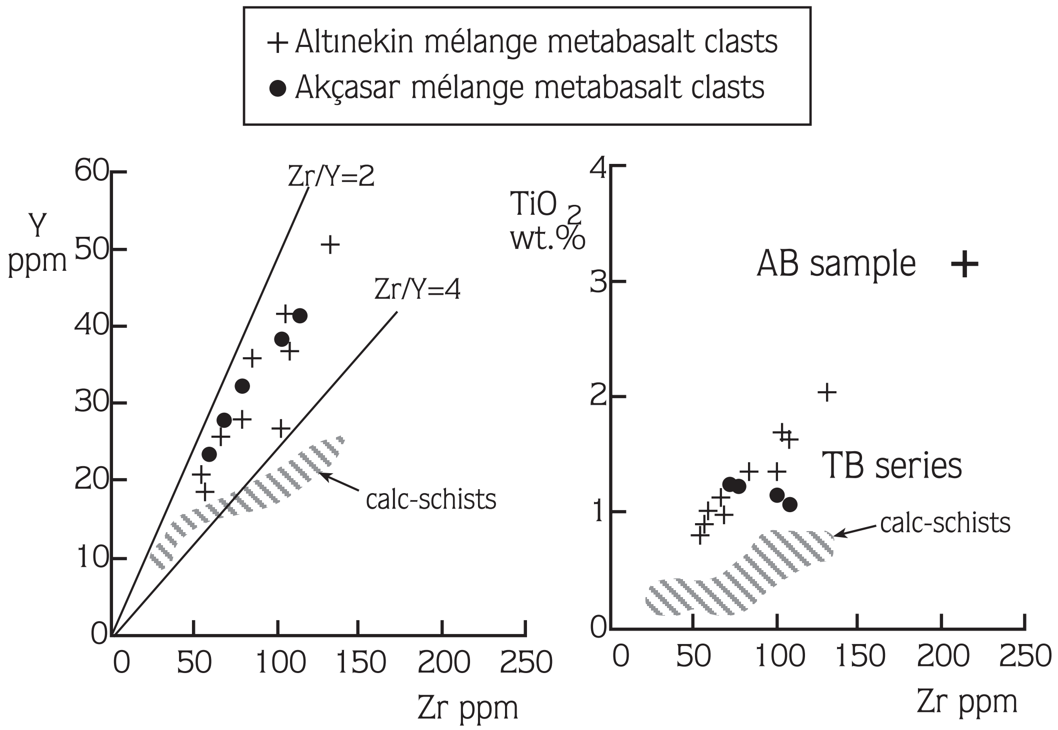

Figure 6. Distributions of Konya mélange metabasites in terms of Y–Zr and TiO_2–Zr. The metabasites from both mélange units appear to define a single co-magmatic suite governed by low-P fractionational crystallisation.

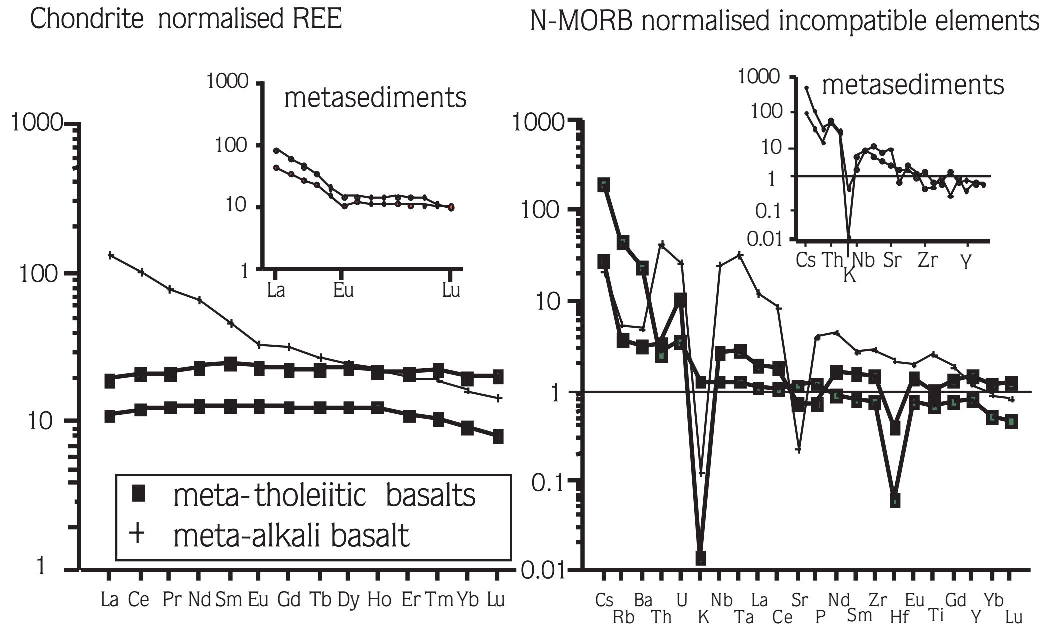

Figure 7. Chondrite and N-MORB normalised patterns for the Konya mélange metabasites. Normalisation factors after Sun & McDonough (1989). Note the enriched pattern of the alkali basalt relative to the tholeiites.

consequence of some sediment contamination. This feature is also indicated in Figure 5 where some of the metabasites are separated from the normal magmatic grouping and approach the pelagic-sediment trend.

In general, the metabasite megaclasts in both mélange units have an affinity with N-MORB and as such are representative of the volcanic portion of the oceanic crust. This chemical interpretation supports the general notion for the Koçyaka Metamorphic Complex based on the association of the different oceanic lithologies present in the mélanges.

Comparison with CACC Ophiolites

The fragmentary stratiform ophiolites of the CACC exhibit chemical features typical of supra-subduction zone (SSZ) ophiolites (Yalınız *et al.* 1996; 2000a, b; Floyd *et al.* 2000). These bodies have a Late Cretaceous formation age similar to the metabasites of the Konya area, and thus, invite comparison in terms of their generation and geotectonic situation, especially if both were initially derived from the I-A-E oceanic segment (see above).

How might the SSZ ophiolites (in the CACC to the north) be tectonically related to the blueschist metabasites with an N-MORB affinity (in the Konya area to the south)? Although both groups (ophiolites and metabasites) are dominated by tholeiitic compositions, a fundamental chemical difference between them is clearly illustrated in Figure 8; the ophiolites have a dominant arc affinity, whereas the metabasites have more MORB-like characteristics. However, there is some degree of chemical overlap. This chemical feature was also found to be typical of some of the SSZ ophiolites (Floyd *et al.* 2000) which had more MORB-type compositions towards the top of the magmatic stratigraphy that could be more related to back-arc, rather than arc, crust.

Because of the difficulties of using LIL elements, most of which are mobile during alteration, the REE and HFS elements are best for comparison and tectonic-environment designation. However, chondrite-normalised REE patterns for arc, back-arc and MORB are not definitive in the sense that there is often considerable overlap, due, in part, to the degree of back-arc spreading or development relative to major spreading-centre ocean

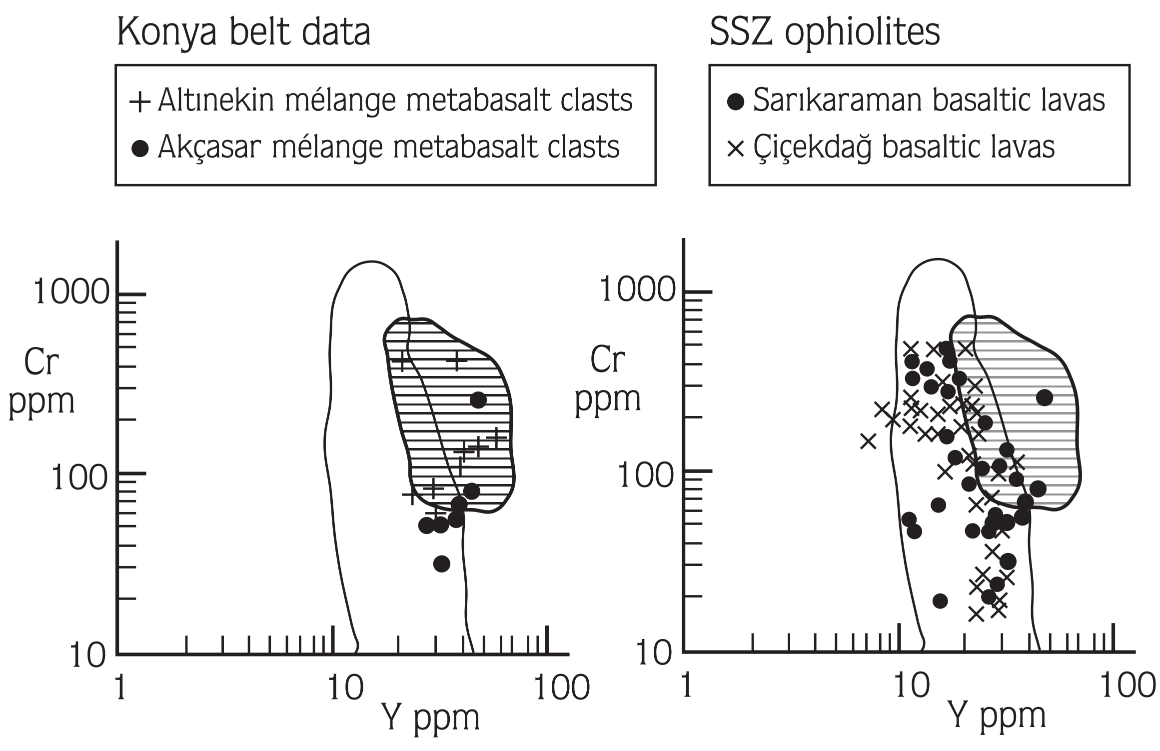

Figure 8. Chemical comparison of the Konya mélange metabasites, with affinities to N-MORB, and SSZ ophiolitic basalt lavas from the Central Anatolian Crystalline Complex with island arc tholeiite (IAT) affinities. N-MORB and IAT fields from Pearce (1980).

crust (Saunders & Tarney 1984). On the other hand, Woodhead *et al.* (1993) compared ratios of HFS elements (in particular, V/Ti) in pairs of coexisting arcs and back-arcs from the western Pacific region. In terms of V/Ti ratios all arcs and back-arc pairs showed only minor chemical overlap with island arcs having a higher and wider range of ratios relative to back-arcs. Typical N-MORB (also from the Pacific Ocean) plots in the back-arc field (shown in Figure 9) as expected from the overlap in compositions from these two eruptive environments. This diagram (Figure 9) also shows the affinity of the SSZ ophiolites for the arc field (IAT) and the Konya metabasites for the back-arc field (BABB). It is suggested that in the light of the similarity of the ages of the two magmatic groups and their tectonic juxtaposition, that they could originally have represented an arc-back-arc pair. This conclusion removes the need for a separate Inner Tauride ocean that had an independent existence relative to the northern Neotethyan oceanic strands.

Geodynamic Considerations

It is commonly accepted that the decoupling of the old oceanic crust within the İzmir-Ankara Ocean, the development of intraoceanic subduction as well as the emplacement age of the Neotethyan ophiolitic nappes onto the Tauride-Anatolide passive continental margin took place during the Albian–Cenomanian time interval (Okay 1989; Önen & Hall 1993; Okay & Kelly 1994; Harris *et al.* 1994). The palaeontological data indicate that formation of SSZ-type oceanic crust within the İzmir-Ankara ocean ranges between Turonian and Campanian (Yalınız *et al.* 1996, 2000a), which is synchronous with the main subduction event (Çoğulu & Krummenacher 1967; Servais 1982; Kulaksız & Phillips 1985; Okay & Kelly 1994; Okay *et al.* 1998). On the other hand, the proposed ages of emplacement of the ophiolites onto the platformal units range from Mid- to Late Cretaceous (Okay 1989) or late Maestrichtian (Özcan *et al.* 1988), and are a matter of debate. These

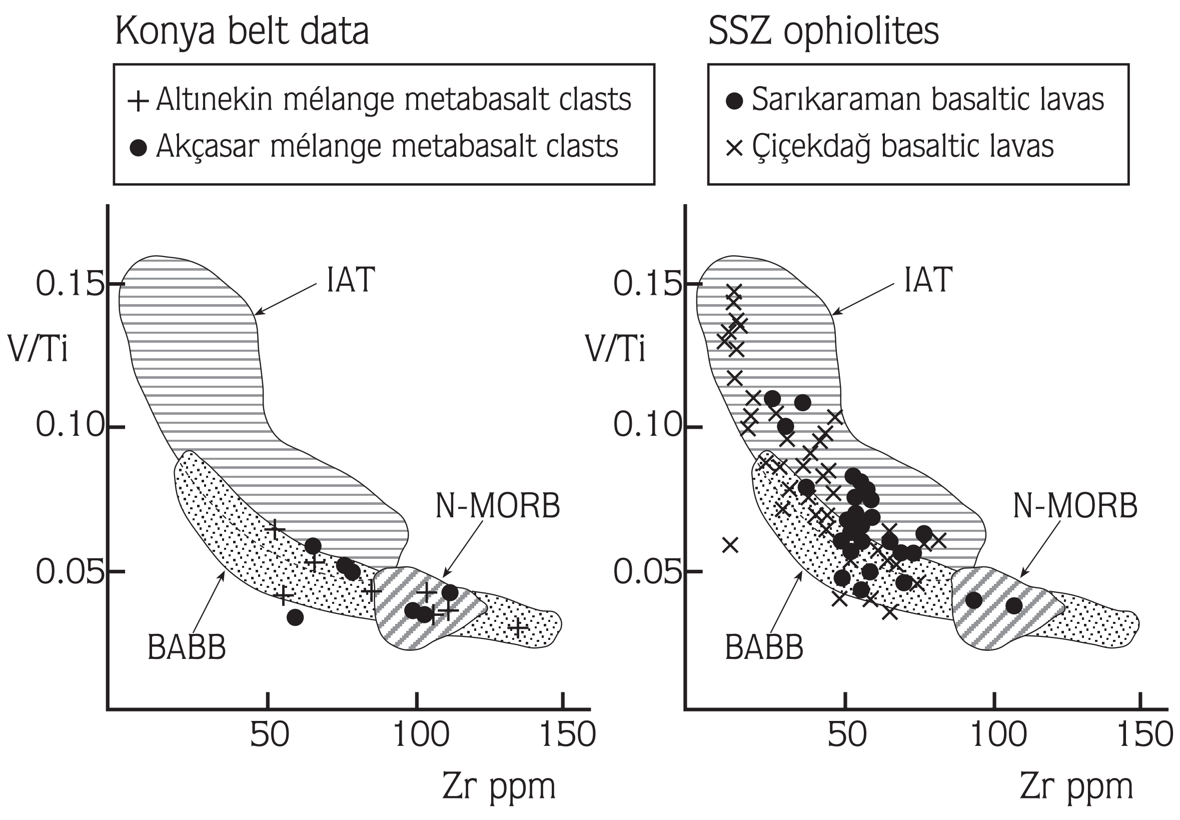

Figure 9. Chemical comparison of the Konya mélange metabasites, with affinities to depleted back-arc basin basalts (BABB), and SSZ ophiolitic basalt lavas from the Central Anatolian Crystalline Complex with island-arc tholeiite (IAT) affinities. Outline of IAT and BABB fields derived from compilation of arc–back-arc pairs by Woodhead *et al.* (1993).

obduction ages are mainly based on fossil data from flysch deposits that include ophiolitic detritus. However, it is not yet clearly documented whether these ages reflect the primary obduction ages of the oceanic assemblages onto the external platform margin or the secondary transportation of the same during the tectonic slicing of the margin. The latter is responsible for the formation of foreland-type basins within the platform and is assumed to be of Middle–Late Eocene in age (Şengör & Yılmaz 1981) in the Taurides but Late Cretaceous in the tectonic slices that originally belong to the northern margin of the Tauride-Anatolide passive margin (Göncüoğlu 2000).

The Koçyaka Metamorphic Complex represents a HP-LT metamorphosed slice of the Tauride-Anatolide passive continental margin. From bottom to top it is made up of platform carbonates, slope-type deposits and mélanges with blocks of oceanic rocks and various carbonates. The olistostromal part typically represents a foreland-type basin deposition that is formed in front of the southward-advancing nappes, derived from the subduction-accretion prism of the İzmir-Ankara-Erzincan subduction zone.

The southward emplacement of this imbricated tectonic package is characterised by overturned folds, which have northward-dipping axial planes, in the Konya area. The initial emplacement of the nappes onto the platform was probably post Turonian–early Campanian (youngest ages of HP-LT metamorphism; e.g., Önen & Hall 1993) and pre-latest Maestrichtian (oldest ages of post-tectonic cover units; Özcan *et al.* 1988). The oldest non-metamorphic cover unit is the molasse-type Kartal Formation of Early Palaeocene age (Göncüoğlu *et al.* 1997), and it indicates that the emplacement of the Koçyaka Metamorphic Complex was already complete prior to the Early Palaeocene.

The above description charts the temporal events that led to the development, initial deposition and final obduction of the metabasite-bearing block mélanges analysed in this paper. A diagrammatic sketch illustrating the geodynamic situation is shown in Figure 10. The interpretation of the geochemical data provides evidence for the original eruptive setting of the metabasalts in a back-arc environment, possibly as a back-arc–arc pair with the SSZ ophiolites. This is the suggested geodynamic relationship envisaged, prior to HP-LT metamorphism, fragmentation of oceanic crust and mélange formation.

Conclusions

1. The LT-HP blueschist belt around Konya is composed of a series of thrust slices containing an admixture of lithologies typical of ocean crust. Different mélange units can be recognised on the basis of their block assemblage and matrix. The Altinekin mélange is dominated by a calc-schist matrix containing numerous metabasaltic blocks, which show pillow lava structure, and are representative of the upper volcanic portion of the oceanic crust. The Akçasar mélange has a sparse serpentinitic matrix with abundant blocks of metabasalt, amphibolite, serpentinite and metachert, and has sampled relatively lower sections of oceanic crust.
2. Associated with the magmatic block mélanges are the calc-schists of the Midos Tepe Formation, which as admixtures of pelagic and carbonate sequences, could be representative of an oceanic sedimentary cover to the volcanic sequence. The calc-schist matrix associated with the metabasaltic blocks of the Altınekin mélange has a similar petrography and chemistry to the Midos Tepe Formation calc-schists.
3. Metabasaltic blocks in all mélanges are dominated by incompatible element depleted tholeiites with an N-MORB-like chemistry. Although overprinted by a HP glaucophanitic assemblage, relict mineralogy and textures indicate that the metabasalts were originally plagioclase-clinopyroxene phyric, quench-textured, basalts.
4. Chemical comparisons with the SSZ ophiolites of the CACC suggest that the Konya metabasites have an affinity with back-arc basalts rather than typical arc basalts. This suggests that the CACC ophiolites and Konya metabasites may have originally represented an arc–back-arc pair during the Late Cretaceous, both having been generated in the İzmir-Ankara-Erzincan (I-A-E) Ocean strand to the north.
5. The above conclusion indicates that the Inner Tauride ocean did not exist as a distinct and separate oceanic strand; instead the ophiolites were directly related to the northern Neotethyan ocean.

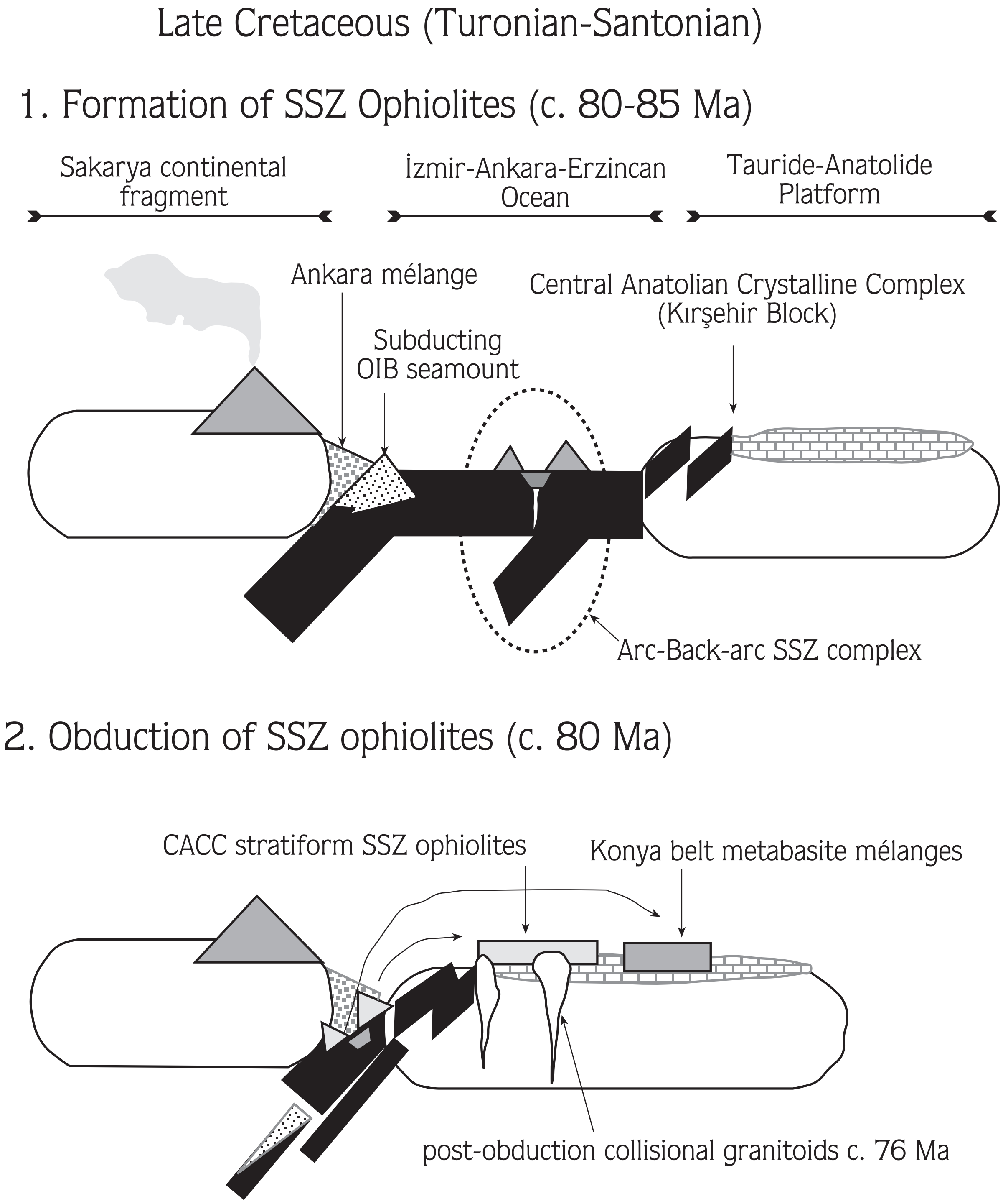

Figure 10. Diagrammatic sketches illustrating the possible events leading to the final obduction of the CACC ophiolites and the Konya glaucophanitic metabasites.

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