Turk J Earth Sci
8 (1999) 103-111
@ TÜBİTAK

Clinopyroxene Compositions of the Isotropic Gabbros From the Sarıkaraman Ophiolite: New Evidence on Supra-Subduction Zone Type Magma Genesis in Central Anatolia

M. Kenan YALINIZ
Department of Civil Engineering, Celal Bayar University, Manisa - TURKEY
M. Cemal GÖNCÜOĞLU
Department of Geological Engineering, Middle East Technical University, TR-06531 Ankara - TURKEY (mcgoncu@metu.edu.tr)

Received: 28.07.1999

Abstract: The Sarıkaraman Ophiolite is one of the least dismembered ophiolitic units of the allochthonous Central Anatolian Ophiolites, which retains its recognizable pseudostratigraphy. The Sarıkaraman Ophiolite is represented in its lowermost part by isotropic gabbros.

Within the isotropic gabbro sequence, clinopyroxenes are observed as small, colorless relicts with a cloudy appearance. In most of the samples, they are completely replaced by a successive generation of green to brown amphiboles.

Clinopyroxenes display diopsitic to augitic compositions within the range of $En_{45}Fs_5Wo_{49}$ to $En_{50}Fs_9Wo_{41}$. They are Ca-rich and Na-poor (Na_2O<0.55) and characterized by high-Mg (Mg#= 81.4-91.19) and low-Ti (<0.68 wt %).

The occurrence of a high-Mg and low-Ti magma constrain the formation of the Sarıkaraman ophiolitic gabbro in a supra-subduction zone environment. The clinopyroxenes of the Middle Turonian-Lower Campanian Sarıkaraman Ophiolite have similar chemical compositions to those of the other supra-subduction zone-type Eastern Mediterranean ophiolites (e.g., Troodos, Varinous, Pindos and Oman ophiolites) that show island-arc affinity.

Key Words: Clinopyroxene, Ophiolite, Chemistry, Turkey

Sarıkaraman Ofiyoliti İzotrop Gabrolarının Klinopiroksen Birleşimleri: Orta Anadolu'da "Dalma-Batma Zonu Üstü" Tipte Magma Oluşumuna İlişkin Yeni Kanıtlar

Özet : Sarıkaraman Ofiyoliti, allokton Orta Anadolu Ofiyolitleri arasında ilksel dizilimini korumuş ve en az parçalanmış ofiyolitik birimlerden birini oluşturur. Birimin yüzeylenmiş en alt bölümünde izotrop gabrolar yeralır.

İzotropik gabro istifinde klinopiroksenler küçük, renksiz ve bulanık taneler halinde izlenir ve çoğunlukla yeşil-kahverenkli amfiboller tarafından replase edilmişlerdir.

Klinopiroksenler diyopsitik-ojitik olup bileşimleri $En_{45}Fs_5Wo_{49}$ den $En_{50}Fs_9Wo_{41}$ kadar değişir. Ca ca zengin ve Na ca fakir (Na_2O< %0.55) olan klinopiroksenler yüksek Mg (Mg#= 81.4-91.19) ve düşük Ti (<% 0.68) içerikleri ile karakterize edilirler.

Yüksek Mg ve düşük Ti içerikli magmanın varlığı Sarıkaraman Ofiyolitinin "dalma-batma zonu üstü" konumunda geliştiğine işaret eder. Bu niteliği ile, Orta Türoniyen-Erken Kampaniyen yaşlı olan Sarıkaraman Ofiyolitinin klinopiroksen bileşimleri, benzer tektonik konumda geliştiği öne sürülen ada yayı afiniteli diğer Doğu Akdeniz ofiyolitleri (Troodos, Varinous, Pindos ve Oman ofiyolitleri) ile benzer jeokimyasal özelliktedir.

Anahtar Sözcükler: Klinopiroksen, Ofiyolit, Kimya, Türkiye

Introduction

Ophiolites represent actualistic equivalents of oceanic lithosphere generated predominantly in at least two main geotectonic settings: mid-ocean ridges of major or small oceanic basins, and island arc supra-subduction zone basin systems (e.g., Miyashiro, 1975; Sun and Nesbitt, 1978, Saunders et al., 1980; Serri, 1981; Pearce et al., 1984).

Several authors have proposed the composition of primary magmatic clinopyroxenes as an alternative parameter in paleotectonic reconstructions of the ophiolites, since the composition of clinopyroxene survives unchanged in ophiolitic rocks, even in those with low-grade metamorphism (e.g., Nisbet and Pearce, 1977; Hebert and Laurent, 1987; Capedri and Venturelli, 1979; Becalluva et al., 1989).

In this study, the geochemical compositions of 27 clinopyroxens from five different isotropic gabbro samples of the Sarıkaraman Ophiolite (SO) are presented. We compared these with their oceanic equivalents in order to highlight the similarities and differences and to determine the tectonic environment in which the gabbroic rocks were formed.

Geological Setting of the Sarıkaraman Ophiolite

The SO is representative of a somewhat dismembered ophiolite body retaining a recognizable pseudostratigraphy (Figure 1). Similar to other ophiolitic bodies of the Central Anatolian Ophiolites (CAO; Göncüoğlu *et al.*, 1992), SO is in thrust-contact with the Central Anatolian Metamorphics (Yalınız and Göncüoğlu, 1998). Voluminous ultramafic bodies 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 basaltic lavas and breccias. The gabbros are cut by intrusive trondhjemitic plagiogranites which are genetically related to various high-level rhyolitic dykes and sills that traverse the upper volcanic section of the ophiolite (Floyd et al., 1998). All units are cut by a late set of isolated dolerite dykes. The upper volcanic section with pillow-lavas is overlain by a sequence of Middle Turonian-Lower Santonian pelagic sediments intercalated with volcanogenic olistrostromal sedimentary cover (Göncüoğlu et al., 1992; Yalınız, 1996). Both the ophiolite and cover sediments are intruded by the Upper Campanian-Lower Maastrichtian Terlemez quartz-monzonite (Yalınız et al., 1997). These granites have their counterparts in other areas of the Central Anatolian Crystalline Complex (CACC) and are not related to the plagiogranites of the SO, 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 Upper Maastrichtian-Lower Paleocene volcaniclastic rocks (Göncüoğlu et al., 1992; Yalınız, 1996).

Field Characteristics

Gabbros are dark green to black, coarse- to fine-grained, frequently amphibolized and most readily distinguished in the field by the absence of cumulate layering.

Gabbros are usually compositionally and/or texturally heteregenous. Random or en-echelon pegmatite veins, pods and dykes are also common in the gabbros. Gabbros have leucocratic, often quartz-bearing patches, and veins or pods up to one meter across which have gradational to sharp contacts with the gabbro host. The veins are commonly associated with coarse, accicular amphiboles and gabbro pegmatites. The leucocratic veins in the segregated gabbro part is usually characterized by well defined irregular to angular margins without marginal chilling, but there is a gradation to diffuse-margined types. As they appear to have no feeder veins, they seem to have originated in-situ by segregation from the gabbro.

Petrography

Fine- to coarse-grained gabbros are characterized by non-cumulus granular texture in which primary plagioclase and secondary amphibole rather than primary clinopyroxene are the dominant minerals. These minerals are often associated with secondary subhedral quartz, calcite, chlorite and epidote. The accessory minerals are euhedral zircon, apatite and rare subhedral to anhedral sphene.

Plagioclases are usually unaltered and form the main primary mineral in gabbroic rocks. The highest modal content of plagioclase is 50%. It occurs as subhedral, elongate crystals which show polysynthetic twinning. The plagioclases generally are unzoned. Normal magmatic zoning is rarely observed. However, small, anhedral, untwinned plagioclases with less calcic composition (An_{45-67}; Yalınız, 1996) than the subhedral, twinned palgioclase are considered to be secondary. They rarely show epidotization.

Clinopyroxenes are rarely observed as small, colorless relicts with a cloudy appearance in the gabbroic sequence of SO. In most of the samples, they are completely replaced by brown-green amphiboles. The amphiboles are yellow-green, green to brown and pleochroic showing a wide range of composition, from Mg-hornblende to actinolite (Yalınız, 1996) and developed as anhedral, rarely subhedral and sometimes polygonal discrete grains. They represent secondary phases and are identified as rims, patches and needles around and/or in pyroxenes. The actinolitic amphiboles are probably derived from magnesio-

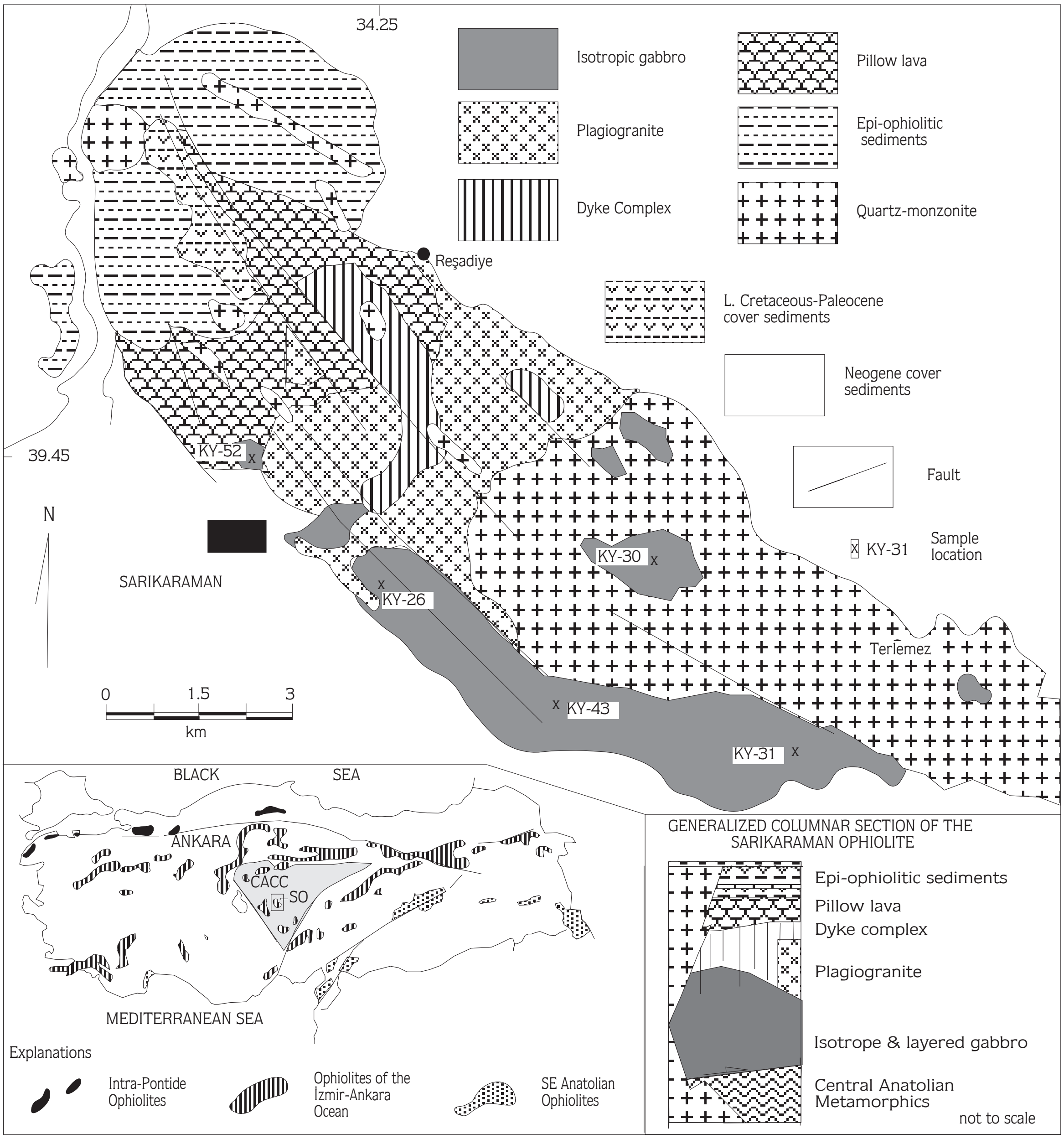

Figure 1. Geological map and generalized columnar section of the Sarıkaraman Ophiolite (after Yalınız, 1996). Inset map shows the location of the study area and the distribution of the ophiolitic belts in Turkey (after Göncüoğlu et al., 1996).

hornblende since the former are found as rims, patches and needles around and/or in magnesio-hornblende.

Mineral Chemistry of Clinopyroxenes

Analytical Techniques

Chemical analyses of clinopyroxenes were made on polished thin sections coated with graphite using a Link QX electron microprobe attached to a Li-drifted silicon detector in the Department of Earth Sciences, Keele University. Calibrations were made with metals and silicate mineral standards. The accuracy and precision of the technique used are given in Yalınız (1996) with corrections using a standard software program, ZAF4-FLS from Link Analytical. Molecular proportions were calculated on the basis of 6 oxygen atoms.

Mineral Chemistry

As pointed out by Nisbet and Pearce (1977), clinopyroxene is often the primary igneous phase to be preserved in altered metamorphosed basalts and they provide several chemical criteria by which clinopyroxenes from different tectonic environments can be recognized.

In the Wo-En-Fs diagram (Deer et al., 1978), the clinopyroxenes display diopsite to augite compositions (Figure 2a). After Morimoto et al. (1988) they are all calculated as the "Quad", which is the identification of Ca-Mg-Fe chemical groups of calcic clinopyroxenes (Table 1). They are Ca-rich (Wo_{41-49}) and Na-poor (Na_2O<0.55). The clinopyroxene composition is in the range of $En_{45}Fs_5Wo_{49}$ to $En_{50}Fs_9Wo_{41}$.

The clinopyroxenes are mainly high SiO_2 (*50.87-54.14 wt%), MgO (14.54-*17.65wt%; Mg*=81.4-91.19), and low TiO_2 (<0.68) (Table 1), Ti/Al (<0.3) relative to alkali basalts, MORB and back-arc basalts (e.g., Capedri and Venturelli, 1979; Duncan and Green, 1987; Leterrie, et al., 1982; Taylor et al., 1992; Arculus et al., 1992; Lapierre et al., 1992).

Significant chemical characteristic of the clinopyroxene samples is their low-Ti content. Because, Ti in clinopyroxenes is thought to reflect the degree of depletion of the mantle source and Ti activity of parent magma that generated the cumulate pile (Pearce and Norry, 1979).

On the basis of the Ti content, clinopyroxenes from SO plot in the low and very low-Ti field similar to samples from other supra-subduction zone-type ophiolites of Troodos, Vorinous, Pindos and Oman (Figure 2b)

The compositional correspondence of clinopyroxenes from various ophiolitic basalts to those from oceanic actualistic equivalents (MORB, IAT and boninites-BON) is shown in Figure 3. Concomitantly with low Ti, Al, Na and high Si contents, clinopyroxenes of Sarıkaraman gabbro are best adequated with those of island arc, with respect to MORB and boninites (Figure 3). It should be noted that some samples are displaced towards the boninites. On the other hand, in Figure 4, the clinopyroxene chemistry of the Sarıkaraman samples displays significant compositional similarities to those from the supra-subduction zone-type Eastern Mediterranean ophiolites rather than MORB-type ophiolites.

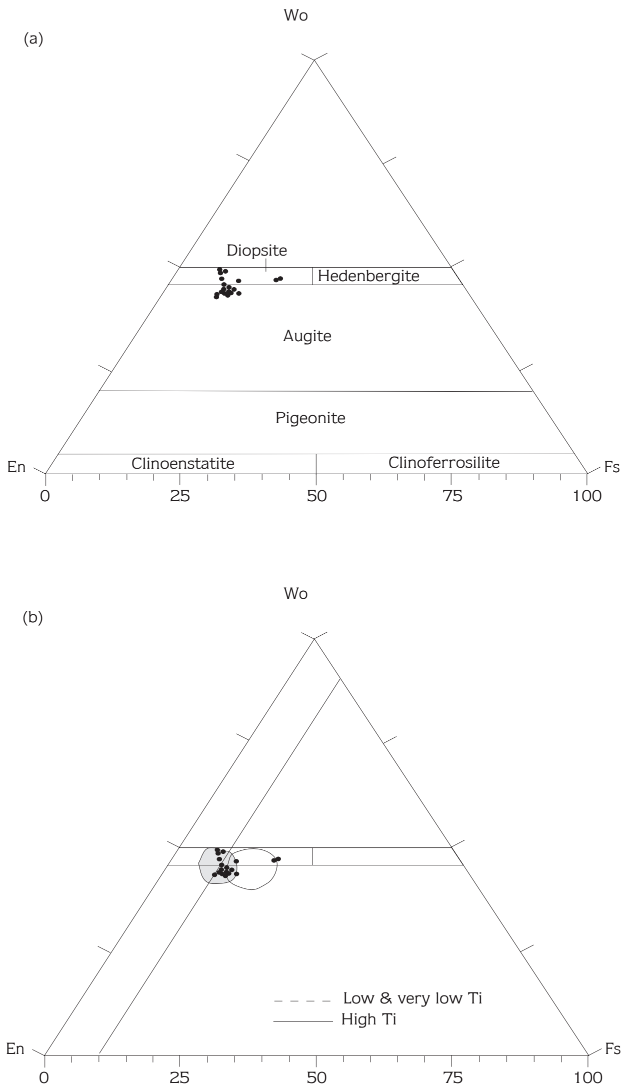

Figure 2. Pyroxene quadrilateral diagrams for the pyroxenes from the studied gabbroic rocks. a- nomenclature (after Morimoto et al., 1988), b- Ti composition (after Beccaluva et al., 1989)

Discussion

Beccaluva et al. (1989) reported that Ti differences in ophiolites correspond well to distinct magma types of the modern oceanic setting, and are grouped as high-Ti, low-Ti and very low-Ti ophiolites. They reported that high-Ti ophiolites compare favorably with the magmatic association occurring at mid-ocean ridges and well developed marginal basins, whereas low-Ti and very low-Ti ophiolites are best equated with the magmatic series of island-arc and boninitic types respectively, generated in the supra-subduction zone settings.

Table 1. Representative chemical analyses of clinopyroxenes from the Sarıkaraman ophiolitic gabbro

Sample		KY-30			KY-31			KY-52			KY-43			KY-26	
number	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
SiO_2	51.58	52.50	51.80	52.19	52.18	53.22	51.83	52.44	50.87	50.85	52.10	51.33	53.42	52.22	54.03
Al_2O_3	2.46	2.52	0.80	3.33	1.96	1.83	2.24	2.17	3.38	3.56	2.20	3.50	1.98	3.76	0.55
TiO_2	0.51	0.39	0.00	0.54	0.87	0.37	0.36	0.28	0.55	0.72	0.32	0.56	0.28	0.00	0.00
Cr_2O_3	0.21	0.00	0.00	0.38	0.00	0.23	0.41	0.45	0.47	0.35	0.35	0.52	0.23	0.45	0.00
Fe_2O_3	2.47	3.24	1.74	0.00	2.89	1.35	3.17	0.23	2.81	0.15	3.44	2.05	0.66	0.87	1.08
FeO	3.86	2.92	9.58	6.03	6.12	3.51	3.03	5.50	3.27	6.01	2.71	4.10	4.45	6.20	3.22
MnO	0.00	0.00	0.37	0.22	0.32	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.18	0.00	0.20
MgO	16.60	16.79	12.45	15.72	15.79	15.98	17.56	17.40	16.65	16.09	17.65	16.40	16.51	15.65	16.60
CaO	21.12	22.11	23.25	21.95	20.47	24.01	20.22	20.64	20.96	20.88	20.74	20.73	22.64	20.14	24.65
Na_2O	0.35	0.42	0.00	0.00	0.00	0.26	0.45	0.00	0.28	0.00	0.40	0.43	0.23	0.55	0.00
Total	99.15	100.90	100.00	100.36	99.06	100.76	99.27	99.11	99.45	98.61	99.91	99.62	100.58	99.84	100.33

Formulae calculated on the basis of 6 oxygens, Fe^{3+} calculated for 4 cations

Si	1.907	1.906	1.956	1.913	1.961	1.938	1.98	1.935	1.876	1.894	1.905	1.888	1.946	1.920	1.973
Al_{IV}	0.093	0.094	0.036	0.087	0.039	0.062	0.092	0.065	0.124	0.106	0.950	0.112	0.054	0.080	0.024
Al_{VI}	0.015	0.014	0.000	0.057	0.008	0.017	0.005	0.030	0.023	0.051	0.000	0.040	0.031	0.083	0.000
Ti	0.014	0.011	0.000	0.015	0.019	0.010	0.010	0.008	0.015	0.020	0.009	0.016	0.008	0.000	0.000
Cr	0.006	0.000	0.000	0.011	0.000	0.007	0.012	0.013	0.014	0.010	0.010	0.015	0.007	0.013	0.000
Fe^{3+}	0.069	0.089	0.050	0.000	0.000	0.037	0.088	0.006	0.078	0.004	0.095	0.057	0.018	0.024	0.030
Fe^{2+}	0.119	0.089	0.303	0.185	0.203	0.107	0.093	0.170	0.101	0.187	0.083	0.126	0.136	0.190	0.098
Mn	0.000	0.000	0.012	0.007	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000	0.006	0.000	0.006
Mg	0.915	0.908	0.701	0.859	0.891	0.867	0.963	0.957	0.915	0.894	0.962	0.899	0.896	0.857	0.904
Ca	0.837	0.860	0.941	0.862	0.875	0.937	0.797	0.816	0.828	0.834	0.813	0.817	0.884	0.793	0.965
Na	0.025	0.030	0.000	0.000	0.000	0.019	0.032	0.000	0.020	0.000	0.028	0.031	0.016	0.039	0.000

Supra-subduction zone ophiolites represent oceanic crust generated by spreading processes that occur above a dehydrating subducted oceanic plate (e.g., Pearce, 1982; Vannucci et al., 1993). The supra-subduction zone environment is capable of generating water-bearing magma derived by hydrous melting of the depleted upper mantle source. The gabbroic rocks of Sarıkaraman ophiolite may be a good example of the derivatives from such refractory source.

The results presented here concern the nature and origin of primitive low-Ti magma and the processes involved during their genesis and relevant to the general debate on the geodynamic significance of low-Ti, high-Mg magma. It is widely accepted that the generation of these primitive High-Mg and low-Ti ophiolites requires the remelting of a severely depleted residual mantle source with the extraction of 20-30% wet partial melting liquid to leave a severely depleted source (e.g., Hebert and Laurent, 1987; Van Der Lann, 1992; Bebard, 1991; Hawkins et al., 1990). Comparison with ocean plutonic rocks show that refractory peridotites exist in the oceanic crust generated in the spreading ridge environment. These rocks, through wet partial melting, may generate high-Mg and low-Ti liquids, as is the case with many supra-subduction zone ophiolites (e.g., Pearce, 1982; Vannucci et al., 1993).

An important chemical characteristic is the low Ti contents of the clinopyroxenes in Sarıkaraman Gabbro. The Ti content of clinopyroxenes in the gabbros is 2-3 times lower than those from MORB. This pattern is thus indicative of the crystallization of clinopyroxenes from a Ti-poor magma. This result is consistent with the generally observed low Ti content of Sarıkaraman lavas and classification of this ophiolite into the low-Ti group defined by Serri (1981). The low-Ti character of the SO makes it very different from MORB suites. The Sarıkaraman primary melt probably formed by the partial melting of a severely depleted upper mantle.

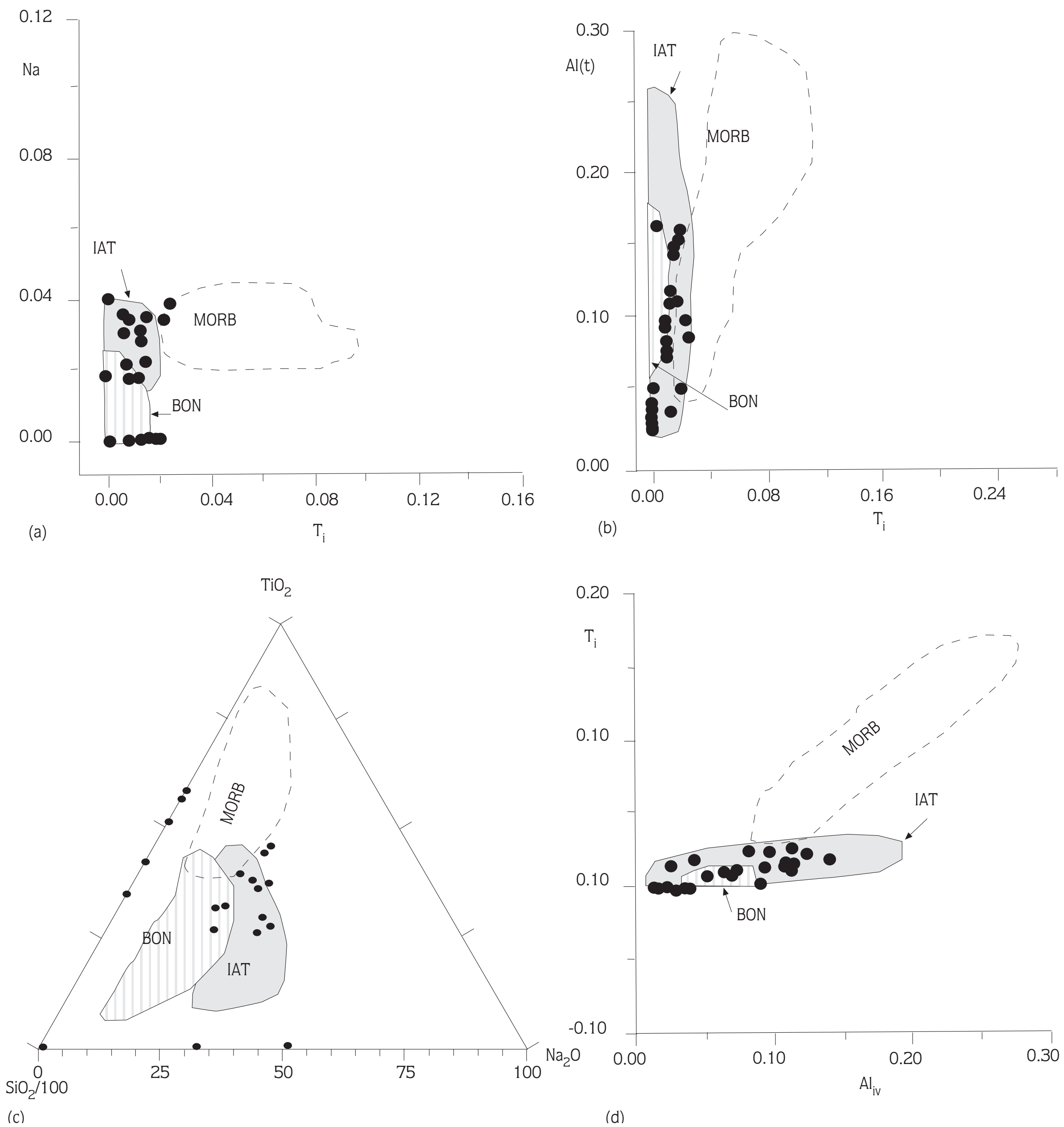

Figure 3. Co-variation diagrams of studied pyroxenes indicating their tectonic settings (IAT: Island Arc Tholeiite, BON: Boninite, MORB: Mid-ocean ridge basalt; after Beccaluva, 1989). a- Na versus Ti (atomic ratios), b- Al(t) versus Ti (atomic ratios), c- TiO_2-Na_2O-SiO_2/100 (weight %), d- Ti versus Al(IV) (atomic ratios)

Conclusions

1- The low-Ti and high-Mg content of the clinopyroxenes suggest that the Sarıkaraman Gabbro was formed by the wet partial melting of an already depleted oceanic lithosphere in a supra-subduction zone environment.

2- The clinopyroxene chemistry of the gabbroic rocks also supports the proposed assertion (Yalınız, 1996; Yalınız et al., 1996; Floyd et al., 1998) of a supra-subduction environment, based on the geochemical features of the basaltic and plagiogranitic rocks of SO.

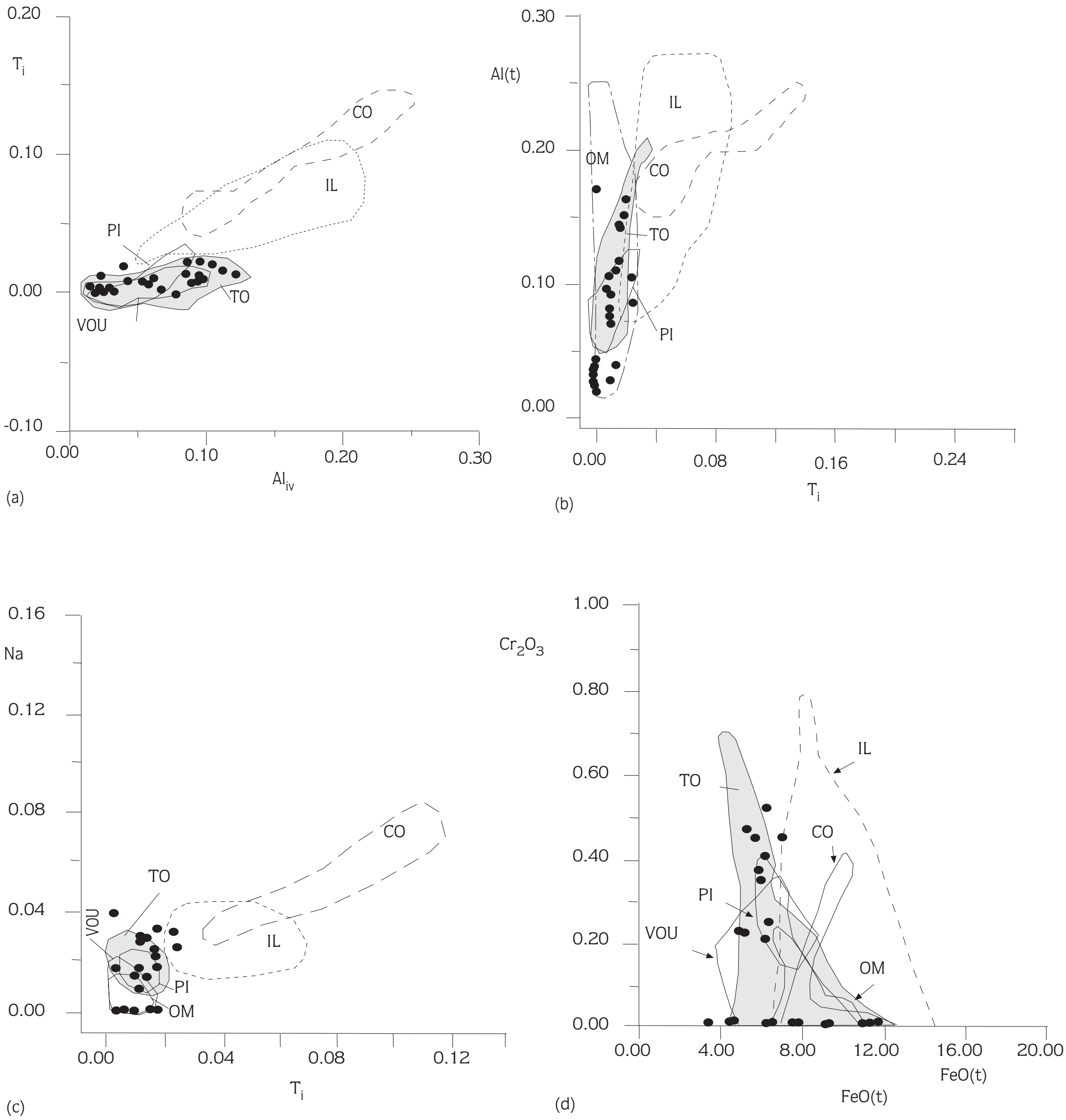

Figure 4. Co-variation diagrams of the clinopyroxenes from the Sarıkaraman gabbros and other well-known ophiolites (OM: Oman, PI: Pindos, TO: Troodos, VOU: Vourinos, CO: Corsica, IL: Internal Ligurian; after Beccaluva *et al.*, 1989). a- Ti vesus Al(ıv) (atomic proportions), b- Al(t) versus Ti (atomic proportions), c- Na vesus Ti (atomic proportions), d- Cr_2O_3 versus FeO(t).

3- It is concluded that the clinopyroxenes of SO have similar geochemical characteristics to those of the other Eastern Mediterranean ophiolites such as Troodos, Vourinos, Pindos and Oman, which show high-Mg and low-Ti island arc affinity.

Acknowledgements

The authors acknowledge TÜBİTAK-YDABÇAG-85 and NATO-CRG 960549 grants and the Turkish Petroleum Corporation for supporting their studies on the

Central Anatolian ophiolites. Dr. P.A. Floyd and Dr. G. Rowbotham, School of Earth Sciences and Geography, Keele University, U.K., are gratefully acknowledged for supplying the EMP facilities. Thanks are due to Dr. P. Önen, Department of Geological Engineering, METU, for computerizing the geochemical data.

References

Arculus, R.J., Pearce, J.A., Murton, B.J., and Van der Laan, S.R., 1992, Igneous stratigraphy and major-element geochemistry of Holes, 786A and 786B. Proc. Ocean Drill. Program Sci. Res.., 125, 143-169.

Bebard, J.H., 1991, Cumulate recycling and crustal evolution in the Bay of Island ophiolite. J. Geol., 99, 225-249.

Beccaluva, L., Maccciotta, G., Piccardo, G.B., and Zeda, O., 1989, Clinopyroxene composition of ophiolite basalts as petrogenetic indicator. Chem. Geol., 77, 165-182.

Capedri, S. and Venturelli, G., 1979, Clinopyroxene composition of ophiolitic metabasalts in the Mediterranean area. Earth Planet. Sci. Lett., 43,61-73.

Deer, W.A., Howie, R.A. and Zussman, J., 1978, Rock-forming minerals, 2A, single-chain silicates (2nd edition). Longman, U.K. and Wiley, New York.

Duncan, R.A., and Green, D.H., 1987, The genesis of refractory melts in the formation of oceanic crust. Contrib. Mineral. Petrol., 96, 326-342.

Floyd, P.A., Yalınız, M.K. and Göncüoğlu, M.C., 1998, Geochemistry and petrogenesis of intrusive and extrusive ophiolitic plagiogranites, Central Anatolian Crystalline Complex, Turkey. Lithos, 42, 225-242.

Göncüoğlu, M.C. and Türeli, T.K., 1994, Alpine Collisional-Type Granitoids from western Central Anatolian Crystaline Complex, Turkey. Journal of Kocaeli University, 1, 39-46.

Göncüoğlu, M.C., Erler, A., Toprak, V., Yalınız, K., Olgun, E. and Rojay, B., 1992, Orta Anadolu Masifinin Batı Bölümünün Jeolojisi, Bölüm 2: Orta Kesim. TPAO Rap. No: 3155, 76s.

Göncüoğlu, M.C., Dirik, K. and Kozlu, H., 1996, General characteristics of pre-Alpine and Alpine Terranes in Turkey: Explanatory notes to the terrane map of Turkey: Annales Geologique de Pays Hellenique, 37, Geol.Soc Greece, 515-536, Athens.

Hawkins, J.W., Lonsdale, P.F., MacDougall, J.D. and Volpe, A.M., 1990, Petrology of the axial ridge of the Mariana Trough back-arc spreading center. Earth Planet. Sci. Lett., 100, 2226-250.

Hebert, R., and Laurent, R., 1987, Mineral chemistry of the plutonic section of the Troodos ophiolite: New constraints for genesis of arc-related ophiolites. In: Malpas G.J. and Moores E.M. (eds.), Troodos 1987 ophiolites and oceanic lithosphere, 149-163.

Lapierre, H., Taylor, R.N., Rouer, O. and Chaisemartin, H., 1992, Mineral chemistry of forearc volcanics rocks from the Izu-Bonin arc, Holes 792E and 793B. Proc. Ocean Drill. Program Sci. Res., 126, 431-447.

Leterrie, J., Maury, C.R., Thonon, P., Girard, D. and Marchal, M., 1982, Clinopyroxene composition as a method of identification of the magmatic affinities of paleo-volcanic series. Earth Planet. Sci. Lett., 59, 139-154.

Miyashiro, A., 1975, Classification characteristics and origin of ophiolites. J. Geol., 83, 249-281.

Morimoto, N., Fabries, J., Ferguson, A.K., Ginzburg, I.V., Ross, M., Seifert, F.A., Zussman, J., Aoki, K. and Gottardi, D., 1988, Nomenclature of pyroxenes. Am. Min., 62, 53-62.

Nisbet, E.G. and Pearce, J.A., 1977, Clinopyroxene composition in mafic lavas from different tectonic settings. Contrib. Mineral. Petrol., 63, 149-160.

Pearce, J.A , 1982, Trace element characteristics of lavas from destructive plate boundaries. In Thorpe, R.S., (ed), Andesites Orogenic Andesites and Related Rocks, 525-548.

Pearce, J.A . and Norry, M.J., 1979, Petrogenetic implications of Ti, Zr, Y, and Nb variations in volcanic rocks. Contrib. Mineral. Petrol., 69, 33-47.

Pearce, J.A., Lippard, S.J., and Roberts, S., 1984, Characteristics and tectonic significance of supra-subduction zone ophiolites. In: Kokelaar, B.P., and Howells, M.F., (eds), Marginal Basin Geology. Geol. Soc. Spec. Publ. Lond., 16, 77-94.

Saunders, A.D., Tarney, J., Marsh, N.G. and Wood, D.A., 1980, Ophiolites as ocean crust or marginal basin crust: A geochemical approach. In: Panayiotou, A., (ed). Ophiolite, Geol. Surv. Dept. Cyprus., 193-204.

Serri, G., 1981, The petrochemistry of ophiolite gabbroic complexes: a key for the classification of ophiolites into low-Ti and high-Ti types. Earth Planet. Sci. Lett., 52, 203-212.

Sun, S.S. and Nesbitt, R.W., 1978, Geochemical characteristics of mid-ocean ridge basalts. Earth Planet. Sci. Lett., 44, 119-138.

Taylor, R.N., Lapierre, H., Vidal, P., Nesbitt, R.W. and Croudace, I.W., 1992, Igneous geochemistry and petrogenesis of the Izu-Bonin forearc basin. Proc. Ocean Drill. Program Sci. Res., 126, 405-430.

Van der Lann, S.R., Arculus, R.L., Pearce, J.A. and Murton, B.J., 1992, 10. Petrography, mineral chemistry and phase relations of the basement boninite series of site 786, Izu-Bonin forearc. Proc. Ocean Drill. Program Sci. Res., 125, 171-201.

Vannucci, R., Rampone, E., Piccardo, G.B., Ottolini, L. and Bottazzi, P., 1993, Ophiolitic magmatism in the Ligurian Tethys: an ion microprobe study of basaltic clinopyroxenes. Contrib. Mineral. Petrol., 115, 123-137.

Yalınız, M.K., 1996, Petrology of the Sarıkaraman Ophiolite (Aksaray-Turkey). Ph.D. Thesis, METU Department of Geological Eng., 270p (unpublished).

Yalınız, M.K. and Göncüoğlu, M.C., 1998, General geological characteristics and distribution of the Central Anatolian ophiolites. H.U.Yerbilimleri, 20, 19-30.

Yalınız, K., Parlak, O., Özkan-Altıner, S. and Göncüoğlu, M.C., 1997. Formation and emplacement ages of supra-subduction-type ophiolites in Central Anatolia; Sarıkaraman Ophiolite, Central Turkey. Çukurova Universitesinde Jeoloji Mühendisliği Eğitiminin 20.Yılı Simpozyumu, Adana, 30 April-3 May 1997, Abstracts, 61-62.