THE HIGH PRESSURE ULTRAMAFIC SEQUENCE OF THE EL TORO FORMATION (EL ORO METAMORPHIC COMPLEX, SW ECUADOR): CHARACTERISATION AND METAMORPHIC EVOLUTION

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GEOLOGICAL SETTING

In the south-western part of Ecuador (between 3°S and 4°S of latitude; 79°30'W and 80°50'W of longitude), in the "El Oro" province, various metamorphic terranes (Feininger, 1982) were grouped under the name of "El Oro Metamorphic Complex" (Aspden et al., 1995). These terranes have been interpreted as independent allochtonous or parautochtonous bodies (Feininger, 1987); as large displaced blocks (Mourier et al., 1988), or as a late Jurassic - early Cretaceous tectonic mélange representing part of an accretionary prism (Aspden et al., 1995). The El Oro Metamorphic Complex is characterised by different lithologies ranging in age from Palaeozoic to Cretaceous (Aspden et al., 1995). This area is crosscut by several E-W-trending faults that subdivide the El Oro Metamorphic Complex into smaller units.

One of these units, the El Toro formation (as defined by Feininger, in Bristow and Hoffstetter, 1977) is bounded to the North by the "La Palma - El Guayabo" fault, and to the South by a major tectonic contact. The El Toro formation consists mainly of variably-serpentinised massive metaperidotites with subordinated amphibole-diopside-chlorite-rich bands. Small dykes of primary mafic rocks (now metabasites) crosscut the ultramafic sequence. The El Toro ultramafites are particularly well exposed in the quarries located immediately to the east of the Tahuin dam, in the "Cerro El Toro" area.

PETROGRAPHY

The metaperidotites with diopside-amphibole-chlorite bands are characterised by a variably pervasive schistosity defined by aligned crystals of antigorite. Olivine, clinopyroxene and orthopyroxene porphyroclasts together with variable amount of brown spinel define the relict primary mantle assemblage in the metaperidotite. The mineral assemblage related to the metamorphic peak is represented by neoblastic olivine, diopside, antigorite and variably amount of clinohumite, which are in textural equilibrium.

The bands in metaperidotites are composed by chlorite and amphibole porphiroblasts; the peak assemblage in these bands is represented by diopside and antigorite.

The mafic dikes consist of amphibole-rich rocks with massive to poorly schistose fabric. They are mainly composed of green to blue-green inequigranular amphibole. Zoisite porphyroblasts are concentrated in domains and they are in textural equilibrium with amphibole. Relics of clinopyroxene and garnet are present: they are clearly replaced by the amphibole and the zoisite. Titanite and rutile are common accessory phases.

MINERAL CHEMISTRY

Relict clinopyroxene porphyroclasts (cpx-1) in metaperidotites are chromian diopside (Cr = 0.083 a.p.f.u.). The neoblastic clinopyroxene (cpx-2) is diopside both in metaperidotites and diopside-amphibole-chlorite bands, showing only minor variations in the Mg and Ca contents, ranging respectively from 0.86 to 0.96 p.f.u. and from 0.87 to 0.98 a.p.f.u. Orthopyroxene is present only in metaperidotites: it shows enstatite composition with an average Mg# 90. The two generations of olivine, olivine-1 porphyroclasts and olivine-2 neoblasts, evidenced on a textural basis, show significantly different composition. Primary mantle olivine (Ol-1) has an higher XMg (in the range 0.90-0.91), and lower Mn (average MnO = ~0.16 wt%). The neoblastic olivine (Ol-2) has a slightly lower XMg (averaging around 0.87), while MnO is up to 0.28 wt%. The serpentine minerals show a wide compositional range: chrysotile is characterised by high Mg values (2.8-2.9 a.p.f.u.) and by very low Al (a.p.f.u. 0.0-0.02). Antigorite has lower Mg (2.6-2.7 atoms a.p.f.u.) and higher Al (up to 0.12 atoms p.f.u.). Chlorite is magnesium-rich (XMg varying from 0.94 to 0.96). The analysed clinohumites are fluorine free titanian-clinohumites having significant amounts of Ti (in the range 0.42-0.45 a.p.f.u.). Two generations of amphiboles are present in the metaperidotites and in the diopside-amphibole-chlorite bands: older porphyroblasts (amphibole-1) and small fibrous crystals or neoblastic grains (amphibole-2). The former are calcic amphiboles (pargasite), the latter are sodic-calcic amphiboles (magnesiokatophorite or richterite, according to the Si content).

In the mafic dykes the analysed pyroxenes are omphacites, which are characterised by an average jadeite content of 34 mol%. Garnets are characterised by an high grossular content (around 76 mol%), and by an average XFe of 0.91. Zoisites are characterised by a Fe3+/(Al+Fe3+) ratio averaging around 0.10. Amphibole is present as i) unzoned pargasites or as ii) grains having a sodic-calcic core (magnesiotaramite) grading to a calcic (pargasite) rim.

WHOLE ROCK CHEMISTRY

The metaperidotites are characterized by relatively low SiO_2 and high MgO (37.03-38.84wt%) contents, typical of olivine-rich mantle peridotites, and CaO (~2.05wt%) and Al_2O_3 (1.48-2.88wt%), closely similar or slightly lower than estimated concentrations in fertile mantle peridotites (Hofmann, 1988; Jagoutz et al., 1979). The amphibole-diopside-chlorite band in metaperidotites has lower MgO (24.89wt%) and significantly higher CaO (10.04wt%) and Al_2O_3 (8.73wt%), which indicate for a mafic composition of the protolith.

The amphibolite-rich mafic dykes have MgO (11.78-17.40), CaO (10.67-15.02wt%) and Al_2O_3 (10.54-13.53wt%) similar to or slightly higher than those of common basaltic compositions.

Concerning the trace elements composition, the metaperidotite sample displays an almost flat C1-normalized Rare Earth Element (REE) pattern, from HREE to MREE, at about 1xC1, significantly depleted for the LREE ($Ce_N/Sm_N = 0.26$): the trace element spiderdiagram evidences a strong Sr enrichment. The diopside-amphibole-rich bands in metaperidotite show a REE pattern, from HREE to MREE, slightly lower than 10xC1, with a significant LREE negative fractionation ($Ce_N/Sm_N = 0.30$): the trace element spiderdiagram evidences a slight Sr enrichment.

The amphibole-rich samples can be divided in two groups. The first group has almost flat REE patterns, form HREE to MREE, at about 6-7xC1, with a slight LREE fractionation ($Ce_N/Sm_N = 0.34-0.54$) and an evident Eu_N positive anomaly; these samples show, moreover, strong Sr enrichment. The second group shows almost flat REE patterns, at about 20xC1, with a slight LREE fractionation ($Ce_N/Sm_N = 0.48-0.67$).

PRIMARY AND METAMORPHIC EVOLUTION

The geochemical characteristics of the metaperidotite are typical of moderately depleted mantle peridotites. One of the analysed diopside-amphibole-rich band has a REE pattern, and overall trace element contents, closely similar to that of LREE-depleted pyroxenite bands in orogenic and ophiolitic peridotites.

The trace element compositions suggest that amphibole-rich rocks, which crop out as dykes crosscutting the ultramafic body, can be divided in two groups: the first one, showing an evident Eu_N positive anomaly, is similar to gabbroic rocks, characterized by cumulus of plagioclase: their protoliths could have been plagioclase-bearing intrusive mafic rocks. The second group most probably derives from rocks of basaltic compositions. These amphibole-rich rocks are commonly characterized by variable LREE negative fractionation, which is strongly indicative of a MORB affinity of the parental melts of their magmatic protoliths.

Available petrographic and compositional data suggest that pristine mantle peridotites, with pyroxenite layers, were characterized by spinel-facies assemblages, indicative of equilibrium recrystallization at moderate pressure conditions (P ranging 10-20 Kb). The development of amphiboles (pargasite and tremolite) and/or chlorite, stable with olivine (amphibole and/or chlorite peridotite facies assemblages), indicates transition to lower pressure and temperature conditions. The intrusion of MORB-type gabbros and basalts suggests progressive decompressional evolution in an oceanic setting: oceanic metamorphic overprint is evidenced by the development of crysotile, chlorite, and tremolite at the expense of mantle minerals and by the Sr enrichment of the whole rocks.

The subsequent metamorphic evolution is related to the subduction of the ultramafic body, which reached eclogite facies conditions. The olivine+diopside+antigorite+Ti-clinohumite assemblage, representing the metamorphic peak in metaperidotites, indicates temperature not higher than 500-550°C (Engi and Lindsley, 1980; Trommsdorff and Evans, 1980), whereas the garnet+omphacite+rutile association in amphibolite-rich mafic dykes indicates the high-pressure conditions. A retrograde evolution is evidenced by the amphibole and zoisite growth in the amphibole-rich rocks.

The El Toro ultramafic rocks can be thus defined as depleted mantle peridotites with pyroxenites bands that recorded a metamorphic HP event. The occurrence of HP metamorphic rocks in SW Ecuador is well documented by the Raspas Complex mafic and pelitic eclogites (Feininger, 1980, Gabriele et al., 1999, Gabriele

et al., 2001). The identification of the El Toro ultramafic body as a new high pressure metamorphic unit provides new insights into the subduction-exhumation processes in active margin setting.

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