SEDIMENTARY MODEL FOR THE ORIENTE BASIN OF ECUADOR DURING THE CRETACEOUS.

Etienne JAILLARD (1)

(1) ORSTOM, TOA, UR 13, 209-213, rue La Fayette, 75480 Paris cedex 10, France.

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During the Cretaceous, the Andean margin of Peru and Ecuador comprised arc and forearc zones, a subsident western trough, an axial threshold, and a shallow marine to continental eastern basin, often named the Oriente basin. Therefore, the latter represented the easternmost marine area of the active margin.

The mainly marine Albian-Maastrichtian succession of the Oriente Basin of Ecuador (Napo Gp, fig.) is marked by four conspicuous facies (Jaillard et al. 1995). The first one consists of massive transgressive, often glauconitic sandstones with erosional base. The second one is made of thin-bedded bioclastic limestones with erosional base, deposited in an open marine shallow shelf environment. The third one is constituted by unbioturbated laminated black shales deposited in a marine, very low-energy, disoxic to anoxic environment. The fourth facies is represented by massive laminated and unbioturbated limestones deposited on a very low energy, disoxic marine shelf. Other facies include open marine marls, marine sand sheets and prograding sandstones.

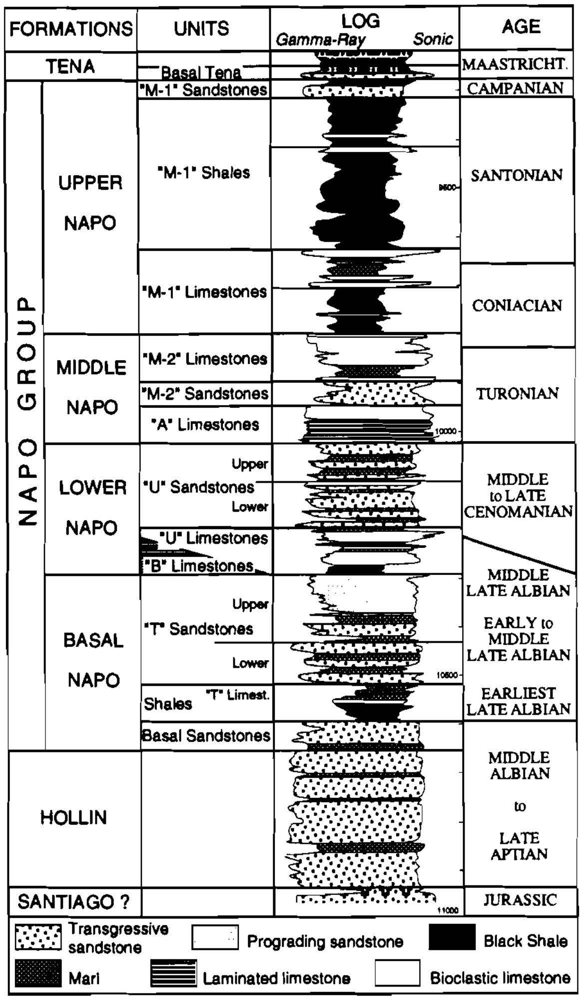
Such a facies succession express the alternation of open marine environments with moderate energy, and restricted low-energy depositional periods. This alternation can be explained through the dynamics of the marine Cretaceous sedimentation of the Oriente basin, controlled by palaeogeographic and climatic features, and by the creation rate of accomodation space.

CHARACTERISTICS OF THE ORIENTE BASIN OF ECUADOR

Palaeogeography. The Oriente basin is located on the eastern side of the South American continent. It was therefore protected from the eastward blowing dominant winds and eastward migrating tropical storms (Whalen 1995). This situation was also responsible for the occurrence of upwellings currents that induced a high planctonic productivity zone and, therefore, an O_2 depleted layer in the water column (Arthur & Sageman 1995). This latter could invade the neighbouring shallow platform, namely the Andean basins, during important sea-level rises, provoking the deposit of anoxic beds (Wignall 1991). Finally, the upwelling of cold water contributed to the inhibition of sedimentary production, and thus favoured the preservation of the organic matter. Several types of topographic thresholds protected the Oriente Basins from the open marine influences. During at least Albian times, a locally emergent volcanic arc developed. During Senonian times, contractional movements produced the emergence of part of the present-day coastal areas. Finally, paleogeographic highs, such as the "Marañon geanticline" acted as efficient thresholds during most of the Cretaceous. These barriers limited significantly the oceanic influences. Most of the marine Cretaceous deposits of the basin are of shallow marine environment. Therefore, the basin was very shallow and its average slope was very low. This feature probably favoured the damping out by friction over the sea-bottom of the open marine factors such as swell, tides, storms and currents. In contrast, the very low gradient may have induced local high velocity tidal currents, since tide surges covered large horizontal distances, even with microtidal regime (Tucker & Wright 1990).

These characteristics altogether explain that the basin was generally protected from the oceanic energetic factors, and that most of the sediments were deposited in very low-energy conditions (Irwin 1965, Friedman & Sanders 1978).

Climate. "Middle" and early Late Cretaceous times were a period of greenhouse climate (Hallam



Cretaceous series of the Oriente Basin of Ecuador.

1985). At this time, the Oriente Basin of Ecuador located in the equatorial zone (Ross & Scotese 1988), was probably submitted to a wet and hot climate. The latter was responsible for the development of a dense vegetal cover on the continental areas that inhibited mechanical erosion, explaining partly the scarcity of coarse detrital particles in the Cretaceous sedimentation.

The hot temperatures induced the formation of a superficial layer of warm, low density water. Heavy rains fed large rivers that flowed into the basin, inducing the formation of a superficial wedge of hyposaline, low density water, reinforcing the density contrast due to the temperatures. Because the lack of significant energetical factors prevented the mixing of this superficial layer with the denser deep waters, the water column was then marked by a thermo-haline stratification that limited or even inhibited the circulation and oxygenation of the lower layer.

Tectonics. The Oriente Basin experienced a low tectonic subsidence rate during the Cretaceous, ranging from 4 to 10 m/Ma, according to the areas (Berrones 1994, Thomas et al. 1995).

Late Albian is a period of contractional deformation in Peru, which can explain the arrival of noticeable clastic amounts in the Oriente Basin («T» sandstones). Coniacian-Santonian times coincide with the beginning of the Peruvian compression that must have triggered the flexural subsidence of the Eastern basins. The high sedimentation rate observed in the Maastrichtian can be related to the renewal of flexural subsidence due to the Campanian tectonic event. The latter can account for the arrival of clastic sediments during Campanian and Maastrichtian times.

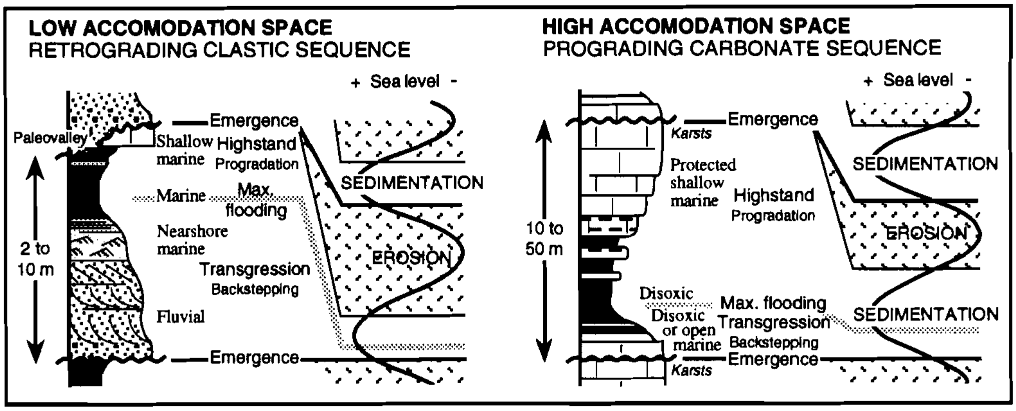
Eustatism. When subsidence is low as in the case of the Oriente basin of Ecuador, the accomodation space variations are nearly coeval with the sea-level changes (Jervey 1988). In the same way, if the sediment input is low, the sedimentary accumulation is low and the facies evolution roughly reflects the thickness of the water column (Jervey 1988).

The high-energy, open marine facies are restricted to the transgressive deposits. During eustatic trangressions, marine influences (swell, currents, tides) were able to enter into the basin, because of its flat topography, and of the low sedimentation rate that did not allow the rapid fill of the accomodation space. This gave way to the reworking and deposition of relatively high energy nearshore sands (Nummedal & Swift 1987), or to the sedimentation of shallow open marine limestones. Both types of deposits overly erosional surfaces formed during the previous emergence period and/or by nearshore wave activity.

DEPOSITIONAL SEQUENCES OF THE CRETACEOUS MARINE SUCCESSION

Two end-member types of depositional sequences can be recognized in the Oriente Basin.

Retrograding sandstone sequences are characterized by an erosional base (SB+TS), an important clastic fraction generally represented by glauconitic sandstones, a clear transgressive vertical facies succession (TST), a shaly maximum flooding (MF), a reduced thickness (2-10 m) and the lack or reduction of prograding deposits (HST). They are interpreted as deposited during periods of low creation rate of accomodation space (Cenomanian, Late Santonian-Early Maastrichtian). Because of the lack of subsidence, only the major eustatic rises reached the basin. The lack of creation of accomodation space provoked the emergence of the basin early in the eustatic cycle, and prohibited the deposition of prograding HST. The



Main types of depositional sequences in the Cretaceous marine series of the Oriente Basin.

abundance of clastic material can be due to the long emergence periods that allowed the progradation of continental clastic systems, and to erosion and reworking of the marine or continental former deposits. Tectonic activity and subsequent rejuvenation of reliefs (Late Albian, Campanian) can also have increased the clastic supply, which inhibited the production of carbonate sediments. Good examples are represented by the "T" (lower part), "U", "M-2"?, "M-1" and Basal Tena sandstones.

Prograding carbonate sequences are relatively thick (10-50 m), predominantly carbonated sequences with erosional base (SB). The TST can be either thin and constituted by calcarenites and/or bioclastic marls, or thick and made up of laminated, anoxic carbonates, depending on the subsidence and sea-level rise rates. The MF is expressed by disoxic marls or shales, and the HST is represented by thick limestones made of stacked shallowing upward parasequences. They are interpreted as deposited during periods of relatively rapid creation of accomodation space (Late Albian, Turonian-Early Santonian). The high relative sea-level provoked the continentward shift of the shoreline, the retrogradation of the continental clastic systems and allowed the carbonate production. Substantial accomodation space allowed the deposition, before emergence, of HST much thicker than the TST. Relatively short emergence hiatuses allowed the preservation of the HST and minimized the production of detrital particles. Good examples of these sequences are the lower "T", "A" and "M-2" limestones. During major sea-level rises (Late Albian, Early Turonian), the O_2-depleted waters of the outer shelf overwhelmed the basin, provoking deposition of dysoxic to anoxic carbonated TST ("B", "A" limestones).

Intermediate cases are represented by two types of sequences. (1) Thick prograding clastic sequences formed during periods of high rate of creation os accomodation space, and of important clastic supply. Both parameters seem to have been controlled by tectonic events (Late Albian Mochica phase for the «T» sandstones, Senonian Peruvian phase for the Tena Fm). (2) Aggradational stacks of thin retrogradational carbonated parasequences («C», upper "T", "U" limest.) seem to correspond to periods of low rate of creation of accomodation space and relatively high average sea level. Due to the reduced accomodation space, the TST is well-expressed, but only the basal HST is preserved below the SB erosional surface. The relatively high sea level account for the scarcity of detrital material and the development of carbonates.

PALAEOECOLOGY OF THE ORIENTE BASIN

Because of palaeogeographic and climatic features, the sedimentological behaviour of the Oriente epeiric basin of Ecuador was comparable to that of a closed shallow sea and shares some features with lakes. The Oriente Basin was protected from oceanic influences by paleogeographic and topographic features. Climatic factors were responsible for the density stratification of the water-column. Wind waves, local storms and the 02-rich river water were able to oxygenate only the superficial water layer. As a consequence, in stable conditions, the isolated cold, saline, dense deep waters could become rapidly anaerobic and promoted anoxic deposits.

Stratification of the water column can also account for the peculiar biota of distal parts of the Andean Basin. During sea-level rise, the thickness of the hyposaline superficial layer was probably minimum, due to the entry of marine energetic factors, and the reduction of continental areas and correlative decrease of fresh water sources ; the fauna was dominantly marine. During highstands, the upper water wedge developed, inducing the development of euryhaline, or mixed, hyposaline and marine faunas. During sea-level drops, the upper low-density water wedge thickened due to the decraese of marine influences, the enlargement of drainage areas and increase of fresh water sources; fresh water to brackish fauna was dominant. Finally, the beginning of lowstand periods could be marked by a lacustrine stage, due to the disappearance of the saline wedge and predominance of the fresh water input. To consider such peculiar conditions may contribute to solve recent controversies about the palaeoecology of some Andean basin fauna (e.g. Gayet et al. 1993, Rouchy et al. 1995).

CONCLUSIONS

The low-energy character of the Cretaceous deposits of the Oriente Basin of Ecuador can be accounted for by mainly paleogeographic factors (western margin of a continent, topographic barriers, gradient of the basin). These, together with climatic factors due to the equatorial latitude (temperature, heavy rains, large rivers) induced an environment protected from the open marine influences and a thermohaline stratification of the water column, which favoured the deposition and preservation of organic matter.

The low subsidence rate and a low sediment supply recorded in the Oriente Basin influenced the nature of the depositional sequences. On one hand, a high (respectively low) rate of accomodation space creation controlled the deposition of mainly progradational (respectively retrogradational) sequences. On the other hand, a high (respectively low) relative sea level and/or a weak (respectively important) tectonic activity induced a low (respectively important) clastic supply, and the deposition of carbonate (respectively clastic) sequences.

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