The MARCONI-3 Deep Seismic Reflection profile: structure of the North Pyrenean foreland at the eastern part of the Bay of Biscay

El perfil de sísmica profunda MARCONI-3: estructura del antepaís pirenaico en la parte oriental del Golfo de Vizcaya

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Abstract: The MARCONI-3 profile denotes that the structure of the North Pyrenean foreland at the western part of the Parentis Basin consists of a wedge of uppermost Cretaceous to Cenozoic synorogenic sediments lying on the top of a thinned continental crust with a major Mesozoic Basin to the north, the Parentis Basin, and a coeval structural high to the south, the Landes High. The Parentis Basin appears bounded southwards by a major normal fault. It is filled by a thick carbonate succession affected by a salt ridge and diapirs formed during the Albian-Late Cretaceous and squeezed during the late Eocene-middle Miocene. The Landes High includes a thin pre-Upper Cretaceous cover which, together with the synorogenic sediments, is deformed by a thrust wedge that constitutes the north-Pyrenean front. This overall structure evidences that the Mesozoic extension played an important role both in the location and features of the north-Pyrenean contractional deformation. Specially, the Alpine structure in the Parentis Basin denotes that the Landes High acted as a buffer for the north propagation of the Pyrenean deformation until early Miocene and vanished afterwards during the last stages of Pyrenean development when some basement faults reactivated in the Parentis Basin.

Key words: Bay of Biscay, Pyrenees, Parentis Basin, seismic profile, salt tectonics.

Resumen: *El análisis del perfil MARCONI-3 muestra que, en la parte occidental de la cuenca de Parentis, la estructura del antepaís nor-pirenaico está caracterizado por una cuña sinorogénica de sedimentos cretácico tardíos-cenozoicos que yacen sobre una corteza continental adelgazada con una cuenca mesozoica al norte (Parentis) y un alto estructural contemporáneo al sur (Las Landas). La cuenca de Parentis, limitada al sur por una gran falla normal, está rellena por una potente sucesión carbonatada que aparece afectada por domos y diapiros salinos formados durante el Albiense-Cretácico tardio y estrangulados en el Eoceno superior-Mioceno medio. El Alto de las Landas presenta una delgada cobertera mesozoica que, junto con los materiales sinorogénicos, tan solo aparece deformada por la cuña cabalgante que constituye el frente nord-pirenaico. Esta estructura denota que la extensión mesozoica determinó la localización y las características de la deformación contractiva nord-pirenaica. Especialmente, se constata que el Alto de las Landas actuó hasta el inicio del Mioceno como una pantalla en la propagación hacia el norte de la deformación pirenaica; pantalla que desapareció en los últimos estadios de desarrollo de los Pirineos cuando algunas fallas de basamento de la cuenca de Parentis fueron reactivadas.*

Palabras clave: *Golfo de Vizcaya, Pirineos, Cuenca de Parentis, perfil sísmico, tectónica salina.*

INTRODUCTION

The eastern part of the Bay of Biscay includes the north Pyrenean front and the adjoining North Pyrenean foreland. Topographically, it belongs to a relative depth platform flanked to the north by the Armorican shelf and to the south by the narrow and shallower Basque shelf. Along the boundary between the platform and both shelves two major E-W oriented Cap Ferret and Cap Breton canyons are incised (Figs. 1 y 2). This region is structurally characterized by a thinned continental crust (Pinet *et al.*, 1987) that coincides with the location of the Mesozoic Parentis Basin, where the crust below the uppermost Cretaceous-Cenozoic sediments is only 15 to 19 km thick (Pinet *et al.*, 1987; Ruiz, 2007).

The Parentis Basin, striking E-W, is filled by a thick Jurassic-Lower Cretaceous syn-rift sequence (near 10 km) that overlies a lowermost Jurassic to Upper Triassic evaporites and Lower Triassic-Permian detrital rocks (Mathieu, 1986). All this Mesozoic succession is affected by E-striking normal faults which compartmentalise the basin (Masse, 1997) and bound it both to the north and to the south. It is also deformed by diapirs of Upper Triassic evaporites that pierce both the basin fill (Mathieu, 1986; Mediavilla, 1987) and the overlying Upper Cretaceous to Cenozoic synorogenic deposits (Curnelle y Marco, 1983, Bois *et al.*, 1997;

Masse, 1997). Southwards, the Landes High, is located between the Parentis Basin and the onshore Basque-Cantabrian Basin. It belongs to a plateau uplifted and eroded with an uppermost Cretaceous-Cenozoic thick sedimentary succession that unconformably overlies the Hercynian basement or a thin and partially eroded Triassic-Jurassic cover (Gariel *et al*., 1997). This area belongs to a plateau uplifted and eroded from Early to Late Cretaceous times as evidenced by the absence of Jurassic to Lower Cretaceous sedimentary record both in the Landes High and north Biscay coast prevents to know if such plateau uplift and erosion started before, during the syn-rift event (late Jurassic and Albian times). Both Parentis Basin and Landes High are overlain by a northwards-thinning thick wedge of Upper Cretaceous to Cenozoic synorogenic deposits which are affected by the north-Pyrenean frontal structures along the Basque shelf (Cámara, 1997; Gómez *et al*., 2002).

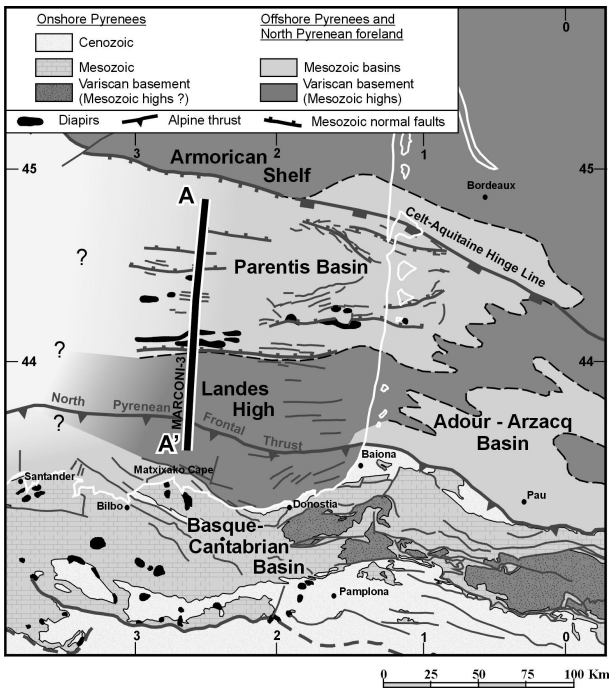

FIGURE 1. *Simplified structural map of the Western Pyrenees combined with an uppermost Cretaceous subcrop map of the adjoining north-foreland (modified from Mathieu, 1986). The map displays the distribution of the main Jurassic-Lower Cretaceous basins and highs developed during the opening of the Biscay Bay. The thick black line shows the location of MARCONI-3 seismic profile (A-A').*

To establish the lithosferic structural features of this portion of the Bay of Biscay as well as to understand the fundamental processes that governed its alpine evolution, a N-trending multichannel deep seismic reflection profile was acquired in September 2003 in the framework of the MARCONI survey (Fig. 1). From this so-called MARCONI-3 profile and the available industrial data, the purposes of this work are twofold: to document the main structural features of the upper crust in the eastern part of the Bay of Biscay; and to discern the role played by the extensional structures, formed during the opening of the Bay of Biscay, in the location and evolution of the Pyrenean contractional structures.

MARCONI-3 PROFILE

The MARCONI-3 profile is about 122 km long and crosses the eastern Bay of Biscay from the Matxitako Cape (north of Bilbo) up to the axis of the Cap Ferret Canyon. Along its trace, it crosses perpendicularly the main structures recognized in the eastern part of the Bay of Biscay except the northern part of the Parentis Basin and the Armorican extensional margin (Fig. 1). From the spatial distribution and thickness of the reflective levels as well as from the geometry of the reflectors, two sectors are distinguished: the Basque slope-Landes High sector and the western part of the Parentis Basin (Fig. 2).

The Basque slope-Landes High sector is characterized by the presence of a thick uppermost Cretaceous-Cenozoic succession, unconformably overlying the Hercynian basement or a thin older Mesozoic cover. This package depicts a wedge-shaped geometry thickening southwards. From a structural point of view, the uppermost Cretaceous-Cenozoic sedimentary wedge and the underlying rocks only appear affected by some minor normal faults and by a major thrust wedge located south of the Cap Breton canyon. This thrust wedge constitutes the North Pyrenean front and is depicted by north-dipping reflectors on top of a north-verging anticline developed on the hanging wall of a north-directed thrust. Its displacement has been evaluated to be about 2 km. Thickness and reflector dip variations in the related foreland syncline denotes that it developed between the late Eocene and early Miocene.

The Parentis Basin appears as a major half graben bounded southwards by a north-dipping master fault called Landes Fault. Basin geometry is characterized by a central ridge (Txipiroi ridge) with Keuper salt and shales in its core. The Jurassic-lower Cretaceous package southwards of this structure is thicker than the other imaged areas of the Parentis Basin. The Mesozoic filling of the basin is affected by folds with a minor wavelength and by Mesozoic extensional faults that generated a system of horts-and-grabens. Diapirs piercing the Mesozoic succession are observed in the northern edge of the basin in relation with these extensional faults. Rym sinclines associated with these diapirs date the active growth of these structures and the partial rise of Txipiroi ridge as Albian-Late Cretaceous.

The Parentis Basin is overlain unconformably by a northwards-thinning uppermost Cretaceous-Cenozoic wedge practically undeformed. The whole deformation corresponds with folds and some faults upon roof diapirs and with the tilted reflectors over the Txipiroi ridge. The package affected by these structures is dated as Late Eocene-Early Miocene. Finally, the Middle Miocene package record the final stages of contractional deformation with the continuation of the Txipiroi ridge rise and the formation of a pop-up by the inversion of the conjugate normal faults that generated the two observed diapirs. The Upper Miocene-Holocene sequence is undeformed.

DISCUSSION AND CONCLUSIONS

The description and geometric analysis of the MARCONI-3 profile show that the present-day structure of the eastern part of the Bay of Biscay results from the succession of two well-differentiated deformational stages: an initial extensional stage, and a younger compressive one.

The first stage is coeval with the opening of the North Atlantic Ocean and the Bay of Biscay. It includes a syn-rift stage in which the Parentis Basin formed from the displacement of a major north-dipping normal fault located along its southern boundary, and a post-rift stage in which diapirs of Triassic evaporites grew close to this major fault. These diapirs led to the development of rym-synclines at their flanks, and their development was accompanied by the formation of a major saline ridge over the crest of the roll-over generated by the major normal fault.

The second compressive deformational stage is coeval with the building of the Pyrenean orogen which led to the development of a foreland basin in the eastern Bay of Biscay at the southern portion of the MARCONI-3 profile. During this stage we can identify an evolutionary trend of the deformation in which two stages can be distinguished. The first one, Late Eocene-Early Miocene, is characterized by the formation of a basement-involved thrust wedge in the innermost parts of the foreland basin, and the squeezing of the diapiric structures formed previously in the Parentis Basin (diapirs and Txipiroi High saline ridge). This resulted in the second episode of active growth of the pre-existing diapirs with formation of secondary near-vertical welds that isolate diapir bulbs from their source layer. The second, Middle Miocene in age, records the final stages of contractional deformation in the Eastern Bay of Biscay. It is a stage characterized by: the continuation of the Txipiroi High saline ridge growth; and the formation of a pop-up in the area comprised between the southern diapirs probably due to the closing of the diapir stems as resulted from the inversion of the conjugate normal faults that generate these two diapirs.

The lack of significant inversion structures in the Parentis Basin, denotes that the Mesozoic Landes High acted as an important buffer for the propagation of the Pyrenean contractional deformation to the north during Late Cretaceous and specially between the Eocene and Early Miocene. The origin of the Landes High deformational buffer is probably related to the different crustal signature that showed this domain in relation to the adjoining Basque-Cantabrian and Parentis basins. In the Landes High the crust was much thicker and stronger that in the adjacent basins. In fact, this difference of thickness acted differently in response to the compressive stresses generated southwards along the Iberian-Eurasia collision boundary.

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REFERENCES

Bois, C., Pinet, B. y Gariel, O. (1997): The sedimentary cover along the ECORS Bay of Biscay deep seismic reflection profile. A comparison between the Parentis basin and other European rifts and basins. *Mémoires de la Société Geologique de France,* 171: 143-165.

Cámara, P. (1997): The Basque-Cantabrian basin's Mesozoic tectono-sedimentary evolution. *Mémoires de la Société Geologique de France,* 171: 187-191.

Curnelle, R. y Marco, R. (1983): Reflection profiles across the Aquitaine basin. En: *A Picture and work atlas. Seismic Expression of Structural Styles* (A.W. Bally, ed.). AAPG Studies in Geology, 2.3.2-11 – 2.3.2.-17.

Gariel, O., Bois, C., Curnelle, R., Lefort, J.P. y Rolet, J., (1997). The ECORS Bay of Biscay deep seismic survey. Geological framework and overall presentation of the work. En: *Deep Seismic study of the Earth's crust. Ecors Bay of Biscay Survey* (Mémoires de la Société Geologique de France, ed.). 171: 7-19.

Gómez, M., Vergés, J. y Riaza, C. (2002): Inversion tectonics of the northern margin of the Basque Cantabrian Basin. *Bulletin de la Société Géologique de France,* 173: 449-460.

Masse, P. (1997): The early Cretaceous Parentis Basin (France). A basin associated with a wrench fault. En: *Deep Seismic study of the Earth's crust. Ecors Bay of Biscay Survey* (Mémoires de la Société Geologique de France, ed.) 171: 177-185.

Mathieu, C. (1986): Histoire géologique du sous-bassin de Parentis. *Bulletin des Centres Recherche Exploration-Production Elf-Aquitaine,* 10(1): 22-47.

Mediavilla, F. (1987): La tectonique salifère d'Aquitaine. Le Bassin de Parentis. *Pétrole et Techniques*, 335: 35-37.

Pinet, B., Montadert, L., Curnelle, R., Cazes, M., Marillier, F., Rolet, J., Tomassino, A., Galdeano, A., Patriat, P., Brunet, M.F., Olivet, J.L., Shaning, M., Lefort, J.P., Arrieta, A. y Riaza, C. (1987): Crustal thinning on the Aquitaine Shelf, Bay of Biscay, from deep seismic data. *Nature,* 325: 513-516.

Ruiz, M. (2007): *Caracterització estructural i sismotectònica de la litosfera en el Domini Pirenaico- Cantàbric a partir de mètodes de sísmica activa i passiva*. Tesis Doctoral, Univ. de Barcelona, 354 p.

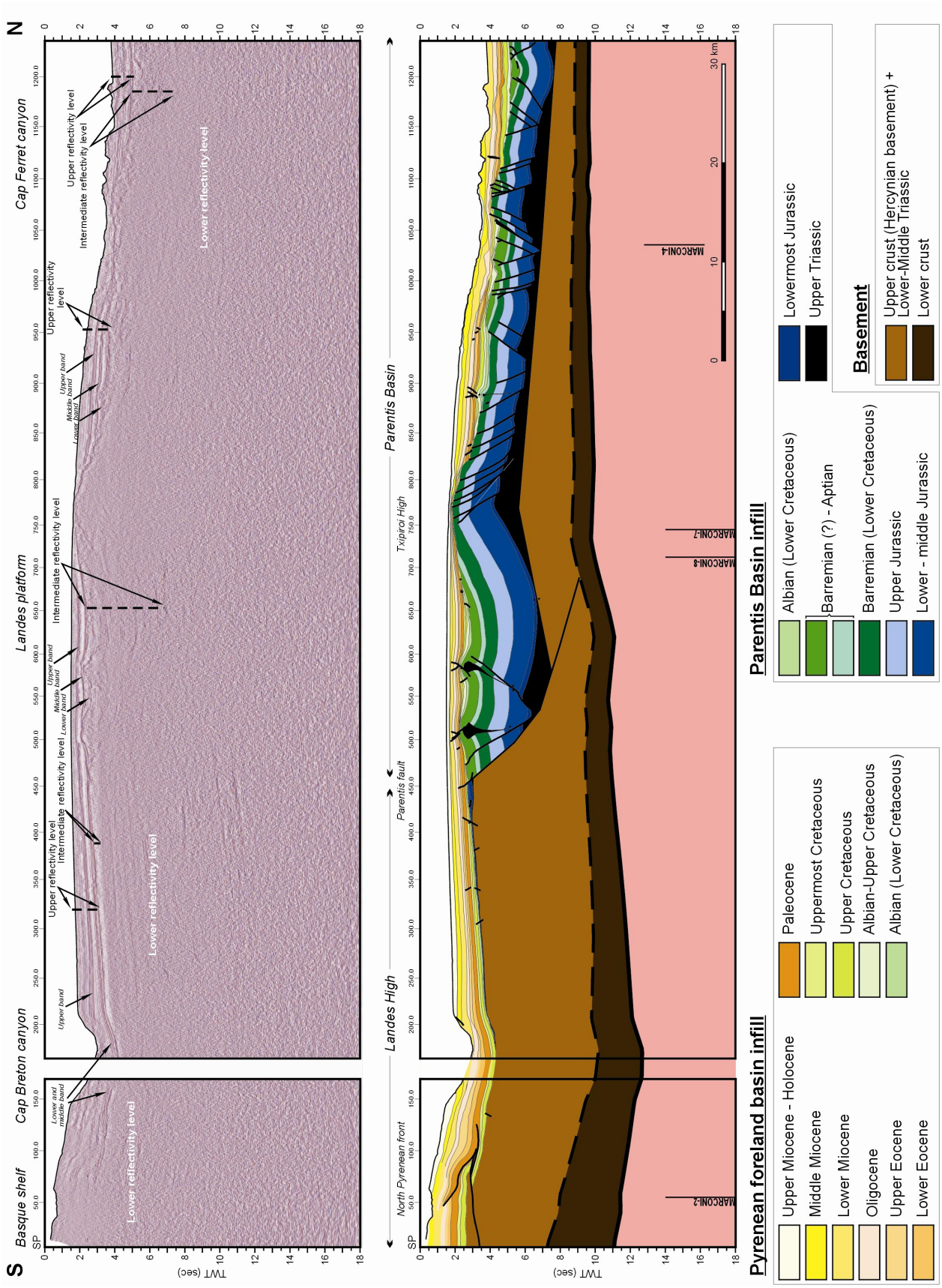

FIGURE 2. ***Migrated two-way travel time section and interpreted line-drawing of the MARCONI-3 deep seismic reflection profile. The main stratigraphic units characterised from reflectivity patterns*** *are depicted in the section.* ***Moho and lower/upper crust boundaries are compiled from Ruiz, 2007.***