Proyecto Dolores-Guayaquil entre el IRD y la EPN

Geodynamic evolution of the southern (the Gulf of Guayaquil-Tumbes basin) and Southeastern (Cañar- Santa Isabel basin) boundaries of the North Andean block during the past 20-25 Ma, role of Strain partitioning along an Andean type subduction zone.
Strain buildup and abrupt co-seismic stress release across the northwestern Peru coastal plain, shelf, and continental slope during the past 200 kyr

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1- Introduction

The Dolores-Guayaquil project between IRD and EPN (2004-2006) questioned two main scientific topics including: (1) the role of strain partitioning in constructing the Ecuadorian Andes and the eustacy (i.e. climate evolution at the time scale of the glacial-interglacial cycle) feedback coupling to seismogenic behavior of the northern Peru subduction zone. The works conducted during this project include extensive field campaigns along the Cañar-Santa Isabel basin, in the area of the Gulf of Guayaquil-Tumbes basin, and along the coastal plain of northern Peru. Also Petroecuador and Perupetro provided the existing geophysical and drill data. These data along with the EM12 bathymetric data acquired during the ANDINAUT cruise (Jacques Bourgois, Chief scientist) of the R/V L'Atalante (GENAVIR/IFREMER) allowed us to reconstruct an interesting story of the continental margin and shelf between 2° and 7° S latitude. A new approach of processes from which main sequences of major earthquakes originated is proposed.

The result of this project that Figure 1 shows general locations includes two main publications in major international journals (Witt et al. 2006; and Bourgois et al., accepted), two "Titulacion para la obtencion del Titulo de Ingeniero Geologo de la EPN" (Lahuathe, 2005; and Verdezoto, 2006), and the publication of the geologic map of Cañar at the scale of 1:50 000.

2- The Gulf of Guayaquil-Tumbes basin

Interpretation of industrial multichannel seismic profiles and well data were used to identify the main tectonic features of the Gulf of Guayaquil-Tumbes basin area (Figure 2). North of the Gulf of Guayaquil, these include two E-W trending major detachments: the Posorja and the Jambelí detachment systems, which represent half grabens with oppositely dipping detachments, to the south and to the north, respectively. The NE-SW trending Puná-Santa Clara fault system developed as a transfer fault system between the Posorja and the Jambelí detachments. The Esperanza and the Jambelí basins exhibit 3-4 km of sediment that accumulated during the past 1.6-1.8 Ma. The PunáSanta Clara fault system bounds the Esperanza and the Jambelí basins, evidencing that the evolution of these basins is tightly controlled by the two detachments at depth. To the west, the N-S trending Domito fault system bounding the Posorja detachment system and the Esperanza basin to the west acted as a transfer zone between the shelf area and the continental slope. Also the Domito fault system connects the northern tectonic boundary of the Gulf of Guayaquil to the southern detachment system, which bounds the Peru Tumbes basin to the south. This southern system includes the northward dipping Tumbes and Zoritos detachments that are both active. The flat Banco Peru located about 60 km offshore the Peru coastline connects the Tumbes-Zorritos detachment system to the Domito fault system.

The Pliocene series show no significant variations in thickness throughout the Gulf of Guayaquil area suggesting that no important tectonic deformation occurred from 5.2 to 1.8-1.6 Ma. The major period of tectonic deformation in the Gulf of Guayaquil area (Figure 3) occurred during the Pleistocene times. Three main tectonic steps are identified. From Early Pleistocene to ~180 ka, major subsidence occurred along the Esperanza and Jambelí basins. From ~180 to ~140 ka, most of the Gulf of Guayaquil area was above sea level during the isotope substage 6 low stand. From ~140 ka to Present, tectonic activity is restricted along the normal faults bounding the Esperanza basin, the Tenguel fault, and the Puná-Santa Clara and Domito fault systems. A N-S trending tensional stress regime characterizes the Pleistocene times throughout. The northward drifting of the North Andean block is proposed to control the tectonic evolution and associated subsidence of the Gulf of Guayaquil-Tumbes area. Also it is accepted that the collision of the Carnegie ridge with the trench axis has to play a major role in controlling the North Andean block northward drift. Because the Carnegie ridge subduction is possibly an ongoing process, which began prior to the Pliocene, we postulate the along strike morphology of the ridge at the origin of interplate coupling variations. The subduction of an along strike positive relief of the ridge is proposed at the origin of the major tectonic reorganization of the Gulf of Guayaquil-Tumbes area occurring at ~1.8-1.6 Ma.

3- The Cañar-Santa Isabel area

The most recent synthesis on Andean geodynamics of southern Ecuador is the work by Hungerbühler et al. (2002). It was the result of extensive field works done by the ETH-Zurich group that include several field works encompassing the Cañar, Azogues, Cuenca, Nabon, Giron-Santa Isabel and Loja basins from north to south. Because tectonic analysis developed in those works exhibits major deficiencies, we decided to revisit the geology of the Cañar, Azogues and Santa Isabel basins. Alsó rapid sampling was done along the Loja basin.

Steinmann et al., (1999) and subsequently Hungerbühler et al. (2002) established the chronostratigraphy of the basin sequences by zircon and apatite fission-track dating. They proposed the following reconstruction for the evolution of the Andes of this area of southern Ecuador: (1) from 15 to 9 Ma coastal marine sediments accumulated along basins during the so-called *Pacific coastal stage*. Subsequently the *intermontane stage* began at 9.5-8 Ma in association with a major E-W oriented compression. As a consequence, the uplift of this segment of the Andes occurred during the past ~9 Myr. Taking burial into account, they calculated that the total rock uplift was 6100 m at a mean rate of 0.7 $mm.yr^{-1}$. The main point to constrain this tectonic evolution is the postulated connection between the Gulf of Guayaquil and the Miocene marine facies of the inter-Andean basins (Figure 4), this assumption being based on the presence of fossils from brackish water environment in the inter-Andean basins.

In order to test this issue, we have sampled the postulated marine fossils of these supposed marine basins for $^{87}Sr/^{86}Sr$ analysis (analysis at the Rennes University, France by Aline Dia).The seven analyses we have obtained show that fossil shells have values far out the reference curves of seawater Sr strontium variations through time (Smalley et al., 1994; Farrell et al, 1995; Hodell et al., 1990). The inter-Andean basins are continental basins. No marine embayment to the Cuenca area (i.e. trough the highest Andes of the Cajas Park) exists in this area during the Miocene. No basis exists for the calculated uplift of the Andes as proposed by the ETH-Zurich group.

The other point of scientific interest is that related to the tectonic evolution of this segment of the Andes. We roughly agree the age of main compression tectonic phase as proposed by the ETH-Zurich group, at around 8-10 Ma. The Ar/Ar datings we have obtained allow us to constrain the tectonic phase to be between 9 and 8 Ma. Along the northern segment from Cañar to Cuenca area no active deformation occurred since that time. Only the southern segment (Santa Isabel area) exhibits a subsequent reactivation along a major normal fault, which bounds the Santa Isabel the East at Present. The lake sediment, which accumulated along the fault-related hemi-graben is assumed to be younger than the compression tectonic phase at 9 to 8 Ma. The sediment older than 9-8 Ma exists along the Santa Isabel basin. However they are restricted to local erosion windows opening on the strongly folded older basin and basement.

4- The Northern Peru subduction zone

A combined analysis of data collected both onshore and offshore along the northwestern Peru forearc area (3°30'-7°30'S), from the coastal plain to the trench axis allowed us proposing a new approach to understand long sequences of major earthquakes.

Onshore, geomorphic analysis places constraints on the relative importance of eustatic versus tectonic factors in sculpting, preserving and modifying the uplifted coastal landforms along the coastal plain that exhibits extensive marine terraces, locally known as *tablazos*. Breaking-wave morphologic markers were dated using the *in situ*-produced ^{10}Be cosmonuclide. The data document a tectonic segmentation, allowing us to differentiate two areas as regard their evolution through time: the northern Cabo Blanco and the southern Paita-Illesca segments. For the past 200 kyr, both segments uplifted at high rates of 10 to 20 $mm.yr^{-1}$ through tectonic pulses. Along the Cabo Blanco segments the tectonic pulse was coeval with the eustatic deglacial sea level rise of isotope stage 1. Along the Paita-Illesca segment the tectonic pulse occurred probably during the sea level rise of warm isotope substage 5e. The uplift and related extensive emersion of the coastal plain require high coupling along the subduction zone and/or underplating at depth.

Offshore, industry-acquired reflection lines combined with EM12 bathymetric data (ANDINAUT cruise) allow us to investigate the tectonic regime and deformation of the continental margin and shelf. Major dipping-seaward detachments control the long-term subsidence of this area. These main tectonic features define a tectonic segmentation. The Talara, Paita, and Sechura segments are identified from north to south. No clear tectonic correlation in time exists between the onshore and the continental margin segmentations, or in space either. The long-term subsidence of the offshore, indicative of subduction-erosion working at depth require high decoupling along the subduction channel at depth.

The distribution of permanent deformation along the northern Peru forearc area includes long-term uplift along the coastal plain and long-term subsidence along the continental margin. The neutral line between uplift and subsidence is located within the 10 km seaward from the Present coastline. At the Cabo Blanco segment, permanent topography is created through a large sequence of major earthquakes suggesting that the seismogenic zone is located beneath the coastal plain, extending seaward to the neutral line (i.e. the updip limit at depth). The aseismic zone extends seaward along the continental margin. Along the coastal plain, no appreciable bending or tilting is associated with the permanent deformation. This situation suggests that the seismogenic zone is periodically strongly locked with low accumulation of interseismic elastic strain to be recovered during co-seismic rupture.

The most recent uplift step (20-23 ka to Present) along the Cabo Blanco segment exhibits clear linkage with a sequence of major earthquakes. We infer that eustacy exerts important feedback coupling to seismogenic behavior of the North Peru subduction zone (Figure 5). We speculate that during sea level fall, pore-fluid pressure diminishes along the subduction channel inducing a possible seaward migration of the locked zone (i.e. migration of the updip limit) reaching a maximum by the end of the eustatic low stand. During eustatic sea level rise pore-fluid pressure increases along the subduction channel. This in turn is capable of weakening the previously locked zone along the plate interface beginning an earthquake sequence. Earth's orbital variations are a potential external cause that may control the physical processes at work along plate interface.

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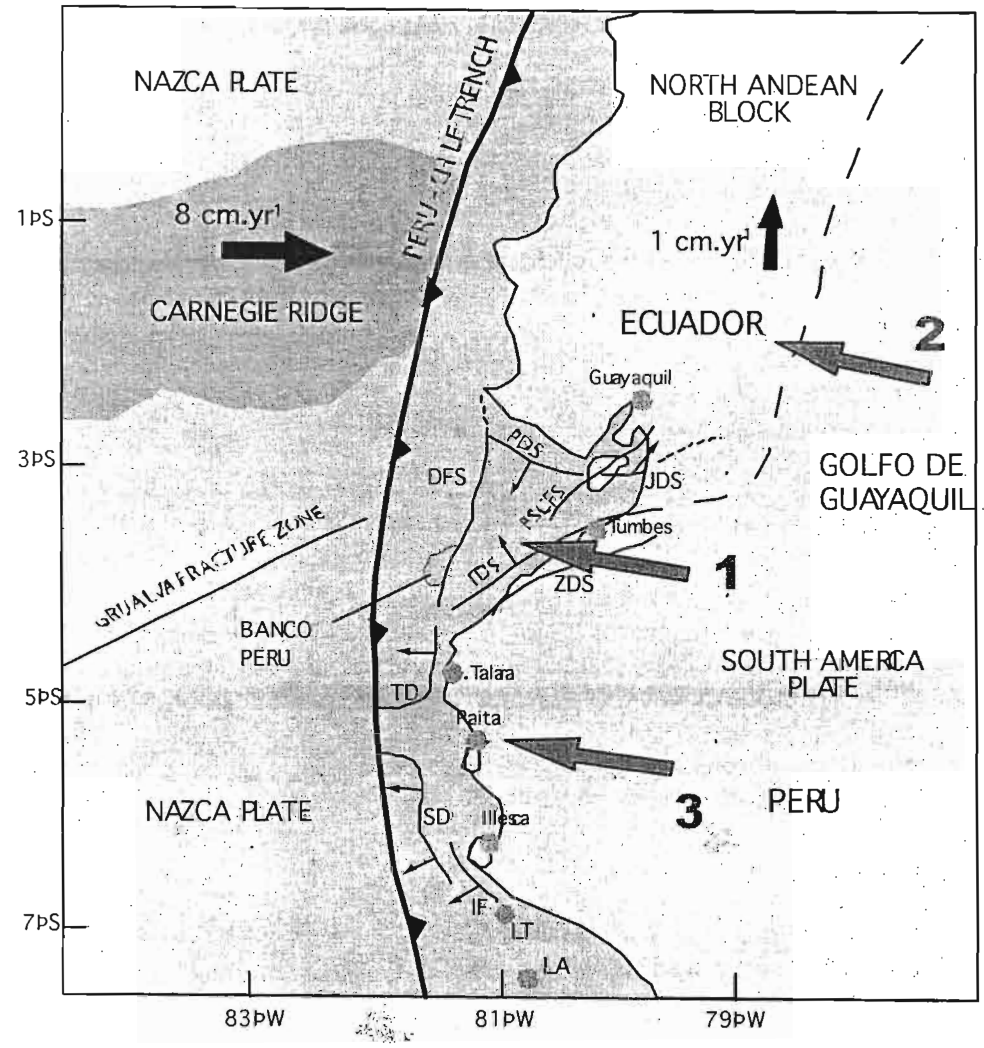

Figure 1 - Location map of the studied area. Black lines with thin arrows, detachment; Dash line, proposed eastern boundary of the North Andean block that migrates ~1 cm.yr^{-1} to the north [*Trenkamp et al.,* 2002]. DFS, Domitos fault system; IF, Illesca fault; JDS, Jambeli detachment system; LA, Isla Lobos de Afuera; LT, Isla Lobos de Tierra; PDS, Porsoja detachment system; PSCFS, Puna-Santa Clara fault system; SD, Sechura detachment system; TD, Talara detachment system; TDS, Tumbes detachment system; ZDS, Zorritos detachment system. Red numbers show the three main areas studied during the Dolores-Guayaquil project.

FIGURE 2. WITT AND BOURGOIS.
FIGURE 2.JPG

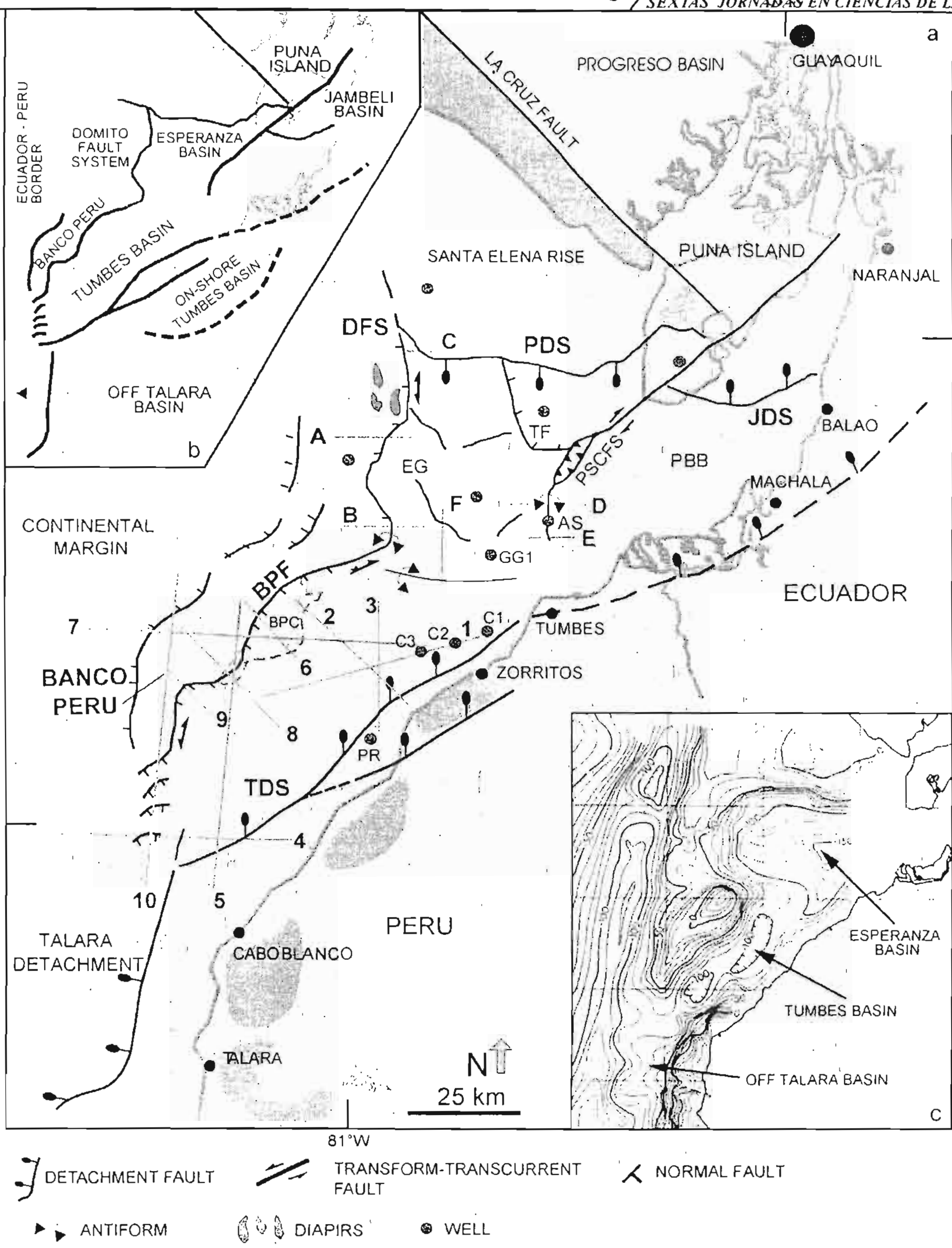

Figure 2 – ***Area 1 as shown on Figure 1.*** **a)** Structural map of the Gulf of Guayaquil-Tumbes basin. Light blue areas define zone where coastal uplift has been active at least since 200 kyr. A to F, seismic lines; BPC, Banco Peru canyon; BPF, Banco Peru fault; DFS, Domito fault system; C1, C2 and C3, Corvina wells; EG, Esperanza graben; GG1, Golfo de Guayaquil 1 well; JDS, Jambeli_ detachment system; PBB; Puerto Bolivar block; PDS, Posorja detachment system; PR, Piedra Redonda well; PSCFS, Puna_-Santa Clara fault system; TDS; Tumbes detachment system; TF, Tenguel fault. **b)** Main tectonic features. **c)** Free-air gravity anomaly map (10 mgal contours), from Sheperd and Moberly (1981).

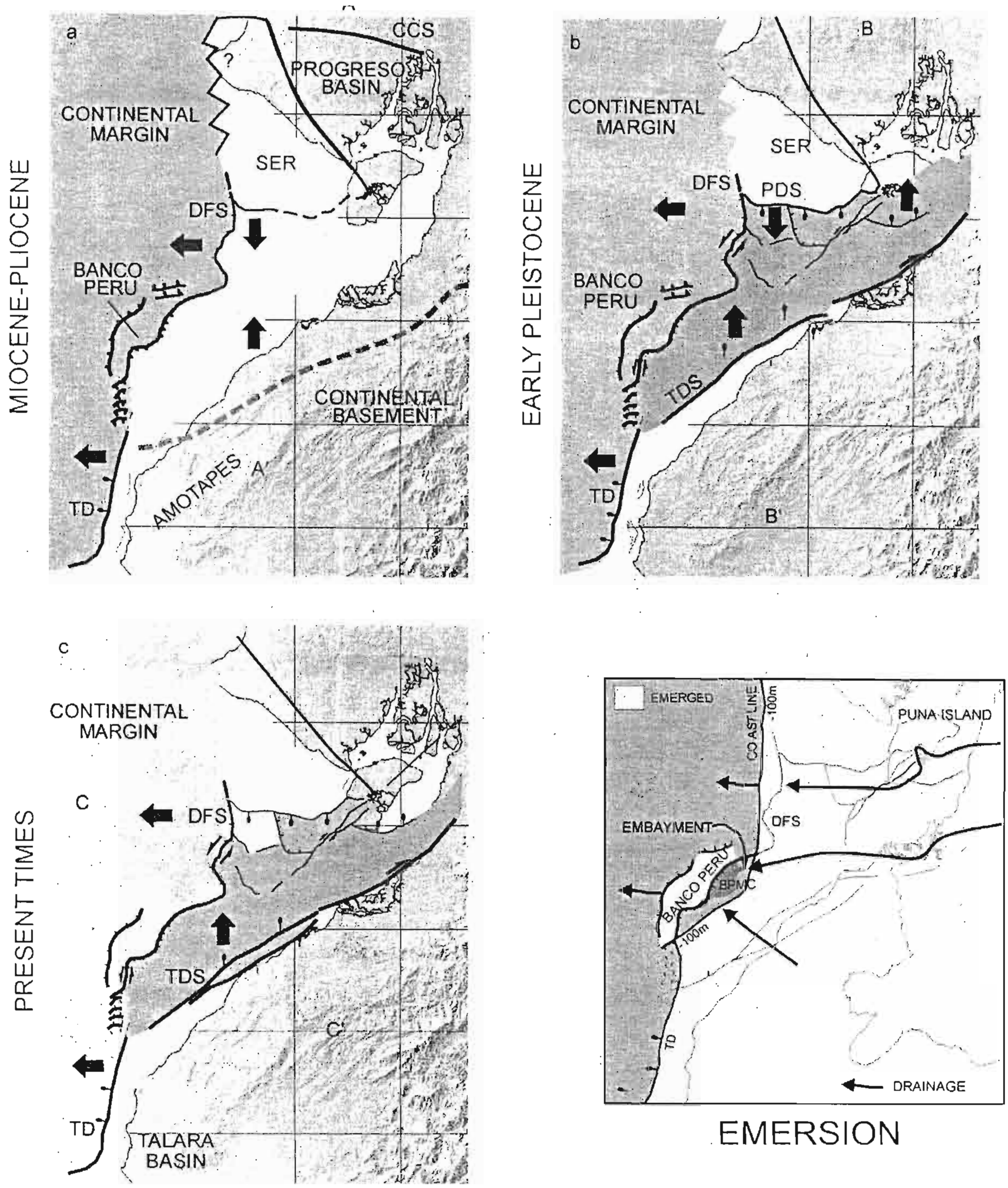

Figure 3 - Schematic map views and cross sections of the tectonic reconstruction of the NAB trailing edge since Miocene times. The coastline is considered only as a geographic reference frame. a) During Mio-Pliocene times subsidence and related sedimentation rates are low. b) Main period of basin formation and depocenter individualisation in the NAB southern tip. c) Present times. Abbreviations are as follows: CCS, Chongón-Colonche sierra; GGTB, Gulf of Guayaquil-Tumbes basin; DFS, Domito fault system; PDS, Posorja detachment system; SER, Santa Elena rise; TD, Talara detachment; TDS, Tumbes detachment system.

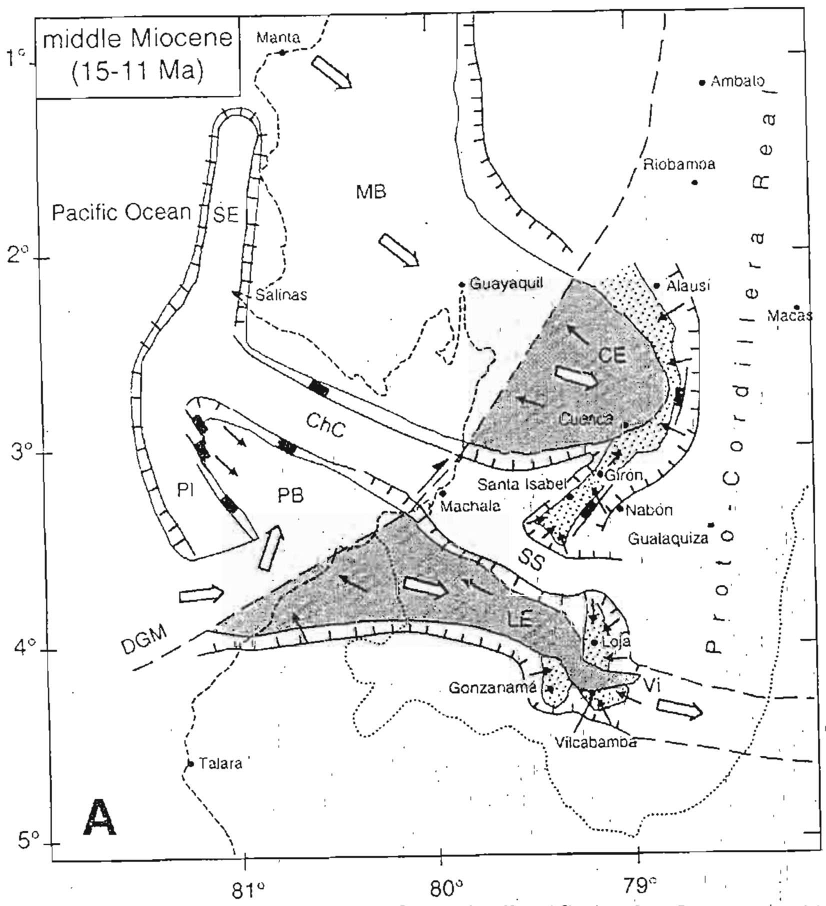

Figure 4 – No marine embayment from the Pacific to the Cuenca and Loja basins exists during the Miocene (after Steinmann et al., 1999; Hungerbühler et al., 2002)

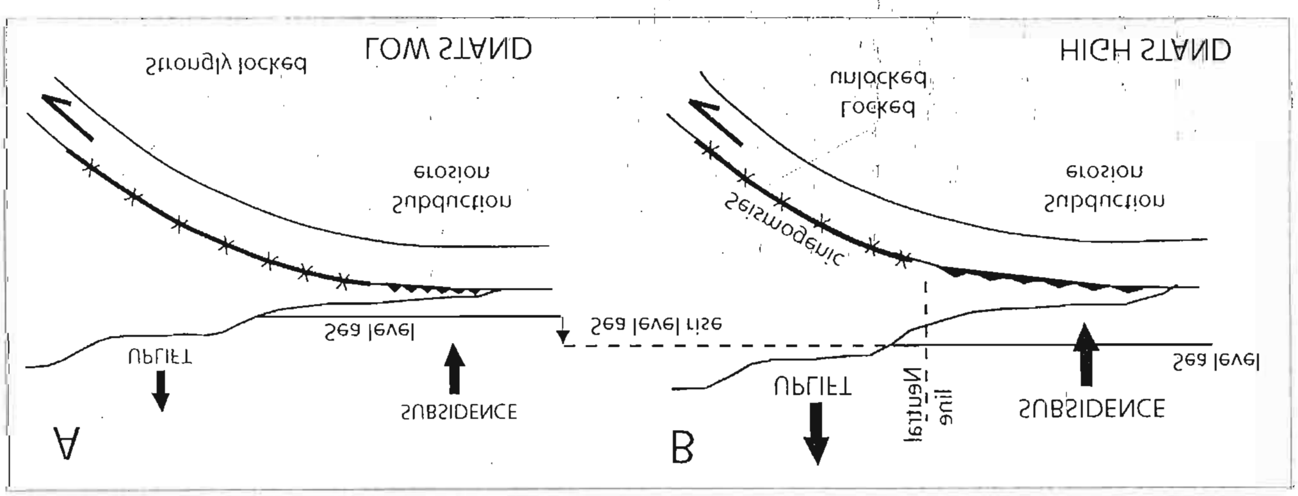

Figure 5 - Eustacy feedback coupling to seismogenic behavior of the northern Peru subduction zone. (A) During sea level fall, pore-fluid pressure diminishes along the subduction channel inducing a possible seaward migration of the locked zone that would reach a maximum by the end of the eustatic low stand. (B) During eustatic sea level rise pore-fluid pressure increases along the subduction channel. This in turn is capable to weaken the previously locked zone along the plate interface. Such weakening might contribute the locked zone to enter a long-lived sequence of major earthquakes.

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