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Supra-subduction zone ophiolites of Central Anatolia: geochemical evidence from the Sarikaraman Ophiolite, Aksaray, Turkey

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Abstract

The Central Anatolian Crystalline Complex (CACC), situated between the northern and southern oceanic strands of Neotethys, contain a number of little-studied ophiolitic bodies of late Cretaceous age that have a bearing on the Mesozoic development of this region. The pillow lavas and sheeted dykes of the Sarikaraman Ophiolite were originally a comagmatic differentiated series of vesicular, aphyric and olivine-poor, plagioclase–clinopyroxene phyric tholeiites, but now exhibit greenschist facies assemblages. A set of late dolerite dykes cross-cutting the whole volcanic sequence are more chemically evolved and were probably derived from a different source. Relative to N-MORB the lavas and dykes are enriched in some LIL elements (K, Rb, Cs, U, Th and Sr) and depleted in HFS elements (Nb, Ta, Hf, Zr, Ti and Y) and light *REE*. In terms of immobile elements the ophiolitic basalts have the broad chemical characteristics of island arc tholeiites that were formed in a supra-subduction zone setting, whereas the late dykes are more akin to N-MORB. In this respect the Sarikaraman Ophiolite is similar to other ophiolites found in the eastern Mediterranean region and emphasizes the preservation of this particular environment in the CACC. If all the Central Anatolian Ophiolites (of which the Sarikaraman Ophiolite is one example) were derived via southward thrusting from the Vardar-Izmir-Ankara-Erzincan Ocean branch to the north, age relationships suggest that this segment of ocean crust was relatively short-lived before obduction onto the CACC.

KEYWORDS: ophiolites, supra-subduction zone, geochemical evidence, Central Anatolia, Turkey.

Introduction

OPHIOLITES, as remnants of obducted ancient ocean crust, mark the presence of former suture zones and play an important role in plate tectonic reconstructions (Coleman, 1977; Moores and Vine, 1971). Those of Mesozoic age are ubiquitous in Turkey and the Middle East region generally (e.g. Vourinos, Othris, Argolis, Troodos, Baer-Bassit, Semail), and represent the variably disrupted fragments of branches of the Neotethyan ocean that was situated between Eurasia and Gondwanaland (Juteau, 1980; Sengör and Yilmaz, 1981; Robertson and Dixon, 1985).

The most outstanding feature that differentiates the Mesozoic suture zones in Turkey (and Greece) from the rest of the Alpine-Himalayan belt, is the significance attributed to the areal distribution of ophiolite-related bodies, and hence the number and location of their root-zones or sources. Interpretative models range from all ophiolitic bodies being derived from a single ocean (e.g. Ricou, 1971; Ricou *et al.*, 1984) to multiple source models, where separate ophiolite alignments are considered to have originated from different ocean basins (e.g. Sengör, 1985; with ten Tethyan sutures recorded).

At the present state of knowledge, a more realistic tectonic approach suggests that the Turkish Neotethyan ophiolites are represented by only three main broadly east-west trending zones, each one characterizing allochthonous ophiolite-related units derived from separate ocean basins (Fig. 1 inset): (a) a northern belt representing remnants of the Intra-Pontide Ocean, (b) a median belt representing two groups of allochthonous units derived from the Vardar-Izmir-Ankara-Erzincan Ocean, (although Görür *et al.* (1984) consider a separate derivation for the Inner Tauride Belt), and (c) a southern belt, variably called the Peri-Arabic Belt (Ricou, 1971) or Southern Neotethyan Ocean (Sengör and Yilmaz, 1981). The ophiolites of the northern belt and the Vardar-Izmir-Ankara-Erzincan suture have not yet been studied in detail, whereas those from the southern belt and Inner Tauride Belt have undergone considerable investigation (e.g. references in Robertson and Dixon, 1985). Despite these more or less well-defined belts, numerous, little known and isolated ophiolitic bodies are exposed in the Central Anatolian Crystalline Complex (CACC), just to the south of the Vardar-Izmir-Ankara-Erzincan suture (Fig.1 inset).

The CACC is a triangular wedge of high-grade (amphibolite facies) metamorphic basement (Göncüoğlu *et al.*, 1991, 1992*a*) which is considered to represent the northern passive margin of the Mesozoic Tauride-Anatolide Platform, facing the Vardar-Izmir-Ankara-Erzincan Ocean (Özgül, 1976). Isolated outcrops of late Cretaceous ophiolitic rocks, termed the Central Anatolian Ophiolites (Göncüoglu and Türeli, 1993*a*) are found as allochthonous bodies in the CACC. Their structural setting differs from the remnants of the Vardar-Izmir-Ankara-Erzincan Ocean that are now represented by an ophiolitic mélange (Çapan and Floyd, 1985; Floyd, 1993) largely generated in a fore-arc accretional prism (Koçyiğit *et al.*, 1988; Koçyiğit, 1991). The Central Anatolian Ophiolites (CAO) are represented by two main groups: (*a*) high-grade ophiolites, deformed and metamorphosed at the same time as the Central Anatolian metamorphic basement, and (*b*) essentially non-metamorphic or low-grade ophiolites tectonically overlying the basement (Göncüoğlu and Türeli, 1993*b*).

The state of knowledge concerning these two groups is relatively poor, both in terms of the pseudostratigraphic relationships of the magmatic units, their chemical designation, and inferred tectonic setting relative to the other ophiolitic belts. In particular, do they display the chemical features that appear to be characteristic of Tethyan ophiolites from the Eastern Mediterranean? For example, ophiolites from the southern Turkish belt (and Greece) exhibit a chemical composition more akin to arc-related tectonic settings than ocean spreading ridges (e.g. Pearce, 1979; Capedri *et al.*, 1980; Alabaster *et al.*, 1982) and have been referred to as supra-subduction zone (SSZ) ophiolites (Pearce *et al.*, 1984). Whether the Central Anatolian Ophiolites represent fragments of a major ocean basin or were produced in a supra-subduction environment is not known, but clearly has important implications for the regional tectonic interpretation of this unique area. Furthermore, if the Central Anatolian Ophiolites were initially derived from the Vardar-Izmir-Ankara-Erzincan Ocean (as suggested by Göncüoğlu, 1982) they represent a better example of largely unfragmented ocean crust than their equivalents in the Ankara ophiolitic mélange.

The object of this paper is to present chemical data on the volcanic component of one of the most complete and best exposed of the second group of CAO bodies — the Sarikaraman Ophiolite — as a basis for tectonic environment evaluation. We aim to compare the geochemical characteristics with other Eastern Mediterranean ophiolites and discuss the implications for current regional geodynamic models (Sengör and Yilmaz, 1981; Görür *et al.*, 1984; Robertson and Dixon, 1985). The Sarikaraman Ophiolite is situated in the southern part of the CACC, between Aksaray (to the south) and Kirsehir (to the north) (Fig.1).

Field relationships and features

The Sarikaraman Ophiolite is representative of a somewhat dismembered ophiolite body retaining a recognizable magmatic pseudostratigraphy (Fig.1). Voluminous ultramafics are not exposed in direct contact with the rest of the ophiolitic slab, the lowest section being composed of isotropic gabbros, which are faulted against a sheeted dyke complex that merges up section into basalt lavas and breccias. The

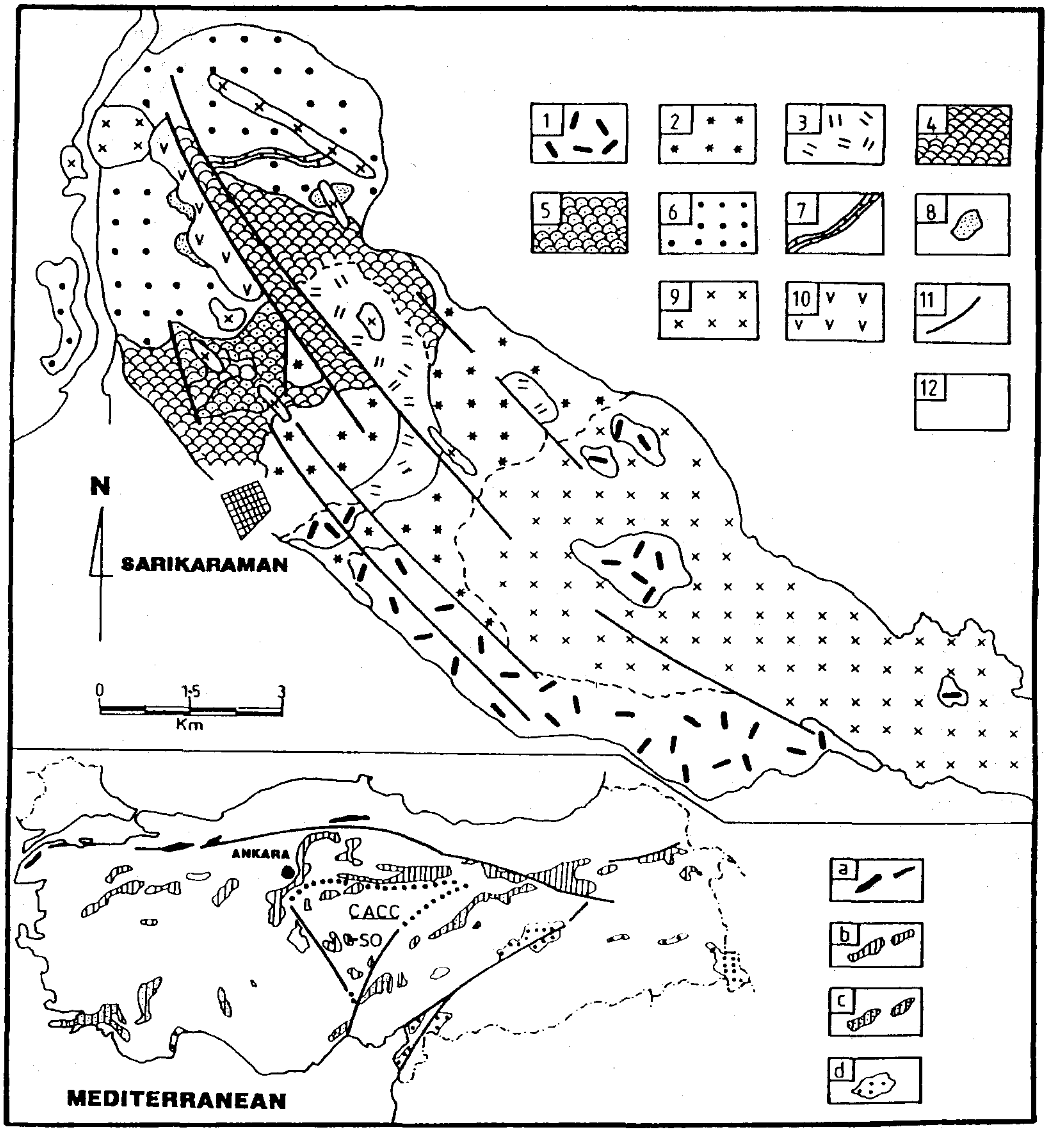

FIG. 1. Geological map of the Sarikaraman ophiolite, Central Anatolia: 1— Isotropic gabbro, 2— Plagiogranite (trondhjemite), 3— Dolerite dyke complex, 4— Basalt pillow lava, 5— Basalt pillow breccia, 6— Lower Turonian-Campanian sediments, 7— Campanian limestone unit, 8— Felsic volcanic block unit, 9— Maastrichtian-Lower Palaeocene(?) Terlemez monzogranite, 10— Palaeocene(?) volcaniclastic unit, 11— Fault, 12— Neogene cover units. Inset shows the ophiolitic belts of Turkey (Juteau, 1980) and the location of the Sarikaraman ophiolite (SO) within the Central Anatolian Crystalline Complex (CACC): a— Intra-Pontide Suture, b— Vardar-Izmir-Ankara-Erzincan Suture, c— Inner Tauride Belt, d— Peri-Arabic Belt.

gabbros are cut by intrusive trondhjemitic plagiogranites which appear to be genetically related to various high-level rhyolitic dykes and sills that traverse the upper volcanic section of the ophiolite. All units are cut by a late set of isolated dolerite dykes. The ophiolite is overlain by a sequence of Lower Turonian-Campanian pelagic sediments (including pink fossiliferous limestones), together

TABLE 1. Representative chemical data for basalt (Bas), pillow lavas (p), massive lavas (m), and dolerites (Dol) from the Sarikaraman ophiolite, Central Anatolian Complex, Turkey

Sample no.	P-1	P-2	P-4	P-6	P-7	P-8	P-9	P-11	M-82	M-33	M-87	M-90	M-92	157-D	M-21	M-24	M-84	KY-18	M-66	M-74
Rock type	Bas(p)	Bas(p)	Bas(p)	Bas(p)	Bas(p)	Bas(p)	Bas(p)	Bas(p)	Bas(p)	Bas(m)	Bas(m)	Bas(m)	Bas(m)	Dol	Dol	Dol	Dol	Dol	L. dyke	L. dyke
Major oxides (wt.%)																				
SiO_2	50.86	57.69	61.10	45.97	45.46	57.38	40.84	52.37	48.59	51.01	62.27	50.92	50.40	53.22	52.26	55.91	50.84	50.13	48.91	51.02
TiO_2	0.74	0.63	0.82	0.74	0.72	0.65	0.74	0.70	0.54	0.79	0.84	0.54	0.88	0.87	1.02	1.81	2.13	1.88	1.42	2.06
Al_2O_3	15.01	12.27	13.01	12.12	14.61	12.73	14.25	15.10	15.80	15.63	12.58	21.17	16.12	16.04	16.11	15.36	14.85	14.52	15.41	14.64
Fe_2O_3*	6.43	6.34	8.92	8.99	9.29	6.84	7.67	8.71	10.78	11.57	6.60	7.97	9.90	10.61	10.59	10.86	13.83	14.74	10.98	14.57
MnO	0.26	0.24	0.07	0.41	0.38	0.18	0.39	0.21	0.15	0.15	0.21	0.12	0.09	0.23	0.19	0.07	0.14	0.20	0.18	0.19
MgO	10.55	8.49	3.75	12.73	15.09	8.59	11.41	12.11	8.15	3.13	1.44	3.83	4.09	3.51	6.31	3.87	3.91	5.26	6.47	4.50
CaO	4.81	6.10	9.51	7.92	3.87	5.20	10.49	1.68	7.30	6.80	9.46	6.37	9.86	6.36	10.17	3.78	5.17	5.61	8.86	8.66
Na_2O	4.04	2.53	0.01	0.03	1.24	2.40	2.93	2.53	1.71	4.74	2.25	4.42	2.04	4.29	2.64	5.26	5.88	5.33	3.08	3.62
K_2O	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.13	0.33	0.45	0.60	0.23	0.26	0.05	0.31	0.12	0.10	0.11	0.04
P_2O_5	0.06	0.04	0.05	0.05	0.05	0.04	0.08	0.06	0.02	0.05	0.08	0.06	0.05	0.04	0.07	0.27	0.18	0.09	0.16	0.16
LOI	7.72	6.03	2.76	10.54	9.41	5.89	11.08	6.82	6.71	6.20	3.60	4.27	6.79	4.89	0.69	2.94	3.42	2.18	4.20	0.35
Total	100.49	100.37	100.01	99.52	100.13	99.91	99.89	100.30	99.88	100.40	99.78	100.27	100.45	100.32	100.10	100.44	100.47	100.04	99.78	99.81
Trace elements by XRFS (ppm)																				
Ba	9	9	6	26	18	19	15	19	21	29	67	96	83	30	19	40	23	35	172	38
Cl	32	55	42	45	53	55	70	33	60	5	20	38	64	62	70	51	109	105	53	170
Cr	376	322	94	509	438	172	360	343	52	129	26	20	49	10	50	8	18	27	97	42
Cu	5	15	10	9	12	20	7	6	55	19	41	85	128	11	69	12	13	19	25	20
Ga	10	9	15	12	12	11	12	12	16	16	14	21	17	18	17	18	18	20	16	20
Nb	1	1	1	2	1	1	2	1	1	1	1	2	3	3	4	3	5	4	3	5
Ni	136	106	31	221	154	76	144	122	24	39	13	16	37	4	29	6	13	19	48	19
Pb	5	2	10	11	6	8	6	11	6	9	10	9	12	9	7	7	7	6	11	8
Rb	4	4	5	5	3	4	4	5	7	14	15	20	10	13	4	8	4	6	4	4
S	72	68	67	77	75	75	82	65	88	92	85	71	95	78	89	68	75	71	83	79
Sr	45	100	233	95	46	108	89	34	105	230	123	401	155	175	139	149	94	161	195	169
V	172	171	265	324	290	253	192	252	347	500	364	258	346	155	306	148	501	579	297	498
Y	11	14	21	17	13	16	18	11	11	18	27	15	22	21	29	42	47	33	36	46
Zn	90	77	23	124	141	87	99	171	67	72	43	70	88	116	51	41	39	75	43	49
Zr	55	49	52	54	54	51	54	54	26	36	58	53	59	39	69	106	137	75	106	118

TABLE 1 (*cont.*)

Sample no. Rock type	P-1 Bas(p)	P-2 Bas(p)	P-4 Bas(p)	P-6 Bas(p)	P-7 Bas(p)	P-8 Bas(p)	P-9 Bas(p)	P-11 Bas(p)	M-82 Bas(p)	M-33 Bas(m)	M-87 Bas(m)	M-90 Bas(m)	M-92 Bas(m)	157-D Dol	M-21 Dol	M-24 Dol	M-84 Dol	KY-18 Dol	M-66 L. dyke	M-74 L. dyke
Trace elements by INAA (ppm)																				
Hf								1.00	0.40					0.90					2.40	2.60
Sc								32	41					41					34	35
Ta								0.07	0.06					0.10					0.10	0.26
Th								0.20	0.30					0.40					0.40	0.50
U								0.20	0.10					0.10					0.10	0.10
La								1.30	1.20					1.70					4.80	5.00
Ce								3.00	4.00					5.00					16.00	17.00
Nd								3.00	3.00					4.00					12.00	13.00
Sm								0.86	0.88					1.51					3.42	4.02
Eu								0.29	0.36					0.82					1.25	1.50
Gd								1.50	1.60					2.30					4.80	5.60
Tb								0.30	0.30					0.50					0.80	1.20
Yb								1.25	1.26					2.19					3.20	4.31
Lu								0.19	0.18					0.32					0.47	0.58
Ratios																				
Zr/Y	5.0	3.5	2.5	3.2	4.2	3.2	3.0	4.9	2.4	2.0	2.1	3.5	2.7	1.9	2.4	2.5	2.9	2.3	2.9	2.6
Zr/Nb	55	49	52	27	54	51	27	54	26	36	58	26	20	13	17	35	27	19	35	24
FeO*/MgO	0.5	0.7	2.1	0.6	0.6	0.7	0.6	0.6	1.2	3.3	4.1	1.9	2.2	2.7	1.5	2.5	3.2	2.5	1.5	2.9

with minor olistrostromes containing felsic blocks derived from the plagiogranites. Both the ophiolite and cover sediments are intruded by a late Cretaceous/Lower Palaeocene monzogranite. These granites have their counterpart in other areas of the CACC and are not related to the ophiolites, being the post-collisional products of the melting of thickened crust (Göncüoğlu and Türeli, 1994). Finally, the ophiolite and late granites are unconformably overlain by Palaeocene volcaniclastites. The field relationships and faunal age of the ophiolite-related sediments indicates that the Sarikaraman Ophiolite is broadly late Cretaceous (Turonian–Santonian) in age.

The volcanic unit of the Sarikaraman Ophiolite is mainly composed of basaltic pillow lavas with subordinate interbedded massive lavas, and associate pillow breccia (Fig.1). The pillowed and massive lava flows are predominantly coloured grey-green to light green and reflect the proportion of secondary minerals, whereas rare reddish-brown flows are the result of subsequent oxidization. Individual flows reach 5–6 m in thickness and may exhibit columnar jointing. The pillow lavas form a pile of draped elongate tubes, some of which may attain a maximum diameter of 2 m. Pillow margins were originally glassy, but are now mostly replaced by secondary chlorite, whereas interiors are holocrystalline and often vesicular. Vesicles (up to 1 cm in diameter) are usually filled with chlorite, epidote, quartz and late replacive carbonate. The sheeted dyke complex comprises 80–100% sub-vertical dykes of dolerite and basalt, generally between 0.5–2.5 m in width. The late set of isolated dolerite dykes that cut the full magmatostratigraphy are more irregular with variable width and sharp margins.

Petrography

In many of the basalts and dolerites of the Sarikaraman Ophiolite primary minerals and textures are strongly overprinted by secondary assemblages produced during initial ocean-floor hydrothermal alteration. However, inference from relict features suggest that recognizable primary textures relate to cooling history with variolitic textures at the margins of flows and intersertal to subophitic textures in the coarser grained interiors. The basalts are aphyric to weakly porphyritic with plagioclase and subordinate clinopyroxene as phenocryst phases. Dolerites are either poorly plagioclase phyric or aphyric.

The effects of alteration may be so intense that only secondary phases are present, with assemblages comprising admixtures of albite, epidote, chlorite, quartz, iron oxide, and minor actinolite, being common. Throughout all the basalts and dolerites, albite replaces both phenocrysts and matrix laths, whereas chlorite commonly occurs in the matrix, apparently replacing original glass. Epidote, as fan-shaped aggregates (up to 2–3 cm in diameter), generally occurs in vesicles along with quartz and minor chlorite. Late quartz may also replace the matrix. Actinolite is much less abundant than other alteration phases, but is present as scattered fibres throughout the matrix or occasionally replacing relict pyroxene rims.

The dominant secondary assemblages indicate that the greenschist facies of metamorphism was reached, although late circulation of low-temperature fluids is indicated by the development of quartz and carbonate that replace earlier alteration phases and occur as veinlets.

Geochemistry

Sampling and analytical methods. Representative basaltic rocks (42 samples) were collected from the Sarikaraman Ophiolite and analysed for major and selected trace elements, with a subset of 5 samples being determined for rare earth elements (*REE*) and Hf, Ta, Th and U. All samples were analysed on an ARL 8420 X-Ray Fluorescence spectrometer (Department of Earth Sciences, University of Keele) calibrated against both international and internal Keele standards of appropriate composition, whereas the *REE* etc. were determined by Instrumental Neutron Activation Analysis (Activation Laboratories Ltd., Canada). Details of methods, accuracy and precision are given in Floyd and Castillo (1992).

Analysed samples were confined to three groups: (a) pillowed and massive lavas, (b) dolerite dykes from the sheeted dyke complex, and (c) late, cross-cutting dolerite dykes; these groups are distinguished in all chemical diagrams. Representative analyses are shown in Table 1.

Chemical alteration features. The basaltic samples all show some degree of low-grade secondary alteration 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 and Thompson, 1978; Thompson, 1991). The wide variation in loss-on-ignition (LOI) values (Table 1) is a crude measure of the degree of alteration and reflects the contribution by secondary hydrated and carbonate phases. LIL element (e.g. K, Na, Rb, Ba) abundances are often highly variable, together with most major elements and ratios (e.g. FeO*/MgO), and thus are unreliable as indicators of petrogenetic relationships. Characteristic and systematic interelement relationships often shown by unaltered basic suites are only shown 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 and Cann, 1973; Smith and Smith, 1976;

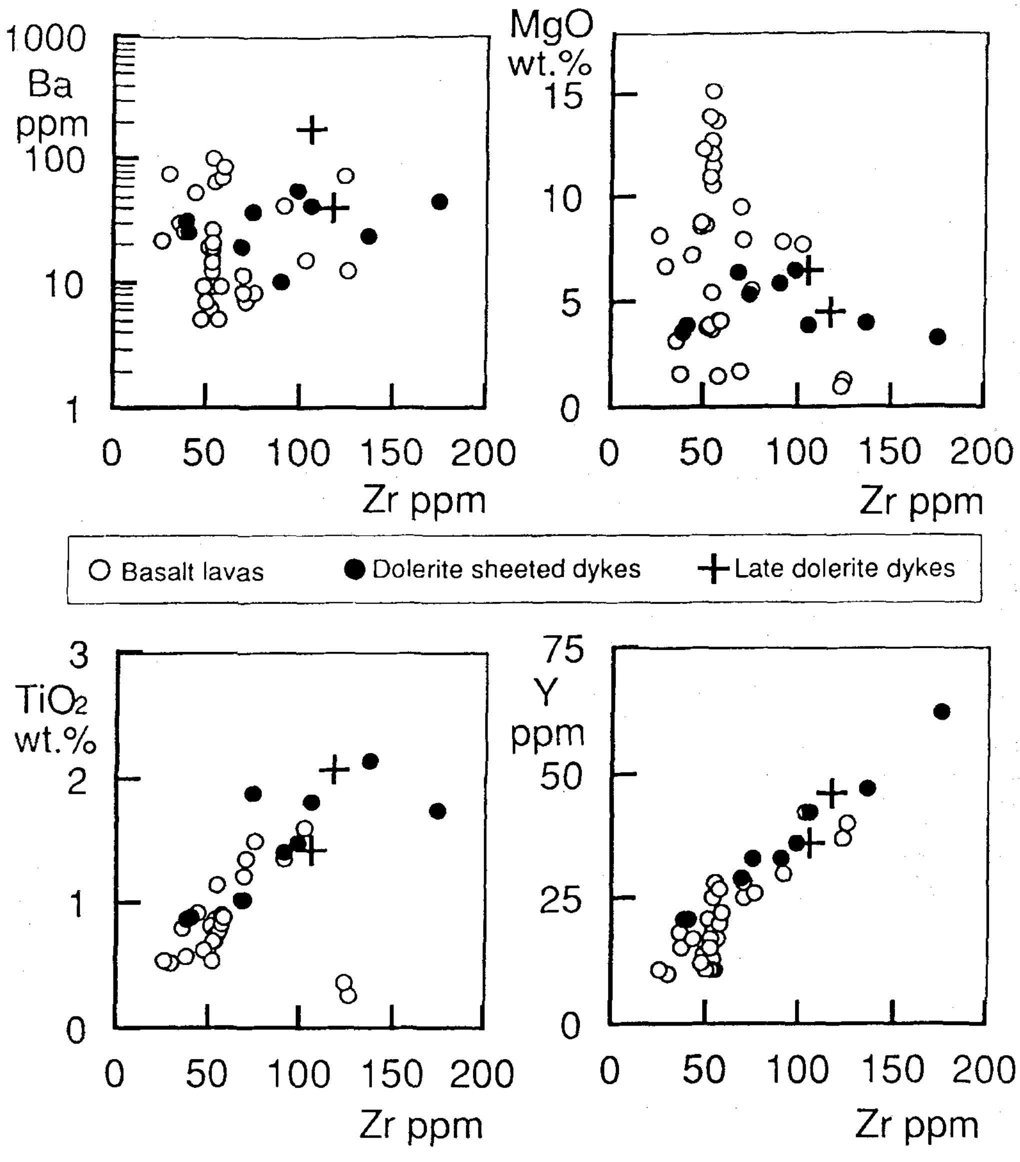

FIG. 2. Variations of mobile (Ba, Mg) and immobile (Ti, Y) elements relative to Zr (corresponding to a stable fractionation index) in Sarikaraman Ophiolite basaltic rocks.

Floyd and Winchester, 1978). As seen in Fig. 2, components that are mobile during alteration (Ba, MgO) exhibit scattered non-magmatic distributions, whereas generally immobile elements (Ti, Y) have characteristic linear relationships, relative to Zr. In a similar manner, normalized *REE* data develop smooth patterns of variation (see later) that are considered typical of their original composition. Under some circumstances, such as extensive carbonation of the lavas, the *REE* and HFS elements can be mobilized and/or abundances diluted (e.g. Hynes, 1980; Humphris, 1984; Rice-Birchall and Floyd, 1988), although in this study such carbonate-rich rocks were avoided.

Volcanic sequences of ophiolites are invariably altered mineralogically and chemically by submarine hydrothermal processes within the zeolite to greenschist facies of metamorphism (e.g. Gass and Smewing, 1973; Pearce and Cann, 1973; Spooner and Fyfe, 1973; Smewing and Potts, 1976; Venturelli *et al.*, 1981), a feature also typical of the Sarikaraman Ophiolite basalts. Thus, the following chemical assessment and discrimination rely mainly on the distribution of the relatively stable HFS and *REE* elements in the mineralogically least-altered samples.

Chemical relationships and tectonic discrimination. On the basis of relatively immobile trace elements the basalts and dolerites show the following broad characteristics (Figs. 2 and 3): (*a*) generally low (depleted) abundances of incompatible elements with a limited range (e.g. 26–124 ppm Zr, 1–5 ppm Nb), but positive interelement covariance, (*b*) low Nb/Y ratios (0.04–0.20) characteristic of sub-alkaline (tholeiitic) basalts (Winchester and Floyd, 1977), (*c*) a wide range of Cr and Ni contents (together with variable FeO*/MgO ratios), and (*d*) a range of chondrite-normalized, light *REE* depleted patterns to flat patterns ($[La/Yb]_N$ 0.6–1.0). Overall the preliminary data indicates that the volcanic samples represent a moderately differentiated (involving mafic and oxide phases) comagmatic, tholeiitic suite featuring depleted characteristics.

However, when the three separate basaltic groups are considered their respective chemical features can be interpreted as follows. The broad overlap in stable incompatible element abundances (Fig.2) and similarity of normalized *REE* patterns (Fig.3) for the basalt lavas and dolerites of the sheeted dyke complex indicate a possible comagmatic relationship.That is, in the chemical sense some feeder dykes can be matched with their extrusive products. However, some of the dykes are more chemically evolved than the bulk of the lavas and suggests that the full range of pillow lavas has not been sampled or they are now missing from the initial volcanic pile. A significant difference is also exhibited by the later cross-cutting dolerite dykes. Relative to the lavas and sheeted dykes, they are generally more evolved and exhibit normalized flat (undifferentiated) *REE* patterns possibly indicative of a different source.

Chemical discrimination of the eruptive environment for basic rocks, using such diagrams as displayed in Fig. 4, suggests that the majority of the Sarikaraman Ophiolite basalt lavas have affinities with island arc-related tholeiites (IAT) rather than typical mid-ocean ridge basalts (MORB). Both the dolerites of the sheeted dykes and late dykes spread across into the MORB fields. The main trace element characteristics of IAT relative to MORB include (*a*) high LIL/HFS element ratios, and (*b*) overall low HFS values (<1) when normalized to N-MORB (e.g.

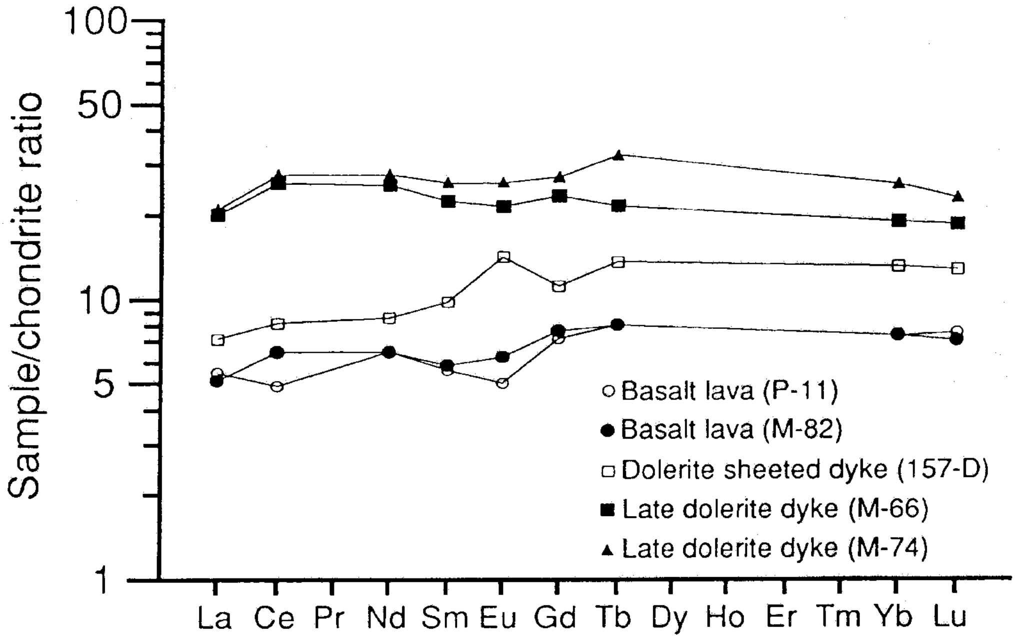

FIG. 3. Chondrite-normalized, light *REE* depleted patterns characteristic of Sarikaraman Ophiolite basalts and flat patterns typical of the late dolerite dykes.

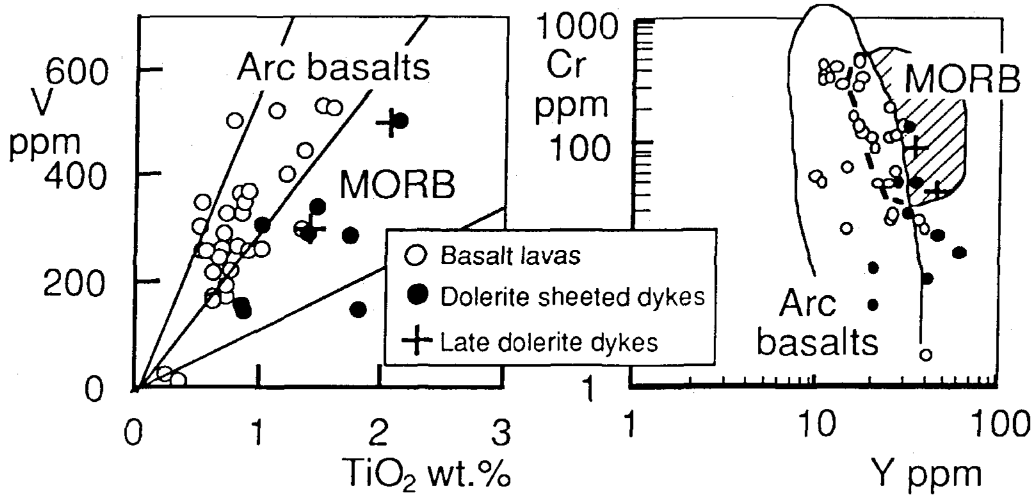

FIG. 4. Chemical discrimination of the least altered basalts and dolerites from the Sarikaraman ophiolite indicates a predominantly subduction-related eruptive environment rather than a major ocean. IAT = Island arc tholeiite field; MORB = Mid-ocean ridge basalt field. V-TiO2 diagram from Shervais (1982) and Cr-Y diagram from Pearce (1982).

Saunders *et al.*, 1979; Pearce, 1983; Saunders and Tarney, 1984), both features of which are exhibited by the Sarikaraman basalts. For samples where reliable data (by INAA) are available, Th/Yb ratios (0.1–0.4) are higher than MORB (0.03) for the same degree of chemical evolution. An N-MORB normalized plot (Fig. 5) exhibits the depletion of the HFS elements (and light *REE*) coupled with the strong enrichment of selected stable LIL elements and broadly confirms the subduction-related character of the Sarikaraman basalts. Note, however, that the late dolerite dykes are distinct and show a pattern parallel to N-MORB, with little Th enrichment. Within the LIL element group, Th is a relatively stable and reliable indicator, whose enrichment relative to other incompatible elements is taken to represent the subduction zone component (e.g. Wood *et al.*, 1979; Pearce, 1983). That is, the source region for arc melts has been modified by the addition of LIL element-bearing aqueous fluids derived from the underlying subduction zone (e.g. Best, 1975; Pearce, 1982, 1983; Hawkesworth *et al.*,1977; McCulloch and Gamble, 1991). The chemical features displayed by the lavas and dykes imply that the Sarikaraman Ophiolite was formed in a subduction-related environment rather than at a large ocean spreading centre and is thus another SSZ-type ophiolite (Pearce *et al.*, 1984). The later dykes appear to be more MORB-like and less depleted in character, and reflect a change in source with time which is considered to be another feature of SSZ ophiolites (e.g. Alabaster *et al.*, 1982).

Comparison with Tethyan ophiolites

The Sarikaraman Ophiolite is just one member of a long linear zone of Tethyan ophiolites that extend from the western Mediterranean to the Persian Gulf and beyond. Several groups of workers (e.g. Nicholas and Jackson, 1972; Rocci *et al.*, 1975; Abbate *et al.*, 1976) have divided the ophiolites of this region into two groups on the basis of degree of tectonic deformation and age: (*a*) fragmented Jurassic ophiolites in the western and central area (Alps, Apennines, Carpathians, Dinarides, Hellenides), and (*b*) mid- to late-Cretaceous ophiolites displaying a pseudostratigraphy, at the eastern end (Troodos, Semail, Baer-Bassit, Hatay). There is also a difference in chemical characterization (Pearce, 1979; Robertson and Dixon, 1985) with the first group displaying MORB-like features, whereas the second group exhibit SSZ features often comparable with younger back-arc basins worldwide (Pearce *et al.*, 1984). This distinction is clearly shown in Fig. 6 with the separation of Cretaceous ophiolites (area 1 plotting in IAT field) and Jurassic ophiolites (area 2 plotting in MORB field). The Sarikaraman data plots with the SSZ ophiolites of the eastern region and covers the full range of Th enrichment displayed. Like the majority of the Troodos basalts, the

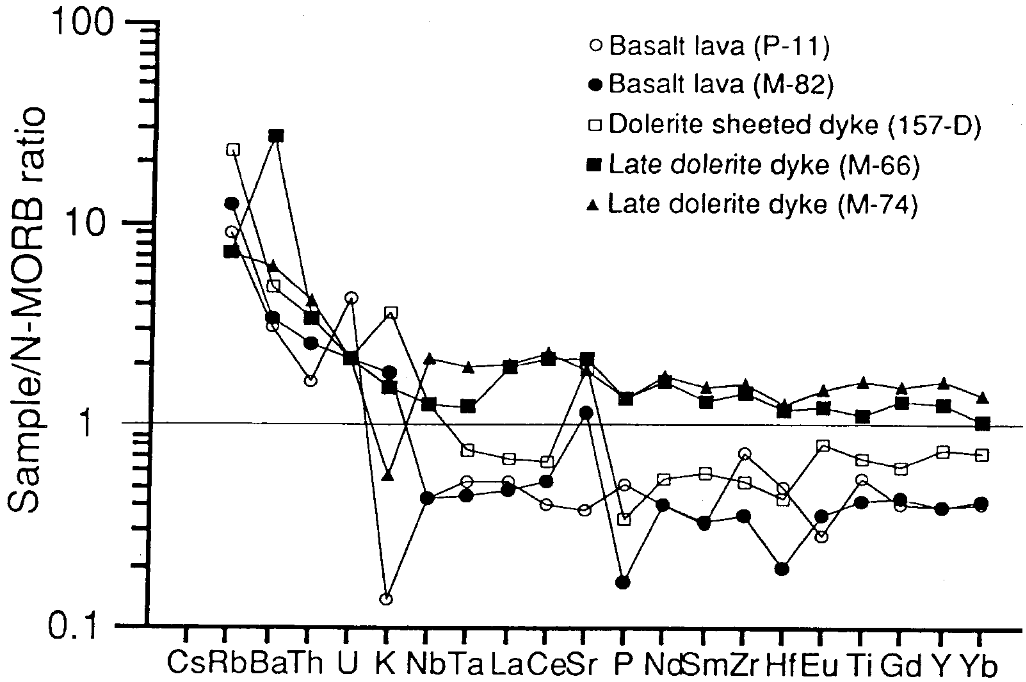

FIG. 5. N-MORB-normalized multi-element diagram for Sarikaraman Ophiolite basalts showing relative HFS element +light *REE* depletion with Th enrichment, and the MORB-like pattern for late dolerite dykes. Normalization factors from Sun and McDonough (1989).

Sarikaraman basalts have low and restricted Zr/Y ratios of between 2.2–5.0 and similar depleted light *REE* patterns. However, what is rarely seen are the more evolved tholeiitic compositions (basaltic andesites and andesites) with high incompatible element abundances described from the lower-series Troodos lavas (Thy *et al.*, 1985). This could be a reflection of limited sampling at the Sarikaraman complex where only higher stratigraphic levels are exposed for study.

Application to regional tectonic environment

The designation of the Sarikaraman Ophiolite as an SSZ-type is in keeping with the recognition that most Eastern Mediterranean ophiolites of Cretaceous age were formed in this eruptive setting. This feature may also be typical of the other, little known, Central Anatolian Ophiolites (CAO) of the CACC. If this is the case, the SSZ setting may help to explain the short time-span between ophiolite generation in the Vardar-Izmir-Ankara-Erzincan Ocean (to the north) and its initial emplacement onto the southern passive margin (the CACC).

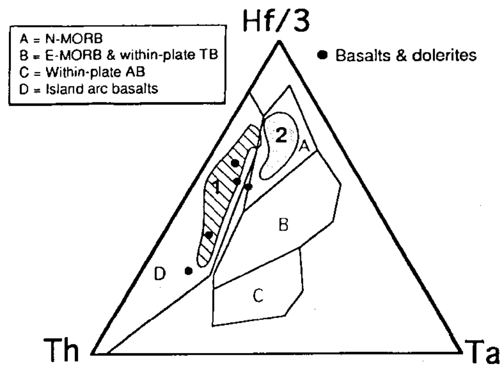

FIG. 6. Comparison of Sarikaraman Ophiolite basalts and dolerites with SSZ-type eastern Mediterranean ophiolites (area 1) and MORB-type western Mediterranean ophiolites (area 2). Comparison data selected from the Tethyan ophiolite literature. Discrimination fields after Wood (1980).

Regional geological data from western Turkey indicates that the Vardar-Izmir-Ankara-Erzincan Ocean had already started to open during the early Triassic between the Sakarya microcontinent to the north and the Tauride-Anatolide Platform to the south (Göncüoğlu *et al.*, 1992*b*). However, early to middle Mesozoic ages for Turkish ophiolites have not been recorded. Faunal data indicates that the CAO (Göncüoğlu *et al.*, 1992*a*) and those in the Kutahya-Bolkardag Belt (Özcan *et al.*, 1989; Göncüoğlu, 1990) range between Turonian and Campanian in age, and were rapidly obducted by pre-Upper Maastrichtian times. Accordingly it can be assumed that this obducted SSZ-type ocean crust was relatively young and short-lived compared with the main Vardar-Izmir-Ankara-Erzincan Ocean. This older, and possibly MORB-type oceanic crust (Çapan and Floyd, 1985), was consumed over a longer period by two penecontemporaneous and northward-facing subduction zones, a northern one beneath the Pontides (creating the Pontide Magmatic Arc) and a southern intraoceanic one (producing the SSZ-type CAO). The later development of the 'young' SSZ setting in the subducting oceanic segment may have been the consequence of crustal 'roll-back' as the oceanic lithosphere was approaching and being consumed in the Ankara (mélange) forearc (Koçyiğit, 1991).

The obduction of Upper Cretaceous SSZ-type ophiolites onto the CACC prior to the Upper Maastrichtian, as implied above, contrasts with the late Cretaceous geodynamic models outlined and reviewed by Robertson and Dixon (1985), especially with regard to the position of the 'Kirsehir Block' (the CACC in our terminology) within the Neotethys. The 'Kirsehir Block' is considered to be in a similar tectonic position to the Sakarya Continent (see Figs 23*d* and *e*; Robertson and Dixon, 1985) and remains unaffected by ophiolite emplacement. This misinterpretation of the position of the 'Kirsehir Block' is said to support the presence of an 'Intra-Tauride Ocean' (Görür *et al.*, 1984) from which the Tauride Ophiolites are generated, although it does not conform with the field data. Instead we suggest that the CACC was the northern promontory of the Menderes-Toros Block during the Mesozoic and that the Vardar-Izmir-Ankara-Erzincan Ocean (as the main northern branch of Neotethys) was located directly to the north.

The presence of intra-oceanic subduction, without the involvement of continental crust, within the Vardar-Izmir-Ankara-Erzincan Ocean may also explain the presence of sub-ophiolitic metamorphic basic soles in N.W. Anatolia (Göncüoğlu, 1990; Onen and Hall, 1993) and the Taurides (Whitechurch *et al.*, 1984).

A tectonic implication of broader significance is that the CAO and hence the Vardar-Izmir-Ankara-Erzincan Ocean can be correlated with the internal ophiolites in Greece and Yugoslavia, which also exhibit similar SSZ tectonic settings (e.g. Bernolulli *et al.*, 1974; Smith and Spry, 1984).

Conclusions

1. The volcanic sequence of the Sarikaraman Ophiolite are a series of aphyric and plagioclase–clinopyroxene-phyric tholeiitic pillow lavas, massive flows, and sheeted dykes exhibiting various alteration assemblages up to greenschist facies. This sequence is cross-cut by a number of late dolerite dykes of broadly similar petrography.
2. Geochemical data indicate that the basalts and dolerites of the volcanic sequence have affinities with basics from an island arc setting rather than an oceanic spreading ridge, whereas the late dykes have compositions more akin to N-MORB. These chemical features are typical of supra-subduction zone ophiolites.
3. This work suggests that the Central Anatolian Ophiolites (of which the Sarikaraman Ophiolite is a recently described example) display a similar tectonic setting to other late Cretaceous Neotethyan ophiolites in the eastern Mediterranean area.
4. It is suggested that, although Central Anatolian Ophiolite SSZ-type crust was probably generated in the long-lived Vardar-Izmir-Ankara-Erzincan Ocean, it was relatively young (Turonian–Santonian) and rapidly obducted (pre-Upper Maastrichtian) after formation onto the CACC in the south.

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