SUBSIDENCE HISTORY OF THE NORTH PERUVIAN ORIENTE (MARAÑON BASIN) SINCE THE CRETACEOUS.

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INTRODUCTION, GEOLOGICAL FRAMEWORK

A study of the subsidence history of the northern Oriente of Perú (Marañon Basin) has been undertaken using the backstripping method (Steckler & Watts 1978, Sclater & Christie 1980, Allen & Allen 1990). This study highlights the tectonic evolution of this distal backarc area during Cretaceous and Tertiary times (Contreras 1994, 1996).

The Cretaceous cycle began with transgressive sandstones (Cushabatay Fm), which rest disconformably on Paleozoic to earliest Cretaceous rocks. Their base is strongly diachronous from West (Valanginian ?, Tarazona 1984) to East (Albian). Marine shales of early Late Albian age were deposited all over the basin (Raya Fm). They are overlain by regressive deltaic to fluvial sandstones (Agua Caliente Fm), the top of which is strongly diachronous, being dated of Late Albian to Early Turonian age from West to East (Kummel 1948). The overlying marls, limestones and scarce sandstone beds of Turonian to Santonian age (Chonta Fm) express a major transgression. Disconformable sandstones are dated as Campanian and Early Maastrichtian (Vivian Fm, Salas 1991). A short-lived marine transgression of early Maastrichtian age (Cachiyacu Fm) is then followed by the deposition of fine-grained red beds of Maastrichtian age (Huchpayacu Fm, Mathalone & Montoya 1995).

The Tertiary series begins with fine-grained continental red beds of Paleocene age (Yahuarango Fm). They are disconformably overlain by disconformable marine to brackish shales and marls, and red siltstones and sandstones of Eocene age (Pozo Fm, Mathalone & Montoya 1995). After a probable hiatus of most of the Oligocene, red beds with local coal measures and evaporites were laid down during the Early Miocene (Chambira Fm). They are followed by a new short-lived, restricted marine transgression of late Early to early Middle Miocene age (Pebas Fm, Hoorn 1993). Red beds with conglomerate intercalations ascribed to the Late Miocene and Pliocene (Marañon Fm) are overlain by coarse-grained fluvial sandstones and conglomerates of mainly Pleistocene age (Corrientes Fm).

METHOD AND RESULTS

Thirty wells have been selected, on the base of their geographic location, suitable depth, good quality electric records and micropaleontological and stratigraphic data. They are scattered throughout the northern part of the Oriente basin of Peru (Marañon Basin).

The age of the formation boundaries was determined using the paleontological data available in published works and confidential industrial reports (fig. 1). However, biostratigraphic revisions of the cretaceous ammonites of Peru are in progress, and some ages will need emendments. The importance and duration of sedimentary hiatuses were often approximated and/or extrapolated. Conversion to absolute ages was made using the time-scale and eustatic chart of Haq et al. (1987).

Corrections for eustatic variations through time were made on the base of the relative sea-level estimates of Haq et al. (1987). Paleobathymetric corrections were estimated following the indications of faunal assemblages and the determination of sedimentary environments.

Data processing was performed with the software "Back" version 01 (Contreras 1996), inspired

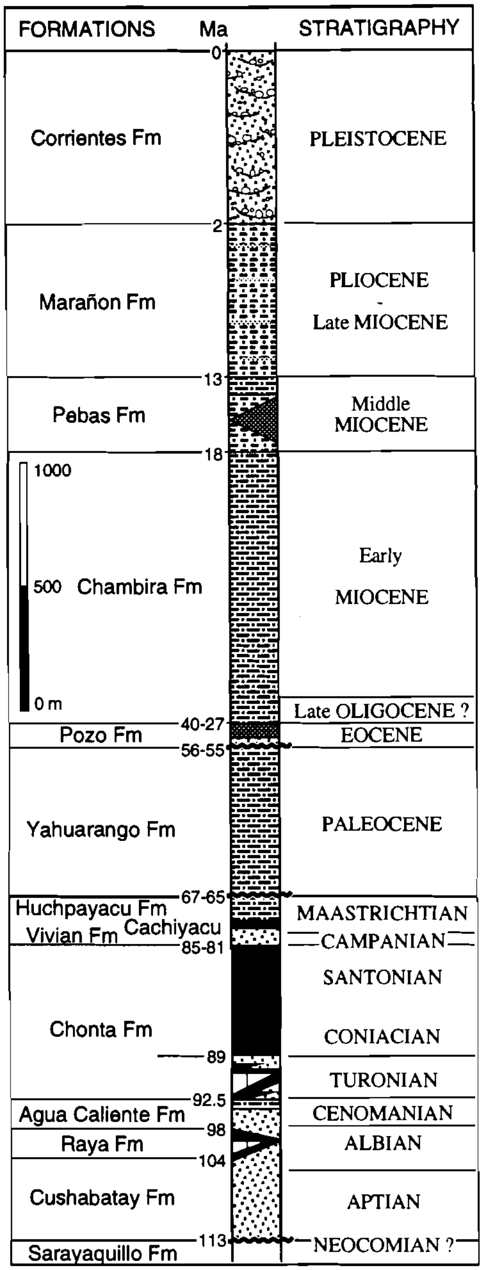

Fig. 1 : Composite stratigraphic log of the Cretaceous and Tertiary series of the Oriente of northern Peru.

from the algorythms elaborated by Stam et al. (1987). "Back" restaures the original thickness of the formations, taking into account the depth-porosity relations obtained from electric logging.

As a whole, tne tectonic subsidence of the Peruvian Oriente is low. Total tectonic subsidence since the Aptian vary from 1.6 km in the Southeast and 3.9 km in the Western part of the basin, with an average rate of tectonic subsidence of ≈ 35 m/Ma (Contreras 1994, 1996). This value is higher than that of the Ecuadorian Oriente (5 to 10 m/Ma, Berrones 1992, Thomas et al. 1995), and lower than that of northwestern Peru during the Cretaceous (30 to 75 m/Ma, Jaillard 1993).

During the Cretaceous, average decompacted sedimentation rates vary between 5 m/Ma (Casa Blanca Fm) to 15 m/Ma (Raya Fm), and 75 m/Ma to 56 m/Ma (Upper Chonta Fm). During the Tertiary and Quaternary, sedimentation rate is maximum during the deposition of the Corriente (160 m/Ma) and Chambira Fms (125 m/Ma) and minimum during the Eocene (9 m/Ma, Pozo Fm).

During the Cretaceous, the average subsidence rates vary between 1 m/Ma (Casa Blanca Fm) to 4 m/Ma (lower Vivian Fm), and 43 m/Ma (Cushabatay Fm). During Tertiary and Quaternary times, they range from 101 m/Ma (Chambira Fm) to 9 m/Ma (Corrientes Fm).

The subsidence rates also vary in space, evidencing a decreasing trend towards the East, SE and NE. During Late Albian and Cenomanian (Agua Caliente Fm), the subsidence rate in the western areas locally reached 35 m/Ma, whereas it is only of 6 m/Ma near the eastern border (fig. 3). During the Paleocene, subsidence rate varied from more than 90 m/Ma in the West to less than 10 m/Ma in the East of the basin. Finally, during the Early Miocene, subsidence rate was more than 160 m/Ma in the northwest, and less than 20 m/Ma in the southern part of the studied area (fig. 3).

TECTONIC HISTORY : INTERPRETATION AND DISCUSSION.

Three major tectonic periods can be distinguished in the evolution of the basin. Each period begins with a high subsidence stage followed by a slowdown or uplift (fig. 2).

The first period corresponds to the Cretaceous (113-65 Ma). The initial subsidence (Aptian-Albian) coincides with the Mochica tectonic period (≈ Albian, Mégard 1984), whereas the uplifts and very weak average subsidence observed during latest Cretaceous times are partially coeval with the Peruvian compressional period (Coniacian-Campanian, Steimann 1929, Jaillard 1993, fig. 2). The depocenter is located near the center of the basin (fig. 3). Detailed analysis suggests that NE and NW-trending paleogeographic structures controlled the subsidence pattern. The low average subsidence rate (≈ 12 m/Ma) and the lack of significant initial subsidence suggest that there was no significant crustal stretching, the Oriente Basin behaving as a stable pericratronic, distal back-arc basin.

The second period (65-28 Ma, Paleogene) began with a drastic increase of the tectonic subsidence (Paleocene) and ended with a slight but long-termed uplift (Oligocene hiatus, fig. 2). During this stage, the depocenters migrated toward the West or Northwest, expressing the flexure of the continental crust due to the incipient crustal shortening and thickening of the paleo-Andes (fig. 3). The subsidence pulse of the beginning of this stage is poorly understood. It could be related to the end of the Peruvian compressional phase. The basal disconformity of the Pozo Fm coincides with the Late Paleocene-Early Eocene contractional Incaic phase. The moderate average subsidence rate (≈ 27 m/Ma), the link between subsidence and compressional tectonic phases and the pattern of the isosubsidence curves suggest that the Oriente basin was submitted to a flexural subsidence regime. This period is regarded as intermediate between the former pericratonic and the subsequent foreland periods.

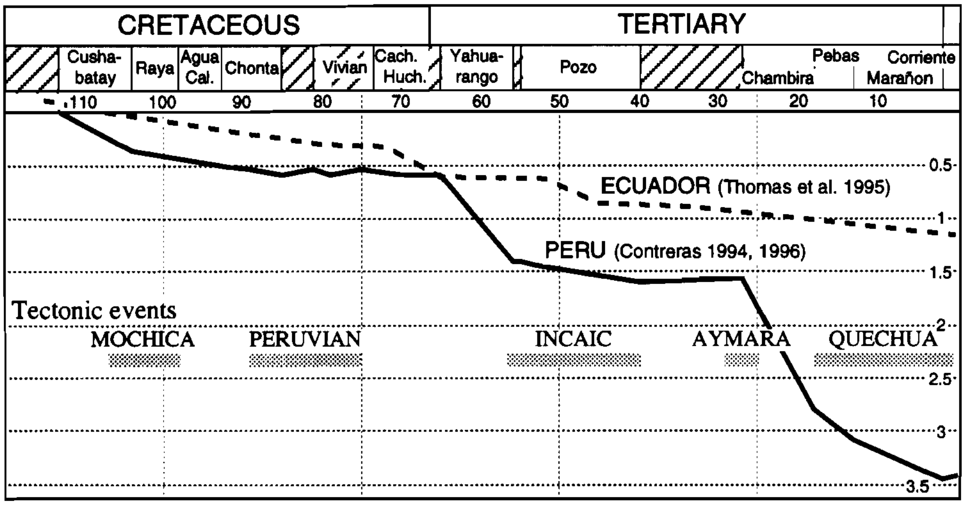

Fig. 2 : Average tectonic subsidence of the Oriente Basin of northern Peru and Ecuador.

The third period (28-0 Ma, Neogene) recorded a dramatic acceleration of the tectonic subsidence (Early Miocene), followed by a slowdown of subsidence (Middle Miocene-Pliocene) and then an uplift of the basin (Pleistocene). The beginning of this period coincides with an important compressive tectonic phase (Sébrier et al. 1988, Sempéré et al. 1990) and with the creation of the Miocene Andean intermontane basins (Marocco et al. 1995). The uplift recorded in the latest Pliocene-Pleistocene could correspond to the general and fast uplift of the whole andean chain since ≈ 6 Ma (Sébrier et al. 1988, Laubacher & Naeser 1994). On maps, the pattern of isosubsidence curves is disturbed, due to the incipient deformation of the subandean zone, located on the western border of the basin (fig. 3). The relatively high average subsidence rate (≈ 67 m/Ma) indicates that flexural subsidence dominates, and that the Oriente basin of Peru has become a foreland basin.

Thomas et al. (1995) identified comparable periods in the Oriente Basin of Ecuador. Their first period (108-72 Ma) seems to correspond to our first stage. However, Thomas et al. (1995) ascribed the whole Tena Fm to the Maastrichtian, while it most probably spans the Maastrichtian and Paleocene stages (Jaillard et al. 1995). Therefore, they determined a strong subsidence rate for the Maastrichtian (35-40 m/Ma) which they include into the second stage, and a hiatus during the Paleocene, which appears as a period of high subsidence in Peru (fig. 2). The age discrepancy about the beginning of the second stage (fig. 2) probably arises from the poor stratigraphic constraints about the Oligocene times. In the Oriente of Peru, the badly documented Oligocene hiatus has been mostly assumed on regional considerations (Contreras 1994).

Our results are in agreement with the interpretation of Thomas et al. (1995) of a flexural mechanism for the subsidence, typical of a foreland basin, from the beginning of the second period onwards. However, problems remain unsolved. (1) There are growing evidences of Senonian contractional deforma-

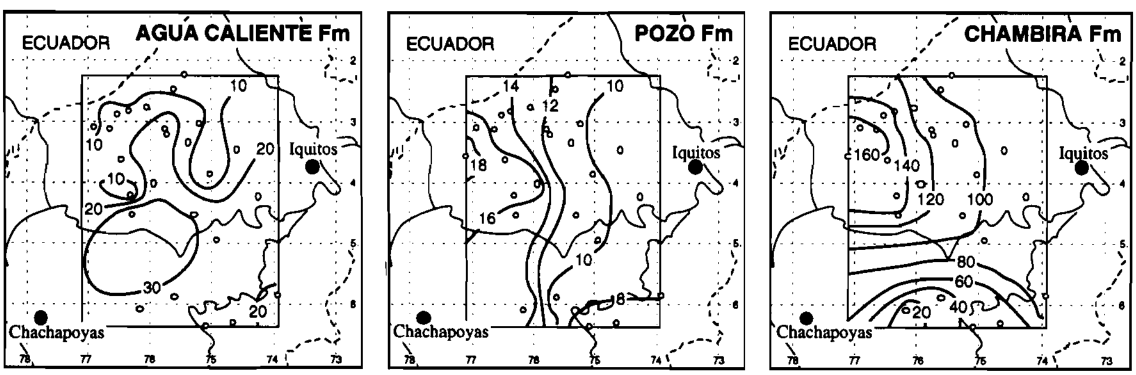

Fig. 3 : Tectonic subsidence rates during Middle Cretaceous, Eocene and Early Miocene times.

tions in the forearc zones, which are not recorded in the subsidence history of the Oriente basins of northern Peru and Ecuador. (2) The hiatuses that follow the subsidence pulses occur in most parts of the Oriente basins and are more frequent and important on their western border. Therefore, it seems difficult to interpret them as due to the migration of the flexural forebulge (Thomas et al. 1995). (3) In Ecuador, the subsidence seems to have not increased during the third stage (fig. 2), which is a period of rapid shortening in the subandean zone.

Therefore, it is necessary to specify the age and tectonic significance of the Tertiary deposits of the Oriente basins, in order to check wether a simple flexural model can account for the subsidence history of the Andean eastern basins at this time.

REFERENCES

Allen, P.A. & Allen, J.R. 1990. *Basin Analysis. Principles and applications.* Blackwell, 450 p., Oxford.

Berrones, G. 1992. Estudio de la subsidencia de la Cuenca oriental ecuatoriana entre el Jurásico superior y el Reciente. *Simp. Nacion. «Investigación y desarrollo tecnológico en el área de hidrocarburos»*, Conuep & Petroproducción, eds., 2, 937-968, Quito.

Contreras, C. 1994. *Subsidencia tectónica durante el Terciario en la cuenca Marañon.* Orstom-Petroperú technical agreement, unpubl. report, 19 p., Lima.

Contreras, C. 1996. *Subsidencia tectónica durante el Cretáceo en la cuenca Marañon.* Thesis Universidad Nacional Mayor de San Marcos, 190 p., unpubl., Lima.

Haq, B.U., Hardenbol, J. & Vail, P.R. 1987. Chronology of fluctuating Sea levels since the Triassic. *Science*, 235, 1156-1167.

Hoorn, C. 1993. Marine incursions and the influence of Andean tectonics on the Miocene depositional history of northwestern Amazonia : Results of a palynological study. *Palaeogeogr., Palaeoclim., Palaeoecol.*, 105, 267-309.

Jaillard, E. 1993. L'évolution tectono-sédimentaire de la marge péruvienne au Crétacé supérieur et Paléocène et ses relations avec la géodynamique. *Bull. Soc. géol. France*, 164, 819-830.

Jaillard, E. et al. 1995. *Síntesis estratigráfica y sedimentológica del Cretáceo y Paleógeno de la cuenca oriental del Ecuador.* Convenio Orstom-Petroproducción, unpubl. report, abstract, 25 p., Quito.

Kummel, B. 1948. Geological reconnaissance of the Contamana region, Peru. *Geol. Soc. Am. Bull.*, 59, 1217-1266.

Laubacher, G. & Naeser, C.W. 1994. Fission-track dating of granitic rocks from the Eastern Cordillera of Peru : evidence for late Jurassic and Cenozoic cooling. *J. Geol. Soc., London*, 151, 473-483.

Marocco, R., Baudino, R. & Lavenu, A. 1995. The intermontane Neogene continental Basins of the Central Andes of Ecuador and Peru : Sedimentologic, tectonic and geodynamic implications. *Am. Ass. Petrol. Geol. Mem.*, 62, 597-613.

Mathalone, J.M.P. & Montoya, M. 1995. Petroleum geology of the Sub-andean Basins of Peru. *Am. Ass. Petrol. Geol. Memoir*, 62, 423-444.

Mégard, F. 1984. The Andean orogenic period and its major structures in Central and Northern Peru. *J. Geol. Soc., London*, 141, 893-900.

Salas, G. 1991. Factores geológicos de control de acumulación de hidrocarburos en las cuencas del Oriente peruano. *IV Simp. Bolivar. "Exploración petrolera en las cuencas subandinas"*, 2, 15 p., Bogotá.

Sclater, J.G. & Christie, P.A.F. 1980. Continental stretching: an explanation of the past-mid-Cretaceous subsidence of the central North Sea basin. *J. Geophys. Res.*, 85 (B7), 3,711-3,739.

Sébrier, M., Lavenu, A., Fornari, M. & Soulas, J.-P. 1988. Tectonics and uplift in Central Andes (Peru, Bolivia and Northern Chile) from Eocene to present. *Géodynamique*, 3, 85-106, Paris.

Sempéré, T., Hérail, G., Oller, J. & Bonhomme, M. 1990. Late Oligocene-early Miocene major tectonic crisis and related basins in Bolivia. *Geology*, 18, 946-949.

Stam, B., Grandstein, F., Lloyd, P. & Gillis, D. 1987. Algorythms for pororsity and subsidence history. *Comput. Geosci.*, 13, 317-349.

Steckler, M.S. & Watts, A.B. 1978. Subsidence of the Atlantic-type continental margin off New York. *Earth Planet. Sci. Lett.*, 41, 1-13.

Steinmann, G. 1929. *Geologie von Peru.* Karl Winter ed., Heidelberg, 448 p.

Tarazona, A. 1985. Palinología de la Formación Cushabatay del Pongo de Tiraco, Oriente peruano. *I Simp. Nac. Carbón*, 20 p., Lima.

Thomas, G., Lavenu, A. & Berrones, G. 1995. Evolution de la subsidence dans le Nord du bassin de l'Oriente équatorien (Crétacé supérieur à Actuel). *C. R. Acad. Sci., Paris*, 320, IIa, 617-624.