Mesozoic ophiolite belts of northern part of the Balkan Peninsula
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A NEOTETHYAN ISLAND ARC SLIVER IN CENTRAL ANATOLIA: INSIGHTS FROM HYDROUS ULTRAMAFIC-MAFIC CUMULATES

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The Turkish sector of the Neotethys, occupying a critical segment in the Alpine-Himalayan orogenic system, is characterized by two major east-west trending ophiolitic belts. From these, the northern branch located at north of the Anatolide-Tauride microplate comprises remnants of Intra-Pontide and Izmir-Ankara-Erzincan (IAE) oceans. Both of them reached their maximum size during early Cretaceous and were consumed by northward subduction beneath Istanbul-Zonguldak and Sakarya continents giving rise to widespread south-vergent obduction of ophiolites. The dismembered ophiolites in central Anatolia, the unfragmented Pozanti-Karsanti Ophiolite and the ophiolite fragments in the Ankara Mélange were formed by this event and transported as allochthonous bodies on the passive margin of the Anatolide-Tauride microplate during Late Cretaceous. The Central Anatolian Ophiolites (CAO) has been generated in a supra-subduction zone (SSZ) during the closure of the IAE seaway. The CAO includes ordered ophiolitic bodies with preserved magmatic pseudostratigraphy as well as several isolated ultramafic-mafic plutonic bodies with differences in the geochemistry and thus variations in source area and tectonic setting within an intra-oceanic subduction zone.

Kurancali ultramafic-mafic body

Among the isolated units of the CAO, an ultramafic-mafic cumulate body in the Kurancali area (Kirsehir, central Anatolia), is unusually rich in pegmatitic hydrous magmatic minerals such as phlogopite (phl) and pargasite (parg) (e.g. Toksoy-Köksal et al., 2001; Toksoy-Köksal, 2003). The plutonic body overthrusts the uppermost unit of the Central Anatolian Metamorphics (CAM) (Fig. 1) as a tectonic sliver from north to south along a E-W trending shear zone. The underlying metamorphic rocks belong to a metamorphic ophiolitic mélange and overlie meta-carbonates of the CAM. All units are cut by NW-SE trending leucocratic felsic dykes of the Central Anatolian Granitoids (CAG). The rocks do not contain ol nor opx and are divided into six groups based on field and petrographical evidences: (a) clinopyroxenite (CPXnite), (b) clinopyroxenite with hydrous minerals and plag (CPXnite WHMP), (c) phlogopitite (PHLtite), (d) hornblendite (HBdite), layered gabbro (LG), and phlogopite diorite (DIO).

CPXnite, composed of variably sized clinopyroxene (cpx) crystals, is characterized by lack of plagioclase (plag) and primary amphibole (amph). Phl bearing CPXnite is generally found close to PHLtite. CPXnite WHMP, existing next to the PHLtite and HBdite, is made up mainly of cpx with varying amounts of plag, amph and phl. Irregular masses of pegmatitic PHLtite, consist mainly of phl and limited amount of cpx but lack plag. HBdite is mainly composed of variably sized prismatic amph (few mm's to up to 20 cm), and plag (less than 10%) is generally found as aggregates forming leucocratic parts due to strong magmatic filter pressing. The small outcrops of LG are marked by rhythmic layering of mainly cpx and plag with low but variable amounts of hydrous phases. DIO contains dominantly light brownish phl and plag (with relict cpx). There are evidences of re-injection of plag-amph liquid as

presence of both pothole-like structures and regular/irregular layers filled by pegmatitic amph and plag within LG and CPXnite WHMP, and small veins of plag-amph in CPXnite, CPXnite WHMP and PHLtite.

Cumulate texture is a distinguishing feature of these hydrous rocks, in which the cumulate minerals are cpx, phl and amph with the order of crystallization, and plag crystallizes last as an intercumulus phase. CPXnite and PHLtite display orthocumulate textures while CPXnite WHMP, HBdite, LG, DIO has adcumulate textures.

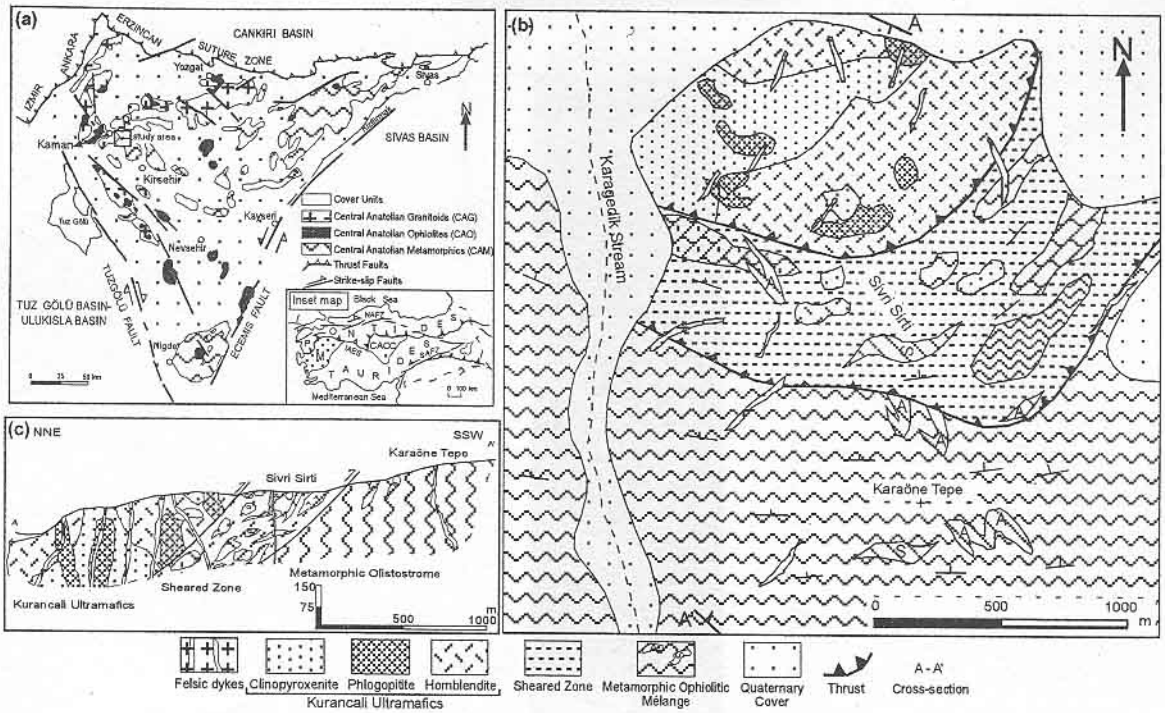

Fig. 1. - (a) Simplified geological map of central Anatolia (In inset map: C: Central Anatolian Crystalline Complex, M: Menderes Massif, NAFZ: North Anatolian Faults Zone, SAFZ: South Anatolian Fault Zone, IAES: Izmir-Ankara-Erzincan Suture), (b) Geological map of the study area, (c) Geological cross-section of the study area.

Geochemistry

The major constituents of the rocks are typified by their unusual compositions as phl with high Fe^{2+}-Fe^{3+}-$Al^{[6]}$-Ti, diopsidic-augite with high Ca-$Al^{(t)}$-Ti, Si-undersaturated parg with high $Al^{[4]}$-K-Na-Ti-contents and plag with a wide range of compositions (An%=40.61-98.58). Substitution mechanisms and elemental variations of the minerals display transitional behavior from calc-alkaline to alkaline and metasomatism. For instance, phl is similar to micas of alkaline rocks in terms of $2Al^{[6]} \Leftrightarrow 3Fe^{2+}$ substitution but dissimilar to micas of calc-alkaline ones by $3Mg^{[6]} \Leftrightarrow 2Al^{[6]}$ mechanism (Fig. 2a,b). It prove opposing relation to the magmatic differentiation trend in $Al^{[6]}$-Mg (Fig. 2b) and is of transitional character between magmatic and metasomatic types. Elemental variations for the phases display two parallel trends (e.g. Fe^{2+}-Mg/(Mg+Fe^{2+}) and Al-Si variations in parg and plag, respectively), where there is no textural control (Fig. 2c). In spite of a wide range of An% composition, $Fe_2O_3^{(t)}$ contents of the plag are almost constant for all rocks. This may indicate strong hybridization in mantle source and strong re-equilibration. Considering properties of the minerals, it is plausible to assume that there was a strong physicochemical disequilibrium in the system representing metasomatism of mantle source of these hydrous ultramafic-mafic plutonic rocks.

Relative proportion and chemistry of the minerals (especially parg and cpx) control the whole-rock compositions of the cumulates, thus the cumulates present wide ranges of compositions 38.40-48.80 (wt% SiO_2), 6.14-26.7 (wt% Al_2O_3), 10.45-22.5 (wt% CaO), 0.34-2.97 (wt% TiO_2), 0.25-3.52 (wt% Fe_2O_3), 3.23-13.17 (wt% FeO), 3.08-12.87 (wt% MgO), 0.17-4.21 (wt% K_2O), 0.46-1.83 (wt% Na_2O). The major elements have quite continuous covariations with SiO_2 (wt%) increasing from Si-undersaturated HBdite to CPXnite and the rest of the rocks are intermediate between them. For instance, CaO content increases as SiO_2 increases; this unusual case is completely controlled by modes and chemistry of cpx and amph. TiO_2, $FeO^{(t)}$, Na_2O and K_2O decreases with increasing SiO_2 from HBdite to CPXnite. This relation is controlled again by element contents of amph with highest TiO_2, $FeO^{(t)}$, Na_2O and lowest SiO_2, while cpx has lowest TiO_2, $FeO^{(t)}$, Na_2O and highest SiO_2. The strong enrichment of TiO_2, $FeO^{(t)}$, Nb, Y, V observed in HBdite due to presence of amph, ilmenite, rutile (rt) may rule out the addition of an alkaline component to the source. Moreover, the unusual behaviour of SiO_2 (i.e. decreasing with decreasing Mg# from CPXnite to HBdite) can be explained by alkaline metasomatism.

The rocks are characterized by moderately high Mg# (0.44-0.75) with the highest Mg# values (0.62-0.75) from CPXnite and PHLtite. Na_2O, K_2O (wt%) and Sr (ppm) contents recognizably increase with decreasing the Mg# values as in the case of calc-alkaline plutons.

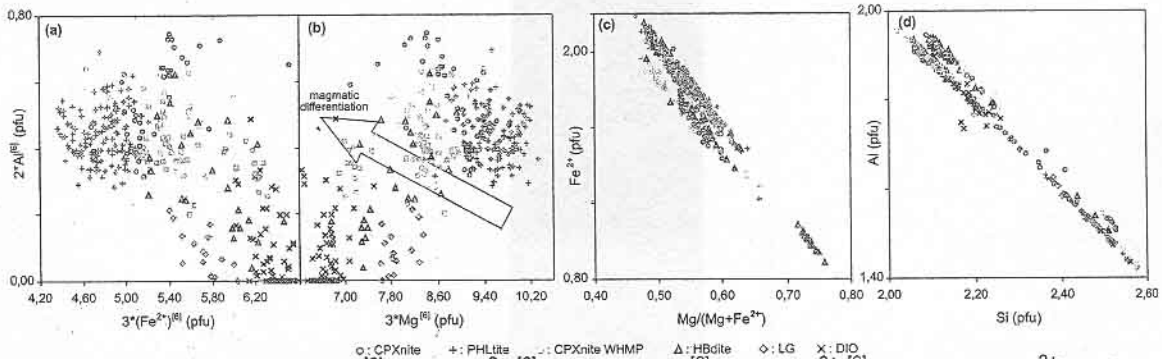

Fig. 2. - Covariation of: (a) $Al^{[6]}$ and $(Fe^{2+})^{[6]}$ in phl, (b) $Al^{[6]}$ and $(Mg^{2+})^{[6]}$ in phl, (c) (Fe^{2+}) and $Mg/(Mg+Fe^{2+})$ in parg, (d) Al with Si in plag.

Trace and REE patterns of the ultramafic and mafic rocks have a steep slope and are almost parallel due to the control of modal mineralogy. All rocks are characterized by a strong enrichment in LILE and LREE relative to HFSE and HREE, respectively, and by marked negative anomalies of Nb, Ta, Ti, Y. Despite depletion in HFSE compared to LILE, some samples show slight enrichment in HFSE relative to N-MORB while HREE are depleted compared to N-MORB (Fig. 3). The rocks, depending on the presence and abundance of hydrous minerals and accessory phases, display marked differences in Th, Ti, Zr, Nb, P (e.g. the strongest positive Ti anomalies for the HBdite enriched in parg with rt needles, and large variation in P anomalies of each rock type from strong positive to strong negative due to sporadic occurrence of apatite in the rocks).

The trace element enrichment in CPXnite (e.g. low Sm/Nd=0.25) showing parallel patterns to those of hydrous mineral enriched ones, may reflect enrichment also in cpx because the rock is dominated by cpx. If this is the case, the trace element enrichment in cpx, and presence of phl and parg in the rocks are consistent with a metasomatic agent that was hydrous in nature.

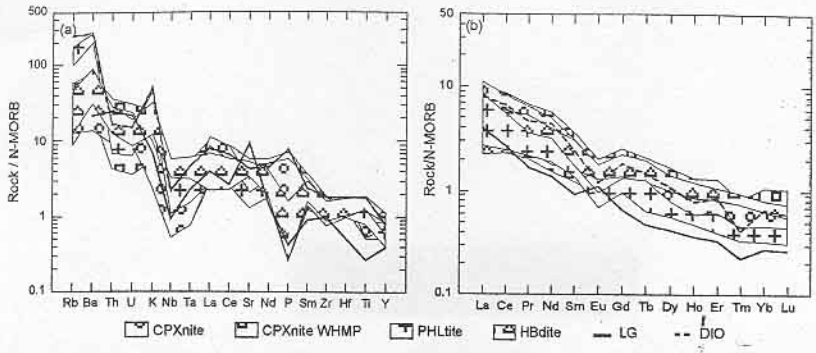

Fig. 3. - N-MORB normalized patterns for the ultramafic-mafic cumulate rocks: (a) trace elements, (b) REE (normalization data from Sun & McDonough, 1989).

Results

The studied rocks are typical cumulates formed during calc-alkaline differentiation and indicate a complex and possibly open system. They display transitional features of high-K calc-alkaline and alkaline rocks. The data, infer that the rocks were generated in an intra-oceanic arc environment where addition of metasomatic alkaline component (fluid/melt) derived from subducting slab and/or OIB-like alkaline melt to the hydrous mantle wedge source came about. The metasomatic processes pervasively enriched the source in incompatible elements, and resulted in SiO_2 undersaturation, Al_2O_3-CaO-alkali-TiO_2 enrichment in both mineral and whole-rock chemistry. The geothermobarometric studies (Toksoy-Köksal, 2003) also reveal that the rocks are representative of arc basement. The geochemical evidences as well field and petrographical facts infer high water pressure and oxygen fugacity during formation of the rocks (e.g. appearance of phl before amph indicating crystallization from magma with high H_2O content).

The Kurancali cumulate rocks provide a rare opportunity to investigate the compositional effects imparted to mantle lithosphere by subduction-derived components under a mature island arc developed within an intra-oceanic subduction zone during the closure of the IAE branch of the Alpine Neotethys in central Anatolia.

Key words: Neotethys, Anatolia, Kurancali, cumulates, intra-oceanic arc, mantle-metasomatism

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