Orogenic buildup of the Ecuadorian Andes

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INTRODUCTION

While the Central Andes (Peru, Bolivia) exhibit a high mean elevation, a large orogenic belt, a significant shortening and the lack of any exotic mesozoic material, the northern Andes (Ecuador, Colombia) are marked by a moderate mean elevation, a narrow shape, a low shortening amount and the presence of large Cretaceous oceanic terranes accreted to the western margin.

The aim of this work is to propose a model for the orogenic buildup of the Andes of Ecuador, which differs from that commonly proposed for the Central Andes, and takes into account the geological evolution and structure of this part of the chain.

GEOLOGICAL DATA

Petrographic and geochemical studies of the oceanic terranes accreted to the western part of the ecuadorian margin indicate that they are mainly fragments of oceanic plateaus of Cretaceous age, overlain by island arcs or pelagic cherts of Campanian-Maastrichtian age (Lebrat et al. 1987, Reynaud et al. 1999, Lapierre et al. 2000, Boland et al. 2000, Kerr et al. 2002, Mamberti et al. 2003, 2004, Jaillard et al. 2004). The basement of the Macuchi island arc, ascribed to the Eocene, is unknown (Egüez 1986).

Mapping of these magmatic terranes allowed to distinguish several tectonic units, separated by major faults and characterized by distinct geological evolutions. For each terrane, stratigraphic studies led to identify major uncoformities, which separate oceanic rocks devoid of detrital quartz (plateau basalts and dolerites, arc lavas and volcaniclastic rocks, radiolarian bearing cherts), from the overlying quartz-bearing clastic sediments (turbidites, marine shelf sandstones, subaerial conglomerates,...). The latter are interpreted as sealing the collision of the oceanic terrane with the continental margin (e.g. Jaillard et al. 2004), and therefore allow to date the accretion events. Accordingly, accretions occurred in the Late Campanian (≈ 75 Ma), sealed by Early Maastrichtian turbidites (Tabacay Fm), Middle or Late Maastrichtian (≈ 70-65 Ma), sealed by Early to Middle Paleocene shelf or turbiditic sandstones (Saquisilí Fm), and early Late Paleocene (≈ 58 Ma), sealed by Late Paleocene coarse turbidites (Azúcar Gp). The Macuchi arc would have been accreted in the Late Eocene (Bourgois et al. 1986).

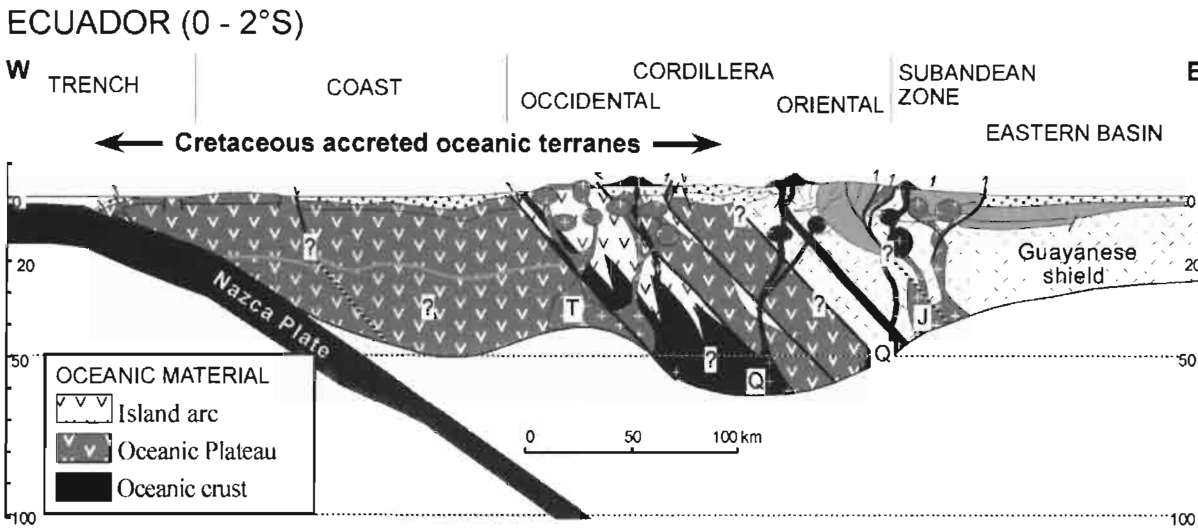

Fig. 1. Crustal scale section of Ecuador, taking into account geological and seismological constrains

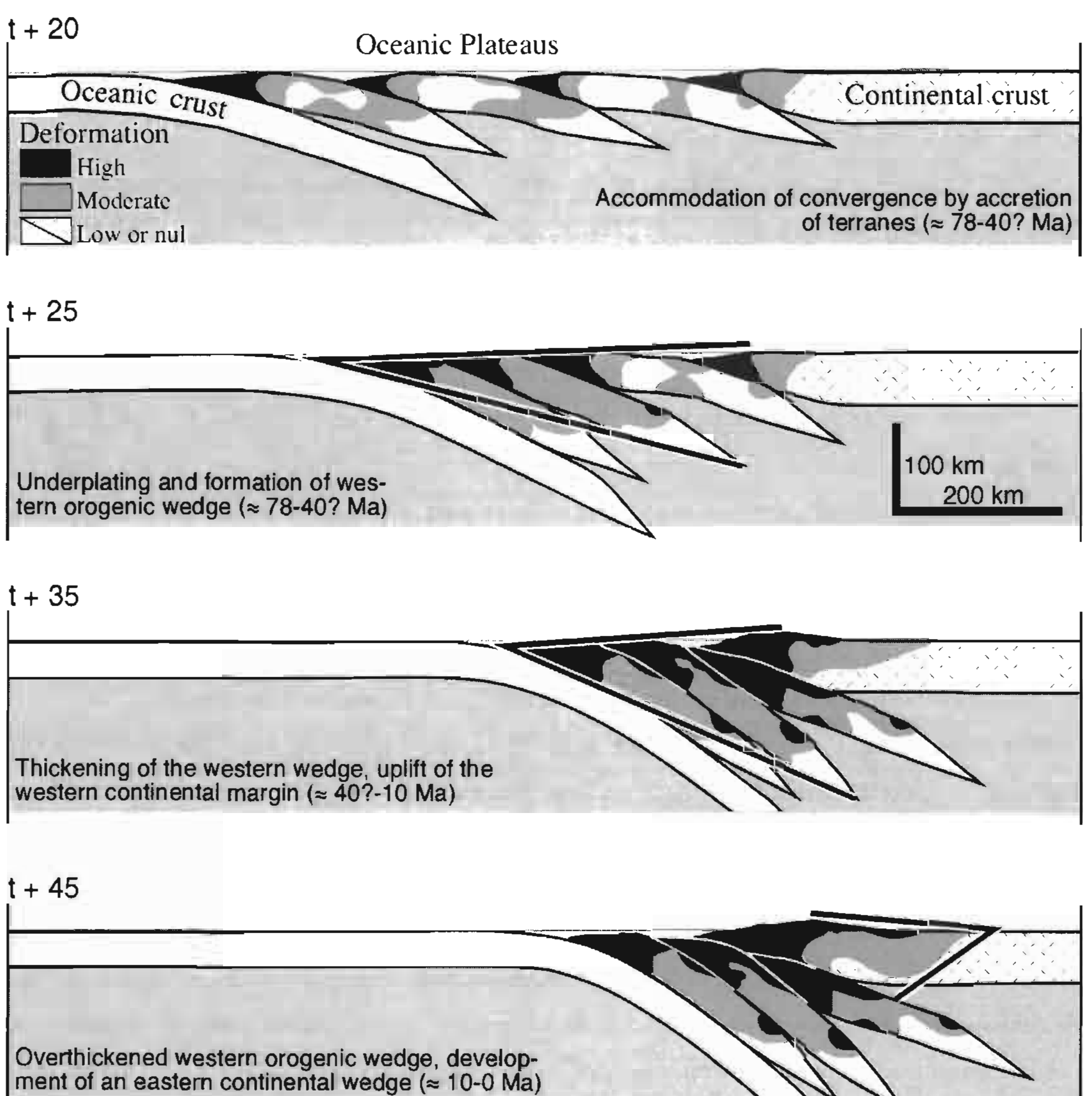

Fig. 2. Numerical modelling of the orogenic buildup of the Andes of Ecuador (Bonnardot 2003)

The scarcity of mafic detritism and the lack of ophiolitic nappes on the ecuadorian margin indicates that accretion of the plateaus occurred through subduction jam and tectonic underplating due to excessive buoyancy (Cloos 1993), rather than by obduction. This have been confirmed by sismological studies (Guillier et al. 2001), which show that the Andes of Ecuador (1) are cut by major East-dipping active planes that coincide with the terranes boundaries, and (2) present a crustal root thickness of 50 to 70 km. On the other hand, Arculus et al. (1999) and Gabriele (2002) demonstrated that, in spite of their high density, eclogitized OIB rocks, burried as deep as ≈ 60 km (15-20 kb, 580°C) did not sink into the mantle, and remained underplated beneath, and incorporated to, the forarc zone of southern Ecuador (Raspas area), thus supporting the likelihood of a deep oceanic crustal root beneath the Andes of Ecuador.

Finally, in the Oriente Basin, the very low subsidence rate (Thomas et al. 1995) indicate that flexural subsidence did not occur before Miocene times, and the very low tectonic shortening (≤ 5%, Vega 1998) suggests that crustal thickening cannot be due to contractional shortening. Moreover, magmatic addition and underplating related to tectonic erosion could not have occurred, since subduction did not take place beneath the ecuadorian margin between ≈ 140 and ≈ 40 Ma (Aspden et al. 1987).

BUILDUP OF THE ANDES OF ECUADOR: SCENARIO AND TESTS

These data led us to propose (Guillier et al. 2001, Jaillard et al. 2002) that the crustal root that supports the relief of the Andes of Ecuador is due to the tectonic underplating of the accreted oceanic fragments, then burried by the ongoing compression.

Petrographic and sedimentological studies of the Late Cretaceous-Eocene, syn-accretion clastic deposits of the Cordillera Occidental od Ecuador (COE) demonstrate that the erosion of the Eastern Cordillera increased from Early Maastrichtian to Late Eocene times, and the deposition depth and areal extent of these sedimentary basins decreased during the same interval (Toro and Jaillard 2005). These observations point to significant uplift of both the western and eastern Cordilleras, related to the accretion and underplating of the oceanic terranes.

The mineralogical and geochemical analysis of amphibolites, granulites and other mafic rocks exhumed by Miocene flower structures crosscutting the COE indicates that (1) they all derive from oceanic plateau and island arc rocks, and (2) some of them underwent metamorphic conditions at 5-7 kb and 850°C (Beaudon et al. 2005). This indicates that the deep levels (≈ 20 km) of the COE are made of oceanic material, and that, if eclogitized, these rocks have been retromorphosed into less dense HT facies, increasing their buoyancy.

After emplacement of the oceanic fragments (≈ 75-58 Ma, maybe ≈ 40 Ma?), the western part of the ecuadorian margin underwent significant deformations (Coastal zone and western Cordillera), while slight uplift occurred in the cordilleras. However, rapid uplift only occurred from middle Miocene onwards (≈ 10-8 Ma, Spikings et al. 2001, Hungerbühler et al. 2002). We interpret this three step evolution as follows: (1) ≈ 75-40? Ma: emplacement of a crustal-scale, gently west-dipping, western accretionary wedge, made of the oceanic material, (2) ≈ 40-10 Ma: contractional deformation, thickening and steepening of the western accretionary wedge, which eventually became too thick to carry on deforming; (3) ≈ 10-0 Ma: the strain due to the ongoing convergence is transmitted by the locked western wedge to the continental margin, which began to deform, creating an opposite, estward dipping, eastern tectonic wedge involving the continental margin. Numerical modelling using standard parameters (Hassani et al. 1997) reproduced this scenario, thus confirming the mechanical likelihood of the model (Bonnardot 2003). In this experience, convergence is accomodated through three successive ways (1) the subduction zone is nearly blocked, the trench migrates continentwards, and the oceanic plateaus subduct beneath each other and beneath the continental margin, creating an incipient accretionary wedge; (2) the oceanic plate subducts, the trench retreat is weak, the incipient wedge thickens and sinks, and the continental margin begins to be uplifted and deformed; (3) the accretionary wedge is blocked, and the continental margin is uplifted, intensely deformed and develops landward thrust planes.

CONCLUSION

While the relief of the Central Andes appears to be mainly due to contractional shortening, that of the Andes of Ecuador is related to a crustal root made of accreted and tectonically underplated oceanic fragments. These were emplaced through subduction jam during the latest Cretaceous-Paleocene (and Eocene?), forming a shallow, western accretionary wedge. During Eocene-Miocene times, ongoing subduction shortened and thickened the accretionary wedge, deforming the western edge of the continental margin. Finally, from Late Miocene to present, the overthickened, locked western wedge transmitted the compressional stress to the continental margin, which was in turn strongly deformed and uplifted, developing an eastern, opposite tectonic wedge, which migrates eastwards.

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