METAMORPHISM OF THE CELICA FORMATION, SW ECUADOR : GEOTECTONIC IMPLICATIONS.

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Resumé

Les roches andésitiques de la Formation Celica (SW Equateur) ont été affectées par un métamorphisme de faciès zéolite et prehnite-pumpellyite. Un gradient thermique modéré à fort, une faible pression lithostatique, une haute fO_2 et un rapport eau de mer/roche plutôt faible, caractérisent ce métamorphisme. Ceci ressemble au métamorphisme de plancher océanique du Groupe Diabasique de la Colombie et appuie en conséquence l'hypothèse d'un bassin marginal (avorté) à l'origine du volcanisme Celica.

Key words: Ecuador, Cretaceous, Celica, low-grade metamorphism,marginal basin, island arc.

Introduction

In Ecuador (Fig.1) volcanic sequences of Mesozoic and Cenozoic age are exposed along the western border of the country. Among them, three volcanic formations of essentially Cretaceous age are distinguished: (a) the marine Piñón Formation with oceanic chemical affinities; (b) the marine Macuchi Formation which represents an oceanic island arc suite of predominant tholeiitic composition , and (c) the Celica Formation, mostly marine, of calc-alkaline nature. This Formation is considered either as a volcanic arc developed on an active continental margin or as an aborted marginal basin with extreme continental crust attenuation. These three Cretaceous units have been affected by low-grade metamorphism.

The Piñón and Macuchi suites are considered as allochtonous *s.l.* and are separated from the ensialic, autochtonous, Celica volcanics by a suture line which largely coincides with the position of the Dolores-Guayaquil Megashear (DGM). (References concerning this introduction to be found in Feininger &Bristow 1980, Baldock 1985, Lebrat 1985 , Aguirre & Atherton 1987 among others)

Field reconnaissance and sampling in the regions of Zaruma, Portobelo, Piñas and Celica and subsequent optical and chemical laboratory work were carried out. This paper intends to establish a metamorphic model for the Celica Formation as a clue to the understanding of the nature of its geotectonic setting.

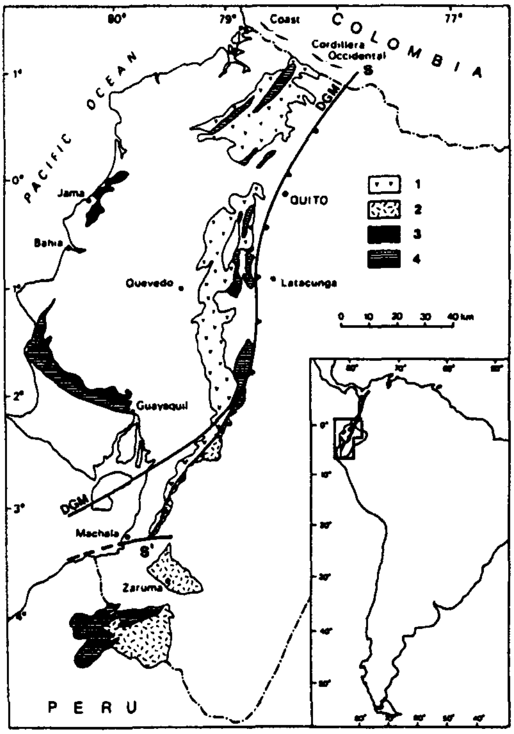

Fig. 1 : Simplified geologic map of western Ecuador. 1 = Macuchi Formation ; 2 = Celica Formation ; 3 = Piñón Formation ; 4 = undifferentiated Cretaceous sediments. DGM = Dolores - Guayaquil megashear. S-S' = suture between the continental and oceanic terrains (from Aguirre & Atherton 1987 ; modified after Lebrat 1985). Inset shows location of the Cretaceous volcanic belt in the Northern Andes.

Petrography

The Celica Formation consists of volcanic rocks with minor intercalated sediments. Andesite flows predominate associated with flow breccias and lithic tuffs of similar composition. Basic and acid units are subordinate and correspond to basalt, dacite and crystal tuff. The andesites are porphyritic with phenocrysts (2-3 mm) of plagioclase ($An_{50-66}Ab_{48.5-32.5}Or_{1.5}$), clinopyroxene ($Ca_{44}Mg_{42}Fe_{14}$) and hornblende. In the basalts, the phenocrysts (2 mm) correspond to plagioclase ($An_{60-86}Ab_{39-13}Or_{1}$) and clinopyroxene (mean of $Ca_{40}Mg_{46}Fe_{14}$) whereas in the dacites they consist of albitized plagioclase, hornblende and embayed quartz. All these rocks are moderately, although extensively, altered. Secondary (= metamorphic) minerals are abundant in veinlets and amygdales and as patchy replacement in primary crystals and in the groundmass.

Geochemistry

The chemistry of the Celica andesites has been studied by Lebrat(1985) who concluded that these rocks are calc-alkaline and can be classified as medium-K andesites. Their REE pattern is enriched in LREE and fall within the range of continental island arc andesites. Their Th/Ta ratio, relatively high, is close to that of recent Andean andesites. According to Lebrat (1985) and Lebrat *et al.* (1987) these lavas are intermediate between island arc calc-alkaline and typical continental margin andesites and resemble the magmas emplaced on a rather thin continental crust.

Metamorphic mineralogy

Two varieties of albite are present: (1) Ab I (An_{0}-An_{06}) which results from simple albitization of the primary , Ca-rich, plagioclase and ,(2) Ab II (An_{05}), a late phase present as a mosaic in veinlets or as neatly defined patches in fresh and albitized plagioclase phenocrysts.

Laumontite and stilbite appear as patchy replacement in phenocrysts and filling veinlets. Coexistence of both zeolites was observed in only one case.

Prehnite is moderately abundant as patchy replacement of plagioclase and in amygdales. Its iron content expressed as XFe^{3+} (= $100Fe^{3+} / (Fe^{3+} + Al_{total})$) varies from 9.3 to 18.7. Prehnite coexists with pumpellyite and, additionally (in one case), with garnet of the andradite-grossular series.

Pumpellyite is fairly abundant as replacement patches in plagioclase phenocrysts. Its $Fe_2O_3^*$ content is almost invariably higher than 10% which is typical of pumpellyites in the zeolite and prehnite- pumpellyite facies (Liou 1983). The XFe^{3+} values for coexisting pumpellyite and epidote show that Fe^{3+} partitioning was equitable: 21.7 to 34.7 for the former mineral and 21.4 to 31.2 for the latter. In pumpellyites from epidote-free assemblages XFe^{3+} ranges from 26.6 to 37.4. As a whole, pumpellyites of the Celica rocks are richer in iron than those of the Macuchi Formation.

Epidote is scarce and appears as replacement of plagioclase and clinopyroxene phenocrysts in assemblages containing pumpellyite, chlorite, titanite, calcite and prehnite.

Garnet of framboidal habit of the andradite-grossular series is found inside chlorite patches in the groundmass of a basaltic flow where it coexists with iron-rich prehnite, iron-rich pumpellyite, laumontite, calcite and chlorite. It closely resembles in composition garnets reported by Coombs *et al.* (1977) from basic volcanic rocks of Southern New Zealand metamorphosed under prehnite-pumpellyite facies.

Chlorite of diabantitic composition is abundant as replacement of plagioclase and clinopyroxene, in amygdales and as interstitial material in the groundmass. An interlayering of chlorite-smectite is suggested by the composition of some brownish phyllosilicates richer in SiO_2 than the diabantites.

Titanite is fairly common as small grains inside plagioclase and clinopyroxene crystals, in amygdales and as spots in the groundmass. Its Al_2O_3 and FeO* contents are high (X= 3.96% and 3.02% respectively); the main substitution corresponds to (Al+Fe*) <-->Ti. These features characterize titanite in the very low grades of metamorphism (Boles & Coombs 1977)

Metamorphic pattern

The mineral assemblages and the chemistry of individual mineral phases indicate that the Celica volcanics have been affected by low-grade, non-deformational, sub-greenschist metamorphism. The assemblages: (1) laumontite + stilbite (prehnite and pumpellyite absents); (2) laumontite + grossular-andradite garnet + prehnite + pumpellyite; (3) prehnite + pumpellyite + Al-rich titanite + (smectites); and (4) epidote + Al-rich titanite + pumpellyite (prehnite absent) are diagnostic of the zeolite and prehnite-pumpellyite facies.

The chemical characteristics of the mineral phases previously described (e.g. XFe^{3+} values of prehnite, pumpellyite and epidote; Al and Fe^{2+} contents in titanite; composition of chlorite among others) suggest a metamorphism at a moderate to steep thermal gradient, weak load pressure, high fO_2 and rather small seawater/rock ratio. This pattern approaches that observed in ocean-floor metamorphism and is closer to the one described for the Diabasic Group of Colombia (Aguirre *in press*) and the Peruvian Casma Group (Offler *et al.* 1980) than to the model known for the Ecuadorian Macuchi Formation (Aguirre & Atherton 1987).

Geotectonic implications

The Celica Formation is considered as a pre-orogenic, calc-alkaline, arc volcanism developed on the sialic western margin of South America between the Albian and the Maastrichtian (Kennerley 1980, Feininger & Bristow 1980, Lebrat 1985 and references therein). An alternative setting has been suggested by Aguirre & Atherton (1987) as part of a wider model for the Cretaceous evolution of the western border of South America. An aborted marginal basin nature , with strong attenuation of the continental crust, is attributed to the Celica Formation according to such model. The general analogies in metamorphic pattern with the Colombian Diabasic Group and the Peruvian Casma Group established here would favour this last hypothesis. However, some important differences with the Casma pattern are also observed in the Celica volcanics: (1) absence of greenschist facies assemblages; (2) absence of the high-T zeolite wairakite; (3) lower geothermal gradient; (4) higher values of fO_2 and Fe^{3+}-activity. These differences are here interpreted in terms of the degree of evolution of a marginal basin. Thus, the steepest thermal gradients, with their accompanying metamorphic pattern, should be found in aborted marginal basins with strong attenuation of the continental crust. In these basins (e.g. the Casma Group) the metamorphism is transitional between burial and ocean-floor type (Aguirre *et al.* 1989). On the other hand, in those basins where maximum degree of crustal thinning has been achieved (e .g. the Celica case in Aguirre & Atherton 1987) or in those where the continental crust has been totally eliminated (e.g. the Colombian Diabasic Group), a decrease of the thermal gradient occurs and the metamorphism is of ocean-floor type.

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