

NEOGENE EVOLUTION OF THE MAIN ECUADORIAN FORE-ARC SEDIMENTARY BASINS AND SEDIMENT MASS-BALANCE INFERENCES

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INTRODUCTION

The Ecuadorian fore-arc region, known as the physiographic “Coastal Region”, is characterised during Neogene times by the development of four sedimentary basins that are from North to South : the Borbon basin, the Manabi basin, the Progreso basin and the Gulf of Guayaquil basin (fig. 1). All these basins are related to dextral shear affecting the coastal region in response to the oblique subduction at the Ecuadorian trench. In three of them (Manabi, Progreso and Gulf of Guayaquil), extensive hydrocarbon exploration and cartography have been carried out by different petroleum companies, Ecuadorian administration and authors (among others Faucher and Savoyat 1973 ; Baldock, 1982 ; Evans and Whittaker, 1982). This yields to numerous data upon the Neogene deposits of these basins although different stratigraphy and formations names were applied. We present and discuss in this paper the tectono-stratigraphic evolution and correlation, as well as the sediment mass-balance calculation, that we have inferred from our work as part of the cooperation convention between the Ecuadorian state petroleum company PETROPRODUCCION and the IRD (French Research Institute for the Development in cooperation).

NEOGENE FORE-ARC TECTONO-STRATIGRAPHY

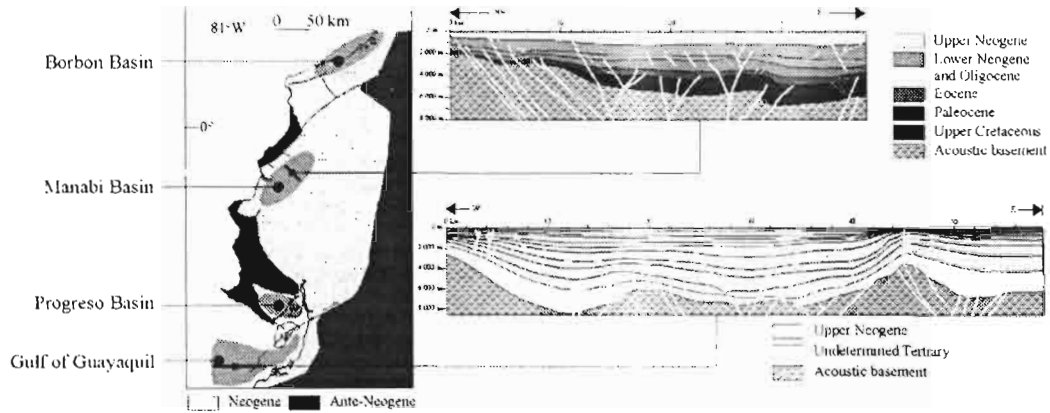


Fig 1 : Localisation and cross sections of the main Neogene Fore-arc Basins

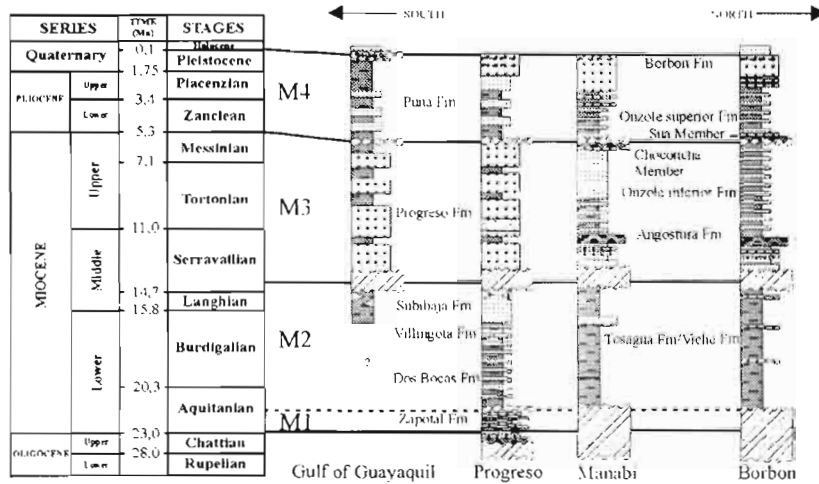


Fig 2 : Correlation between litho-stratigraphic columns of the main ecuadorian fore-arc basins

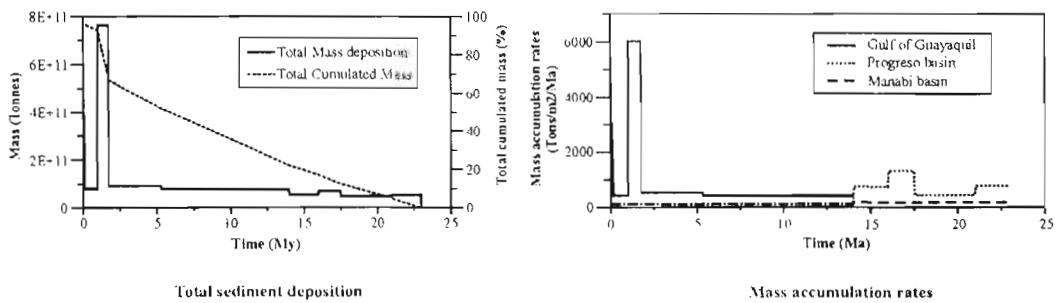


Fig 3 : Total net sediment deposition and Mass accumulations rates in the main Ecuadorian forearc sedimentary basins

The stratigraphy of the Ecuadorian fore-arc sedimentary basins may be divided in 4 mega-sequences, namely M1 to M4, separated by unconformity and possible hiatus (fig. 2). The M1 sequence is formed by conglomerate, sandstone and clay in granulometric decreasing sequences, and corresponds to the Zapotal Formation that is only known in the Progreso basin. Its age is referred to the basal Lower Miocene. This sequence is related to the opening stage of the Progreso Basin in a close to North-South extensional trend. The M2 sequence is a rich clayey marine transgressive sequence that reaches 2000-3000 m in the Progreso basin (Dos Bocas, Villingota and Subibaja Formations); and 1000 m in the Manabi and Borbon basins (Tosagua and Viche Formations, respectively). M2 age ranges from the Lower Miocene (Biochronozone NN2) to the Middle Miocene (Biochronozones N9-N10). It corresponds to a generalized extension in the Coastal region. The M3 sequence is a thick sandy, silty and muddy sequence

ranging in age from the Middle Miocene (Biochronozone N9-N12) to the Upper Miocene (Biochronozone N16-N17). It corresponds to the Progreso Formation of the Progreso and Gulf of Guayaquil Basins. In the Progreso Basin, it is a regressive sequence formed by shore and beach sandy deposits; whereas it corresponds in the Gulf of Guayaquil to a transgressive sequence marked by micro-conglomerate and sandy deltaic channel that pass upward to deltaic silty mud, and is linked to the first stage of opening of the Gulf of Guayaquil basin in a transtensive way along the Dolores-Guayaquil Megashear (Deniaud et al., 1999). The same double evolution can be seen in the Manabi and Borbon. In the Manabi Basin, M3 is a regressive sequence that starts with the sandy shore deposits of the Angostura Formation, is followed by the silty deposits of the Lower Onzole Formation, and ends with the 50 meters thick regressive sandy and conglomeratic Choconcha Member (Benitez, 1995). In the Borbon Basin, it forms a transgressive sequence starting with the sandy Angostura Formation and ending with the deepening up silty muddy Lower Onzole Formation (Evans and Whittaker, 1982). The M4 sequence corresponds, in the Progreso and Gulf of Guayaquil basins, to the Puna Formation which age ranges from the top Upper Miocene (Biochronozone N18) to, respectively, the top Upper Pliocene (Biochronozone N21) and the actual. In the Progreso basin it forms a regressive sequence of beach and swamp and deltaic muddy deposits that leads to the emergence of the basin, whereas in the Gulf of Guayaquil, it forms a thick sandy and muddy deltaic transgressive sequence directly related to the main opening stage of the Gulf of Guayaquil pull-apart basin (Deniaud et al, 1999). In the Manabi and Borbon basins, the M4 sequence corresponds to a regressive sequence which age ranges respectively from the Upper Miocene to the Lower Pleistocene (Biochronozones N18-N21) and from the Upper Miocene to actual. It is formed by the Upper Onzole and Borbon formations. In the Borbon Basin it starts with the transgressive sandy deposits of the Sua Member that disappear eastward. It is followed by the tuffaceous silty and muddy Upper Onzole Formation that pass upward to the beach sand of the Borbon Formation. The Borbon Formation is diachronous with an age ranging from the Lower Pliocene to the Lower Pleistocene (Biochronozones N19-N22) in the Manabi

Basin and from the Upper Pliocene to Actual (Biochronozones N21-N23) in the Eastern Borbon basin where it forms a thick serie also referenced as Cachabi Formation.

SEDIMENT MASS-BALANCE METHODOLOGY

In order to better understand and constrain the evolution of the Neogene fore-arc basin dynamic, we intent to quantify the sediment mass deposition during Neogene time in the Gulf of Guayaquil, Progreso and Manabi basins. This quantification is based on close to 3000 km of seismic lines and wells that were re-interpreted. Seismic sections and well data are used together to construct time (double way travel time) maps of selected horizons at basin scale. Time maps are then converted into depth map using wells data and seismic velocity analysis. Sediment mass estimations are then derived at each point of the basin from the relationship (Métivier, 1996) :

$$M(dt) = (P_g * Z_2 + 0,43 * P_g * 3014 * \exp(-Z_2/3014)) - (P_g * Z_1 + 0,43 * P_g * 3014 * \exp(-Z_1/3014))$$

where $M(dt)$ is the sediment mass in kg for the time interval dt related to the horizons depth Z_1 and Z_2 , and P_g is the theoretical grain density of $2,7 * 10^3 \text{ kg/m}^3$.

The integration on the basin area of the values obtained at each point provides the deposited mass of sediment for the considered time interval. This value can therefore be divided by the time interval and the basin area to obtain accumulation rates of sediment mass per square meters and time. Precision of the method depends on the accuracy of the time depth measurement, on the accuracy of the time to depth conversion law, on the accuracy of the mass estimation equation and on the accuracy of the horizon datation. It should be on the order of 20 % in the Gulf of Guayaquil and 40 % in the Manabi and Progreso basins. The application of this methodology to main Ecuadorian fore-arc basin is however restricted to the area where seismic sections are available. As seismic coverage do not exactly fit the extend of sedimentary basins, and as smaller contemporaneous basins were not surveyed, the total mass of sediment is certainly underestimated. Results of these calculations are shown in figure 3.

RESULTS AND CONCLUSIONS

The stratigraphy and sedimentological features as well as the sediments mass-balance of the main fore-arc basins of the Ecuadorian coastal region can be divided in a three-stage development history.

The first stage extends from the beginning of the Miocene to the Middle Miocene (ca 14 Ma). It is marked by the initiation of the Progreso Basin with the conglomeratic and sandy M1 sequence which marks the starting activity of the La Cruz and Carrizal Basin boarder faults; and by a widespread fine

marine transgressive sedimentation that affects the whole fore-arc area (sequence M2). The Manabi and Progreso basins show their highest mass accumulation rates during this time (fig. 3).

The second stage corresponds to the M3 sequence and extends from the Middle Miocene (ca 14 Ma) to the upper part of the Upper Miocene (ca 5.3 Ma, Biochronozone N18). It marks a major change in the dynamic of the Neogene fore-arc with a drastic change in the sedimentation of the whole fore-arc which turns to a marked sandy sedimentation with shallow water sedimentary structures. The mass accumulation rates show at this times the progressive ending activity of the Progreso and Manabi Basins and the coeval starting development of the Gulf of Guayaquil basin. An important transgression is also known in the Oriente basin of Ecuador at this time.

The third stage corresponds to the last sedimentary cycle that started at the beginning of the Pliocene and goes on actually. It is marked by a double evolution. In the Manabi, Progreso and West Borbon basins a regressive sedimentation took place during the Pliocene that led to the total emergence of these two basins. On the opposite the Gulf of Guayaquil and the eastern part of the Borbon basin undergo strong subsidence with the development of large deltaic or shelf deposits. The main stage of sediment storage in the Neogene fore-arc basins takes place during this stage in the Lower Pleistocene and is coeval with the main stage of development of the Gulf of Guayaquil (Deniaud et al, 1999). The drastic rise of the sedimentary mass stored in the fore-arc basins at this time should be related to an increase of the sediment supply through the erosion of the Andean cordillera which start growing up around 9 to 8 My (Steinmann, 1997) and to the creation of a large space for the sedimentation in the fore-arc. The delay between the Andean cordillera uplift and the sediment storage in the fore-arc may be linked in part to sediment fore-arc bypass to the trench, in peculiar before the main development of the Gulf of Guayaquil Basin.

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