MINERALOGICAL AND GEOCHEMICAL CHARACTERIZATION OF MIDDLE CRETACEOUS TO PALEOCENE OCEANIC AND CONTINENTAL VOLCANIC ROCKS FROM SOUTHWESTERN ECUADOR.

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KEY-WORDS : Late Cretaceous, Paleogene, oceanic plateau, island arcs, continental arc, geochemistry.

INTRODUCTION AND GEOLOGICAL SETTING

Southwestern Ecuador includes oceanic terranes of Cretaceous age accreted to the continental Andean margin between late Cretaceous and late Eocene times (Goossens & Rose 1973, Feininger & Bristow 1980, Jaillard et al. 1995). The oceanic floor, known as the **Piñón Fm**, yielded 110-100 Ma K/Ar ages (Aptian-Albian, Goossens & Rose 1973). It is thought to constitute the basement of the whole coastal area of Ecuador, and bears three distinct island arcs. In the Guayaquil area, the thick volcaniclastic deposits of the **Cayo Fm** of Cenomanian?-Campanian age are believed to represent the products of an island arc (≈95-75 Ma, Bristow & Hoffstetter 1977, Jaillard et al. 1995). It overlies the Piñón Fm through a thin but distinctive volcanic layer referred to as the **Las Orquídeas beds**. The presently NE trending **San Lorenzo Fm** is represented by conglomerates and greywackes intercalated with lava flows, which crop out NW of a fault system that separates it from the Cayo Fm (Manta area, fig. 1). It yielded consistent late Santonian-Paleocene ages (85-53 Ma, Goossens & Rose 1973, Lebrat et al. 1987, Wallrabe-Adams 1990). The **Macuchi Fm** of early to middle Eocene age crops out in the NNE-trending Western Cordillera.

The continental Andean margin of southernmost Ecuador includes various volcanic units. The **Celica Fm** consists of submarine, mainly andesitic lava flows, agglomerates and tuffs that crop out near the Peruvian border. It is usually interpreted either as a continental arc (Lebrat et al. 1987, Wallrabe-Adams 1990). Since it is crosscut by the Tangulla granite which yielded inconsistent 114 to 49 Ma K/Ar ages, an early Cretaceous age was inferred for the Celica Arc (Kennerley 1980). However, its extension in Peru is dated by Albian to Cenomanian fossils. The Celica Fm is overlain by the **Alamor Fm** made of coarse-grained greywackes and intercalated volcanics of early late Cretaceous age (Jaillard et al. 1996). Farther East, the **Sacapalca Fm** consists of subaerial agglomerates, tuffs and lavas, interpreted as a continental volcanic arc (Mamberti 1995). Since it is crosscut by plutons, which range in age from 26-21 Ma to 59-51 Ma or even 66-61 Ma, the Sacapalca Fm would be of early Eocene-Paleocene, or even late Cretaceous age (Jaillard et al. 1996).

The aim of this paper is to present preliminary results about the mineralogy, geochemical composition and geodynamic significance of the middle Cretaceous to Paleocene volcanic units of both, oceanic and continental origins.

MAGMATIC AFFINITIES

All the volcanic-rocks of southern Ecuador are affected by a low grade hydrothermal alteration with preserved magmatic textures. Clinopyroxene and plagioclase are replaced by smectites and calcite + epidote, respectively. The groundmass is always replaced by smectites while prehnite + pumpellyite + smectites fill vacuoles. The samples analyzed for this study are relatively fresh with preserved clinopyroxene and plagioclase.

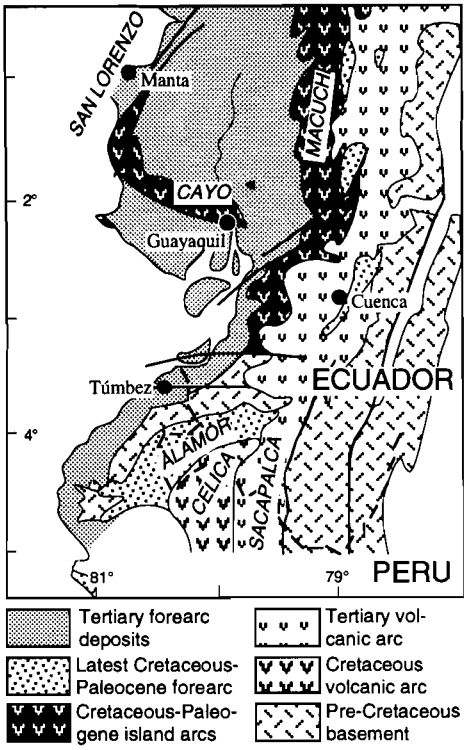

Fig. 1 : Location of the studied area.

The volcanic rocks of **oceanic origin** (Piñón and San Lorenzo Fms, Las Orquídeas beds) show mafic (MgO>5%) to intermediate compositions and are mainly dolerites, basalts and andesites. Basalt is the main rock type of the Piñón Fm and Las Orquídeas beds. Dolerites occur in the Piñón and San Lorenzo Fms while andesites are only found in the San Lorenzo Fm. All these rocks are formed of plagioclase, clinopyroxene and Fe-Ti oxides. The crystallization sequence in the basalts and dolerites of Pinon and Las Orquídeas Fms. is: plagioclase -> cpx -> oxides while in the rocks of the San Lorenzo Fm, Fe-Ti oxides crystallize before plagioclase. Orthopyroxene is uncommon. Plagioclase predominates (50 to 80 % of modal composition) in all the rock-types and shows normal zoning with labradorite core (An_{75}) and oligoclase rim (An_{10}). Clinopyroxene exhibits augite composition (En_{45}, Fs_{12}, Wo_{43}). In the San Lorenzo andesite, clinopyroxene shows diopside core rimmed by augite. Oxides are Ti-rich (TiO_2 ~ 5%) magnetites.

Basalts and dolerites of the Piñón Fm show E.MORB affinities with flat REE patterns [0.9<(La/Yb)C <1.3, fig. 2A) and Nb, Hf, and Ta enrichments relative to N.MORB (fig. 3A). They cluster in the E.MORB field in the Hf/3-Th-Ta diagram (Wood 1980, fig. 4). Basalts, dolerites, andesites of the Las Orquídeas beds and San Lorenzo Fm differ from the E.MORB of the Piñón Fm by LREE enriched patterns [2.31<(La/Yb)C<3.9, fig. 2B] and a depletion in Nb, Hf, and Ta relative to N.MORB (fig. 3B). They are enriched Ba, Rb, Sr relative to N.MORB (fig. 3B). All these rocks fall in the calc-alkaline field in the Hf/3-Th-Ta diagram (fig. 4). The REE abundance of the basalts and dolerites of the Las Orquídeas beds is 10 times the chondritic abundance and markedly lower than that of the San Lorenzo rocks. Moreover, the igneous rocks of Las Orquídeas beds show a significantly depletion in HREE, Zr, Ti, and Y, compared to the calc-alkaline rocks of San Lorenzo and more generally to the calc-alkaline mafic rocks of oceanic arcs (Wilson 1989).

The Piñón E.MORB tholeiite is characterized by an εNd, back calulated at 110 Ma, of +7 (fig. 5) which falls in the range of Oceanic Island Basalts. The Las Orquídeas calc-alkaline rocks show similar εNd ratios, back calulated at 110 Ma, that range between +6 and +7 (fig. 5). These εNd ratios fall in the range of oceanic arcs. In contrast, the initial $(^{87}Sr/^{86}Sr)i$ ratios of the E.MORB tholeiite and calc-alkaline lavas, back calculated at 110 Ma exhibit a wide range of values (-4.2<εSr<+4.2). The enrichment of both rocks in radiogenic Sr is probably linked to hydrothermal alteration experienced by these submarine lavas.

Thus, the basalts and dolerites of the Piñón Fm display E.MORB tholeiitic affinities, very similar to those of oceanic plateau basalts (Floyd 1989). Moreover, they share in common with the Late Cretaceous tholeiites from Curaçao (Kerr et al. 1996) and the Cenomanian-Coniacian E.MORB tholeiitic basalts from Hispaniola (Dupuis 1995), flat REE patterns, Ta, Nb, Hf enrichments relative to N.MORB and εNd ratios of +6/+7. The Las Orquídeas and San Lorenzo calc-alkaline rocks display petrological and geochemical features of intra-oceanic arc-rocks. The low HREE and Y contents of the Las Orquídeas rocks suggest the presence of residual garnet in the mantle source.

The lavas exposed on the **continental margin** (Celica, Alamor and Sacapalca Fms) show contrasting petrological and geochemical features with respect to the E.MORB tholeiites and calc-alkaline rocks. They occur as flows or fragments in pyroclastic breccias. They show intermediate to felsic compositions. Dacite is the most common rock-type. Mafic to acidic andesites are also present. Plagioclase is the most abundant mineral (30 to 80% of phenocrysts) and exhibits anorthite composition (An_{90}). Two groups of rocks may be distinguished on the basis of the nature of the ferro-magnesian phenocrysts. The lava in flows and pyroclastic breccias of the Celica Fm are clinopyroxene- and orthopyroxene-phyric, respectively. The andesites and dacites of the Alamor and Sacapalca Fms are amphibole- phyric. The dacites include quartz phenocrysts. Amphibole is always zoned ; it is a K-poor (K_2O<1%) hornblende. Fe-Ti are TiO_2 (4 to 6%) rich magnetite and crystallize before the plagioclase and clinopyroxene.

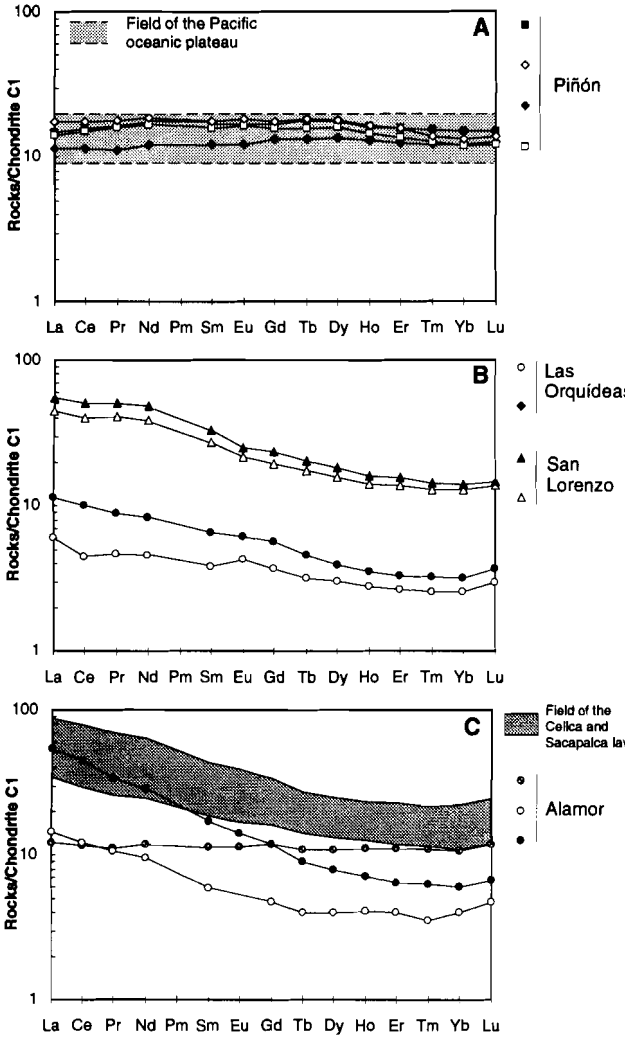

Fig 2 : Rare Earth Element normalized abundance normalized to C1 chondritic meteorite values (Normalisation values : Sun and Mc Donough, 1989).
A : Piñón Fm.
B : San Lorenzo Fm. and Las Orquídeas Beds.
C : Celica, Alamor and Sacapalca Fms.

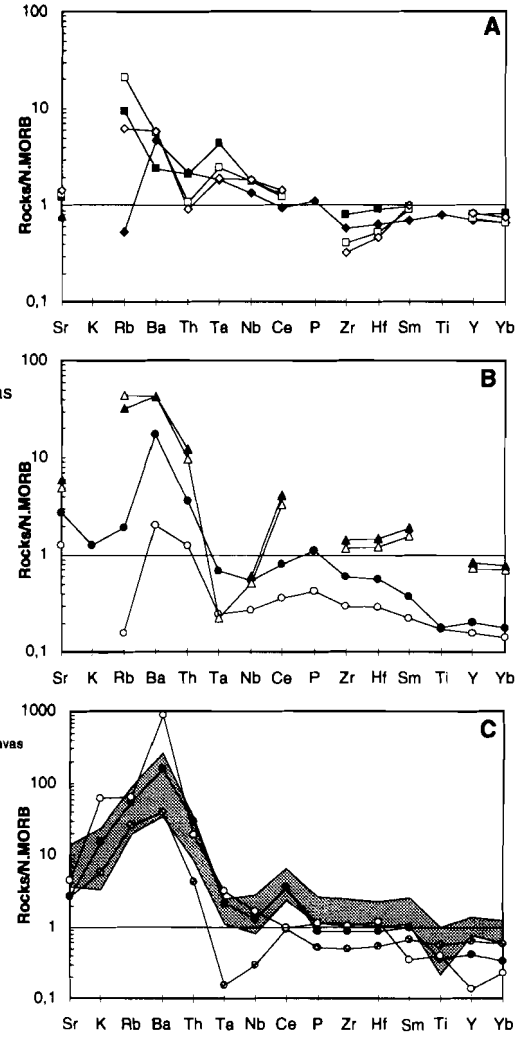

Fig 3 : N.MORB-normalized spiderdiagrams (Normalisation values : Sun and Mc Donough, 1989).
A : Piñón Fm.
B : San Lorenzo Fm and Las Orquídeas Beds.
C : Celica, Alamor and Sacapalca Fms.

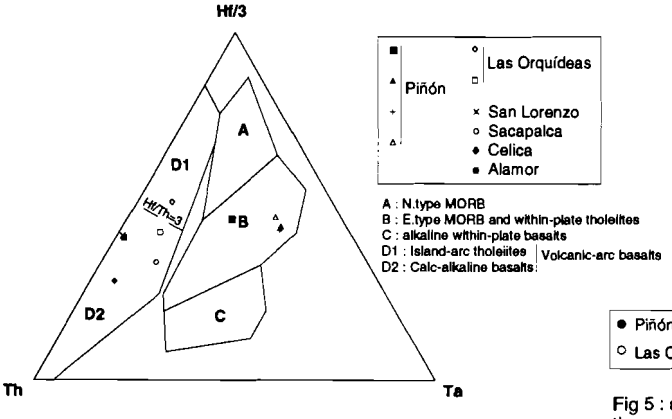

Fig 4 : Hf/3-Th-Ta discrimination diagram (after Wood, 1980).

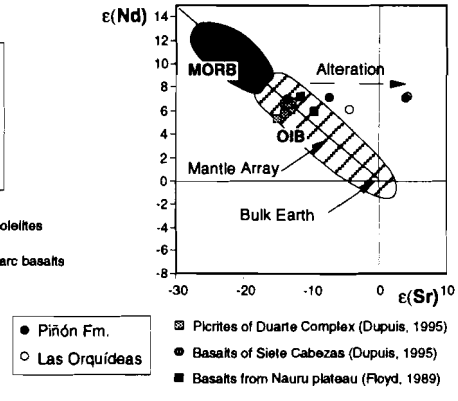

Fig 5 : ε(Nd) vs ε(Sr) isotopique correlation diagram showing the position of the Piñón and Las Orquídeas samples (calculated at t=110 My).

All the lavas show LREE enriched patterns [1.5<(La/Yb)C<3.11, fig. 2C], except for a volcanic fragment in a breccia of the Alamor Fm, which shows a flat REE pattern [(La/Yb)C=1.06]. A dacite of the Alamor Fm differs by lower REE concentrations (10 times the chondriitic abundance), but his REE pattern is of calc-alkaline type. The trace element patterns normalized to N.MORB are enriched in LILE and depleted in Ti and Nb (fig. 3C). In the Hf/3-Th-Ta diagram (fig. 4), these rocks fall in the volcanic arc basalt field, and more specially in the calc-alkaline field. Their Th levels are relatively high (2.31<Th ppm<4). This suggests a crustal contamination.

Thus, the lavas of the Celica, Alamor and Sacapalca Fms show calc-alkaline affinities. The predominance of dacites, the presence of hornblende and the high content in Th suggest that they were developed in an active continental margin setting.

CONCLUSIONS

The Piñón Fm may represent part of a Cretaceous Caribbean-Colombian Pacific-derived oceanic plateau. This would explain whyit could not be subducted and was part of the terranes accreted to the North and South American cratons sometimes during the late Cretaceous-early Eocene. Because of its oceanic plateau nature, the Piñon basement constituted the upper plate of successive intra-oceanic subduction systems. The overlying Las Orquídeas and San Lorenzo calc-alkaline rocks developed in island-arc setting. A calc-alkaline volcanism developed on the continental margin of southern Ecuador during late early Cretaceous (Celica Fm), late Cretaceous (Alamor Fm) and Paleocene (?) times (Sacapalca Fm).

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