ORTHOGONAL DEFORMATION IN THE EASTERN ANDES OF ECUADOR

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Patterns of seismicity, volcanism and mineralization leave little doubt that the Pacific Plate is being consumed beneath South America (Gansser 1973). The Andes have grown by compression, uplift, intrusion, crustal thickening and volcanism. Along most of their length subduction has been perpendicular since at least the Jurassic. However, a large part of the northern Andes is regarded as allocthonous, accreted by strike-slip during the Cretaceous and Tertiary (Feininger & Bristow 1980; McCourt *et al.* 1984; Aspden & Litherland 1992) (Fig.1). The Huancabamba Deflection, where the Andes swing from NNW to NNE, probably marks the southern limit of the allocthonous Andes.

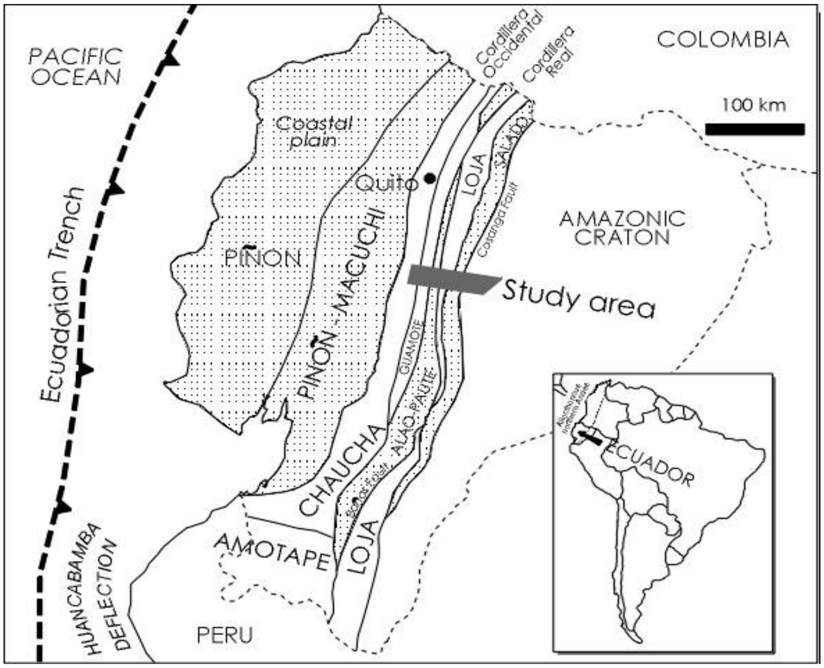

Fig.1. Simplified terrane map of Ecuador (Litherland et al, 1994). Oceanic terranes are stippled

In Ecuador, the Andes separate a broad coastal plain, underlain by Jurassic/Cretaceous oceanic basalts (Piñón Formation), from the Amazon basin and underlying Precambrian Guyana Shield. A topographic trough, the "inter-Andean Graben", divides the Andes into two ranges: the Cordillera Occidental (W) and the Cordillera Real (E). The

Cordillera Occidental comprises Cretaceous pillowed basalt, correlated with the Piñón Formation of the coast (Sauer 1965), and an Eocene island arc (Eguez 1986) (Fig. 1). The Cordillera Real comprises N-striking Palaeozoic and Mesozoic metamorphic rocks. Both cordilleras, and the trough, are partly concealed by subduction-related Tertiary to Recent volcanic rocks. The boundary between oceanic and continental crust is not clear.

We mapped a well-exposed E-W corridor across the Cordillera Real (Figs. 1, 2). The main rocks are graphitic phyllites, mica schists, greenschists, marbles and calc-schists (Table 1). We recognize clear lithostratigraphical divisions in these metamorphosed sedimentary and volcanic rocks (Fig. 2). Four major granitoids, and minor amphibolites, complete the section. Recent lavas from the active volcano Tungurahua occur as erosional outliers along the Río Pastaza.

The strata strike N-S and are commonly sub-vertical. Metamorphic grade ranges from low to high greenschist facies. Schistosity is generally sub-parallel to bedding or compositional layering. The most important structures, both still active, are the Peltetec and Sub-Andean faults (Fig. 2). The Peltetec defines the western edge of the Cordillera Real and includes serpentinite slivers. The Sub-Andean is a reverse fault that separates the true metamorphic Andes, in the W, from the Sub-Andean Zone, a weakly metamorphosed thrust belt, in the E.

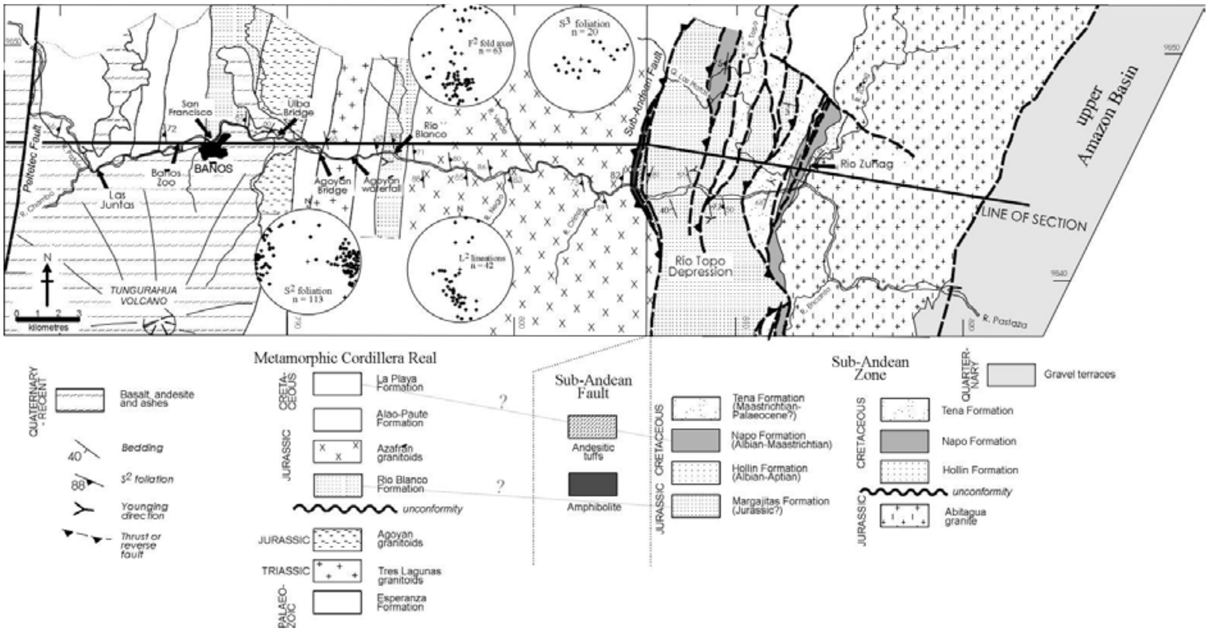

Fig. 2 Geological map of the Río Pastaza corridor with stereograms of structural data from the metamorphic portion of the Cordillera Real. Minor outcrops of amphibolite and Recent lava are omitted.

METAMORPHISM

There are two discrete phases of regional metamorphism in the main metamorphic Cordillera Real. Low greenschist conditions accompanied the formation of the S1 slatey cleavage; graphite was preserved. Subsequently, a high greenschist regional metamorphism occurred in the anticlinal core of the Cordillera Real. This began with porphyroblast formation (albite, garnet) and a foliation (S2) defined by quartz, muscovite, biotite and chlorite. With progressive metamorphism and deformation, pressure shadows of quartz and muscovite developed around the garnets. Subsequently, the S2-related metamorphism had a strong thermal (static) component. It caused widespread granoblastic recrystallization of quartz and randomly oriented coarse muscovite. Garnet was commonly retrogressed to chlorite at this stage.

Stratigraphic Unit	**Age**	**Petrography and geological setting**
		Metamorphic Cordillera Real
Esperanza Formation)	*Triassic-Palaeozoic*	Pelites forming the anticlinal core of the Cordillera. Intruded by granitoids. Includes the highest grade metamorphic rocks
Río Blanco Formation (= Margajitas Fmn?)	*Jurassic?*	Chloritoid schists meta-volcanic, and metamorphosed clastic, rocks. Metamorphic grade reaches high greenschist facies
Alao-Paute Formation	*Jurassic-Cretaceous(?)*	Greenschists, greenstones, metabasalts and metadolerites in the greenschist facies.
La Playa Formation)	*Cretaceous?*	Calcareous phyllite with pyrite and quartz lenses, calc-schists (calcite + talc + chlorite ± fuchsite), scattered marbles
		Sub-Andean Zone and Amazon Basin
Margajitas Formation	*Jurassic ? pre-Albian?*	Pyritous non-calcareous cleaved mudstones, scattered quartzites with distinctive blue quartz grains
Hollín, Napo and Tena formations	*Aptian to Maastrichtian / Palaeocene*	Occur as a complete outcrop in the W flank of the Abitagua granite and as thrusted fragments in the Margajitas Fm
		Intrusions
Tres Lagunas granite	*late Triassic-early Jurassic*	Foliated granite (kfs and blue qz phenocrysts). The western contact is sharply defined against crystalline Esperanza schists
Agoyán granitoids	*late Triassic-early Jurassic*	Metadiorite to metagranodiorite. Good gneissose banding enhanced by boudinaged garnetiferous amphibolites.
Azafrán granitoids	*Jurassic*	Metadiorite to metagranodiorite. Schistosity reflects mica growth and strong grain-size reduction. Micaceous domains
Abitagua granite	*Jurassic*	Jurassic Kfs rich batholith in the eastern foothills of the Cordillera. Shows no evidence of metamorphism.

Table 1. Summary of lithostratigraphic units in the Cordillera Real (Study area)

TECTONIC EVENTS

We see no evidence of the Triassic “Tres Lagunas” dextral strike-slip event of Litherland *et al*., (1994). The Tres Lagunas granite does not have an old (syn- to late-emplacement) schistosity. Furthermore, the amphibolite dykes and pegmatites were clearly deformed during S1/S2 development. The foliation in the granitoids throughout the Pastaza corridor was formed by relatively brittle processes and was dominated by grain size reduction rather than new mineral growth. There is no structural evidence of pervasive or localized strike-slip deformation. Lineations are instead consistent with oblique dip-slip.

We envisage a structural history with a single progressive deformation. This began with slatey cleavage development (S1) and developed into a low to high greenschist regional metamorphism and deformation (S2). This progressive event was probably the Cretaceous Peltetec deformation. It affected the entire Cordillera. Grades were highest in the core. The Peltetec Event was orthogonal. Its age is poorly known.

The Peltetec Event is younger than the Lower Cretaceous and it occurred at the Napo-Tena formation transition (Maastrichtian), when the Cordillera emerged and carbonate shelf sedimentation in the Amazon basin switched to continental red-bed deposition (Tena Formation) (Baldock 1982). The deformed Napo (Albian/Maastrichtian) limestones, or deeper water equivalents, occur in the Cordillera Real at Baños (La Playa Formation) and Cerro Hermoso (Tschopp 1956). The Margajitas Formation is broadly equivalent to the Río Blanco Formation. Our correlations suggest a mid- to Late Cretaceous age for the Peltetec Event. This is closer to the substantial peak in (reset) K-Ar dates at about the Cretaceous/Tertiary boundary (Feininger, 1982; Litherland *et al*. 1994). Compressive deformation continued into the Tertiary, probably in pulses, and continues at the present time.

We model the Cordillera Real as an anticlinal core of Palaeozoic basinal or deep shelf sedimentary rocks. They were deposited on the edge of the Precambrian Guyana Shield, on a stable shelf. They probably link with the Palaeozoic rocks of the Peruvian Andes and with the Palaeozoic and Triassic mudstones and limestones of the Amazon basin of Ecuador. The Palaeozoic rocks were intruded by a Triassic S-type granite (Tres Lagunas), reflecting possible rifting (Aspden & Litherland, 1992), and subsequently eroded and overlain unconformably by Jurassic/Cretaceous sediments and submarine basalts/andesites (Alao-Paute). We interpret these rocks as the fill of a marginal basin on thinned continental crust. The Alao-Paute basalts/andesites may correlate with the Misahuallí intermediate volcanic rocks. Major I-type magmatism in the Jurassic (Azafrán and Agoyán granitoids) is probably related to subduction.

The Jurassic/Cretaceous depositional environment was probably controlled by N-S faults, not dissimilar to the current disposition of strata and intrusions in the Sub-Andean Zone. Basin geometry was probably also affected by the intrusion of linear, buoyant batholiths (Abitagua and Azafrán). Local horst and graben tectonics are indicated by the unconformity of the Hollín quartzites (Aptian-Albian) directly upon the Abitagua granite (Jurassic). Immediately to the W, Margajitas Formation is preserved beneath the Hollín unconformity in the Río Topo Depression (Fig. 2). Early on, the unroofing of the Tres Lagunas granite provided blue quartz grains to many Jurassic/Cretaceous sedimentary formations in Ecuador. This blue quartz provides links between the two sides of the Cordillera and is additional evidence for a coherent stratigraphy.

The boundary between oceanic and continental crust must lie W of the Cordillera Real. Collision between the Pallatanga/Piñón crust and continental South America in the late Cretaceous may have driven the orthogonal Peltetec deformation of the Cordillera Real. Alternatively, changes in plate convergence rates and vectors may be responsible. Choking up of the subduction zone by an oceanic plateau or ridge, as appears to happen presently with the Carnegie Ridge off Ecuador, may explain the deformation. The profound shortening of the Cordillera Real implies a strong orthogonal component to this collision.

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