THE CRETACEOUS TO EARLY PALEOGENE TECTONIC EVOLUTION OF THE CENTRAL ANDES AND ITS RELATIONS TO GEODYNAMICS.

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RESUMEN : Las fases compresivas y la subsidencia de la margen andina durante el Cretáceo superior-Paleógeno están analisadas en relación con la geodinámica. El regimen compresivo a largo plazo sería controlado por el movimiento hacia la fosa de la placa americana, mientras que las fases compresivas breves coinciden con cambios en la velocidad de convergencia (aceleración). Además períodos de convergencia rápida coinciden con épocas de subsidencia importante.

KEY-WORDS : Late Cretaceous, Paleogene, Andean tectonic phases, Subsidence, Plate Tectonics.

INTRODUCTION

Many classical geodynamic models proposed to explain the origin of the tectonic phases in continental active margin have been elaborated through the observation and comparison of various present-day active margins or through physical modelling. Only few have been elaborated through the study of active margin during long-termed periods. The aim of this paper is to propose some geological constraints and new hypothesis about the origin of the tectonic phases of continental active margins, through the study of the Central Andes from middle Cretaceous up to late Eocene times.

EVOLUTION OF THE CENTRAL ANDES FROM LATE JURASSIC TO EOCENE TIMES.

The Cretaceous evolution of the Central Andes actually began by late Jurassic times. It can be divided into various periods (Jaillard 1993a, Sempéré 1993, and references therein). At this time, the Andean margin comprised a subsident Western trough and an Eastern, less subsident basin, separated by an axial swell.

1. Tithonian-Berriasian (Virú period). During Tithonian times, tectonic, mainly extensional events are coeval with the activity of a volcanic arc along the Peruvian margin, and provoked the sedimentation of widespread clastic deposits, the emergence of part of Southern Peru and the creation of a very subsident sedimentary basin in Northern Peru.

2. Valanginian-Aptian. During early Cretaceous times, east-deriving fluvio-deltaic sandstones were laid down throughout the Central Andean domain. Magmatic and tectonic activities are virtually lacking.

3. Late Aptian-Turonian (Mochica period). During late Aptian times, the Andean margin recorded an extensional tectonic activity, scattered volcanic outflows related to intracontinental tensional regime, and the large-scale on-lap of fluvio-deltaic deposits on the Eastern border of the Andean Basin, due either to eustatic sea-level rise or to tectonic subsidence. The Albian period is marked by a marine transgression that overwhelmed the whole domain, and then by a regression, that culminated in early Cenomanian times with the progradation of eastern deltaic sandstones. The Western part of the margin recorded the intense activity of a volcanic arc, the beginning of magmatic intrusions, and alternating extensional and compressional tectonic deformations. The volcanic activity ceased by late Albian-early Cenomanian times, as the western part of the margin was deformed by a first major compressional phase (Mochica phase). This was probably associated with a strong dextral wrenching component, and is recorded by extensional synsedimentary tectonic features in the whole western domain.

During Cenomanian and Turonian times, a major transgression deposited widespread shelf carbonates that recorded the main eustatic discontinuities.

4. Coniacian-early Late Paleocene (Peruvian period). On the whole Andean margin, Coniacian times were marked by the beginning of fine-grained detrital, mainly argillaceous sedimentation, probably related to the erosion of locally tectonized coastal areas. After a period of tectonic quiescence (Santonian-early Campaian), a major compressive phase occurred during late Campanian times. It is responsible for large-scale overthrusts (SW Peru), creation of subsident troughs (Cuzco), marine transgression in the forearc regions (Talara) and deposition of widespread sandstones in the Eastern domain. A new tectonic quiescence occurred during Maastrichtian times, which are characterized by widespread, short-lived marine transgressions. Maastrichtian and Paleocene times were a period of intense and widespread volcanic activity throughout the Central Andean margin.

5. Late Paleocene-Late Eocene (Inca period). From Bolivia to N Peru, widespread unconformities are observed between fine-grained Paleocene and coarse-grained Eocene continental deposits (Inca 1 phase). In the forearc regions, the accretion of the oceanic-floored Peninsula of S Coastal Ecuador was concealed by latest Paleocene unconformable coarse-grained high density turbidites (Benitez et al. 1993). It was followed by the accretion of the Amotape continental Terrane of N Peru (Berrones et al. 1993), concealed by early Eocene coarse-grained conglomerates, and expressed by a sedimentary gap in Coastal Ecuador. Middle Eocene times were a period of extensional subsidence and of eustatic sea-level rise, which provoked the deposition of a shallowing-upward marine sequence. This period ended up by the deposition of polygenic sandstones and conglomerates, interpreted as resulting from the overthrust of the oceanic-floored coast of Ecuador on the continental Andean margin by early Late Eocene times (Benitez et al. 1993).

In summary, compressional deformations of the Andean margin began in Albian times. Discrete tectonic phases occurred during late Albian-early Cenomanian, Coniacian, late Campanian, late Paleocene, earliest Eocene times and middle to late Eocene times, and are separated by quiescence periods.

SUBSIDENCE HISTORY

The Cretaceous-Paleogene subsidence evolution of the Peruvian margin can be divided into four periods.

Between **145 and 130 Ma** (late Jurassic-Berriasian) either uplift (SW Peru), or rapid subsidence occurred. In N Peru, a major extensional tectonic phase was responsible for the creation of the Chicama basin, that controlled the whole Cretaceous subsidence history of this area (fig. 1).

During early Cretaceous times **(130 to 110 Ma)**, important thermal subsidence occurred in the newly created basin, whereas the unstretched areas recorded a slow subsidence rate.

From **110 up to 90 Ma** (late Aptian-Turonian), the subsidence rate increased in all the Western Peruvian areas, floored by stretched continental crust. In Eastern Peru, no significant changes are observed.

Between **90-80 and 40-30 Ma** (Senonian-late Paleogene), two situations occurred. In all areas of N Peru, the

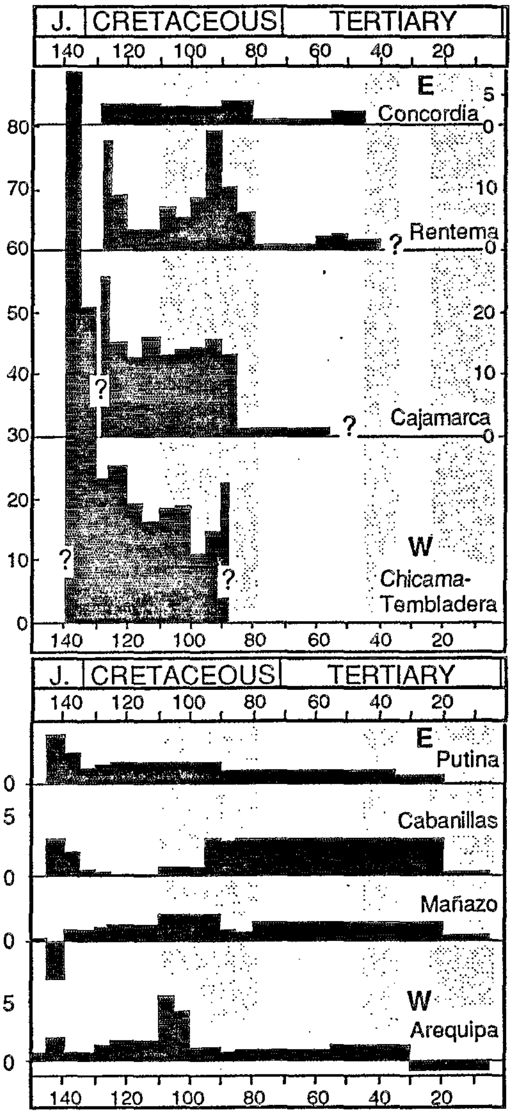

Fig. 1: Average subsidence rates (in cm/Ma) in Northern (above) and Southern Peru (below).

subsidence rate drastically decreased, whereas it remained unchanged or slightly increased in S Peru (fig. 1). In Bolivia, the strong increase of subsidence is interpreted as due to lithospheric flexion related to the incipient Andean shortening (Sempéré 1993).

RELATIONS TO GEODYNAMIC PARAMETERS

Although the geodynamic reconstructions are rather uncertain for the late Cretaceous period, some parameters can be analyzed in relation to the tectonic evolution of the Andean margin.

1. Age of the subducted slab. Classical models assume that the subduction of a young, buoyant oceanic lithosphere induces a the compressional strain in the overriding continental plate (Molnar & Atwater 1978, Cross & Pilger 1982). After Soler et al. (1989), the rejuvenation of the oceanic plate roughly coincides with the beginning of the compressional period (Albian). However, the late Cretaceous and Paleogene compressional phases occurred during a continuous increase in the age of the slab, fig. 2). Therefore, the age of the slab could contribute to the appearance of a long-termed compressional regime, but cannot account for short-termed compressional tectonic phases.

2. Absolute trenchward movement of the overriding plate. As noted by many authors (e.g. Bourgois & Janjou 1981), the beginning of the westward shift of the South American plate at the equatorial latitudes during Albian times roughly coincides with the beginning of the compressive period in the Andean margin. Thus, this parameter seems to control the long-termed compressive regime of the continental active margin.

3. Collision of continental or oceanic obstacles. Cross & Pilger (1982) proposed that the arrival in the subduction trench of oceanic or continental obstacles (aseismic ridges, sea-mounts, continental microplates), will provoke the blocking of the subduction and the compressive deformation of the continental margin. However, near the Peru-Ecuador border, the accretions of the Amotape continental terrane (earliest Eocene) or the oceanic terranes of Coastal Ecuador (late Paleocene p.p, late Eocene) coincide with compressional phases observed in Bolivia or Southern Peru where no collisions are known to have occurred. Thus, it seems that accretions or collisions of terranes are consequences rather than causes of the compressional phases, and that both accretion-collision and compressional phases are consequences of a same mechanism.

4. Convergence rate. Following Uyeda & Kanamori (1979), Cross & Pilger (1982) or Pardo-Casas & Molnar (1987), a rapid convergence between the oceanic and continental plates provokes a compressional stress in the latter. On the Andean margin, periods of high convergence rates occurred in Albian-Campanian and late Eocene-early Oligocene times, which roughly coincide with tectonic periods (fig. 2). However, the short-lived compressional events seem to concide with changes in the convergence velocity (i.e. acceleration), rather than with the velocity itself. If the reconstruction of Soler & Bonhomme (1990) is correct (fig. 2), such changes occurred in late Aptian (≈ 110 Ma), late Albian-early Cenomanian (≈ 100-95 Ma), late Santonian (≈ 85 Ma), late Campanian (≈ 75 Ma), late Paleocene (≈ 55 Ma) and late Eocene times (≈ 45 Ma). Except for the late Santonian, all these periods coincide with important compressional tectonic Andean phases.

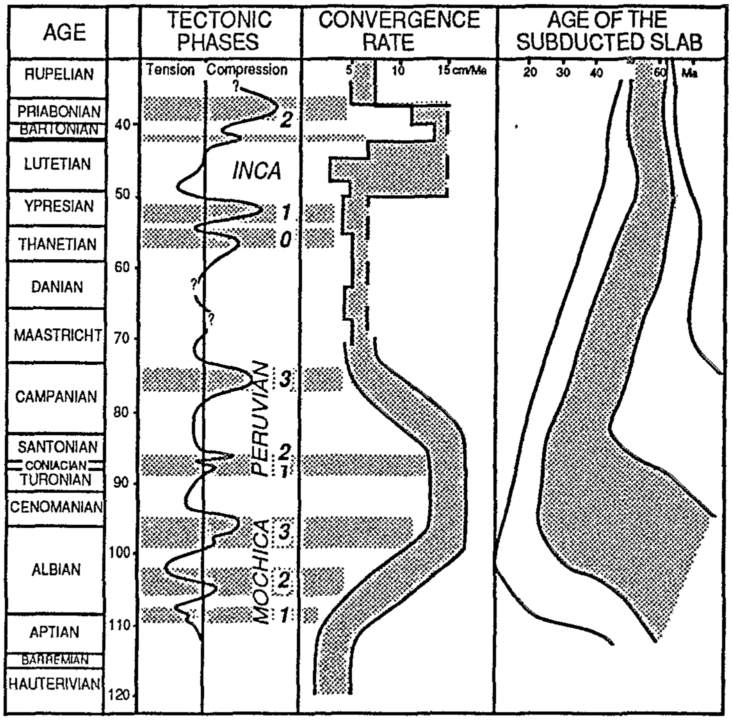

Fig. 2: Relations between tectonic phases and subduction parameters during middle Cretaceous - Paleogene times.

5. Mechanical instabilities at the trench. According to Sébrier & Soler (1991), the late Tertiary Andean compressive phases are due to mechanical instabilities in the subduction zone, that make impossible the retreat of the trench to accomodate the trenchward movement of the continental plate. However, the causes of these instabilities are not clear. Further investigations would be necessary to explore the relations between such instabilities and the convergence pattern.

6. Direction of Convergence. The geometry of the geodynamic reconstruction are too poorly constrained to allow a valuable discussion for the late Cretaceous. The Inca tectonic phases (late Paleocene to late Eocene) coincide with changes in both direction and rate of convergence (Pilger 1984, Pardo-Casas & Molnar 1987), that make difficult to separate the part of each parameter. Whatever the case, a change in the convergence direction, necessarily provokes a change in the normal convergence rate, and, therefore, could have the effects assumed for the convergence acceleration. Moreover, the important changes in the convergence direction from NNE to ENE by late Paleocene-early Eocene times must have induced drastic changes in the subduction geometry. The Ecuadorian margin changed from a mainly transform to a chefly convergent regime, inducing the accretion of neighbouring terranes and the birth of new subduction zones West of them (Benitez et al. 1993). Thus changes in the convergence direction play a part both in the normal convergence rate, and in the regional subduction regimes, that could in turn influence the tectonic regime.

7. Relation convergence rates-subsidence. In Northern Peru, slow convergence correlates with low subsidence rates (130-110 Ma ?, 80-45 Ma). Conversely, the periods of high convergence velocity are coeval with periods of increased subsidence rate (110-80 Ma, and 45-35 Ma ?). This could be explain by an increased tectonic erosion of the deep continental margin (von Huene & Lallemand 1990, von Huene & Scholl 1991). However, this model only account for the subsidence of the external part of the margin, close to the subduction zone, whereas increased subsidence is observed as far as the present-day Eastern Cordillera. In contrast, these observations are consistent with the thermal model of Mitrovica et al. (1989), that assumes that a fast convergence provokes an increase of the subsidence rates in the whole continental margin. The lack of such correlations in S Peru is most probably due to the fact that compressional tectonics began earlier than in N Peru. There, tectonic uplift of the margin by crustal shortening and thickening, and overload tectonic subsidence of the foreland prevailed since Senonian times (Sempéré 1993, Jaillard 1993b).

CONCLUSIONS

According to the study of the Andean continental margin during Cretaceous-Paleogene times, long-termed compression seems to be controlled by the absolute trenchward motion of the overriding plate, and, to a lesser extent, by the young age of the subducted lithosphere. Short-lived compressional phases seem to be mainly linked to acceleration (or deceleration) in the convergence between the oceanic and continental plates, and probably to changes in the convergence direction. Periods of high and low convergence rates seem to coincide with increased and decreased subsidence ratse in the margin, respectively, and appears to be rather independant to compressional-extensional regimes.

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