Salt tectonics in the Parentis Basin (eastern sector of the Bay of Biscay)

Tectónica salina en la Cuenca de Parentis (sector oriental del Golfo de Vizcaya)

O. Ferrer[1], E. Roca[1], J.A. Muñoz[1] y A. Frankovic[2]

1 Dept. Geodinàmica i Geofísica, Facultat de Geologia, Universitat de Barcelona. 08028 Barcelona. joferrer@ub.edu
2 SHESA, Sociedad de Hidrocarburos de Euskadi, S. A. 48011 Bilbao.

Abstract: Detailed review of seismic data denotes that salt tectonics played an important role in the evolution of the Parentis Basin. Salt structures have been strongly influenced by the thickness of the Mesozoic sequence overlying the Triassic salts. They are widespread and show a more evolved development in the areas where the Jurassic-Lower Cretaceous successions are relatively thin. Thus in the eastern Parentis Basin, at the southern margin of the main half graben, salt ridges, salt walls, diapirs and glaciers occur. In the western part, where the Mesozoic succession is thicker, diapirs are less developed and restricted to the Landes Fault along the southern edge of the basin. On the contrary, salt ridges show a greater size. Salt structures were initially developed at Albian-late Cretaceous times after the syn-rift faults and contemporaneously with the opening of the Bay of Biscay. Subsequently they were rejuvenated during late Eocene-Middle Miocene as the Pyrenean deformation progressed into the northern foreland.

Key words: salt tectonics, Parentis basin, Bay of Biscay, extensional faults, Pyrenean contractional deformation.

Resumen: *La revisión de datos sísmicos muestra que la tectónica salina jugó un papel importante en la evolución de la Cuenca de Parentis. Las estructuras salinas fueron fuertemente influenciadas por el grosor de la secuencia mesozoica suprayacente a las sales triásicas. Muestran un desarrollo más evolucionado en áreas donde la sucesión Jurásico-Cretácico inferior es menos potente. Así en el dominio oriental, en el margen meridional del semigraben principal, existen ridges salinos, paredes de sal, diapiros y glaciares salinos. En el dominio occidental, donde la sucesión mesozoica es más potente, el desarrollo de diapiros es menor y está restringido a lo largo de la Falla de la Landas en el margen sur de la cuenca. Por el contrario los ridges salinos muestran un tamaño mayor. Las estructuras salinas se desarrollaron inicialmente durante el Albiense-Cretácico tardío posteriormente a las fallas syn-rift y contemporáneamente a la apertura del Golfo de Vizcaya, y fueron rejuvenecidas durante el Eoceno tardío-Mioceno medio mientras la deformación pirenaica progresaba en el antepaís septentrional.*

Palabras clave: *tectónica salina, cuenca de Parentis, Golfo de Vizcaya, fallas extensivas, deformación contractiva pirenaica.*

INTRODUCTION

The Parentis Basin is a major intracontinental Mesozoic basin located in the eastern part of the Bay of Biscay between the Landes High to the south and the Armorican Shelf to the north (Fig. 1). It is a deep basin opened westwards to the Bay of Biscay abyssal plain, which is floored by oceanic to transitional crust.

The Parentis Basin is filled by syn-rift Jurassic-Lower Cretaceous carbonate to terrigenous rocks that overlie lowermost Jurassic to Upper Triassic evaporites and Lower Triassic-Permian detrital rocks (Dardel & Rosset, 1971; Mathieu, 1986). Thickness of synrift deposits increases westwards and reaches its maximum values in the hangingwall of the Ibis and Landes major north-dipping normal faults. Above these deposits, the basin fill is overlain by post-rift Upper Cretaceous sequences and, unconformably, by a southwards-thickening wedge of uppermost Cretaceous to Cenozoic sediments belonging to the North foreland basin of the Pyrenees.

The Jurassic-Lower Cretaceous basin fill is affected by E-striking normal faults and by salt diapiric structures cored by upper Triassic evaporites. Diapirs and salt ridges also deform the Upper Cretaceous successions and, in minor degree, the overlying Upper Cretaceous to Cenozoic synorogenic deposits (Curnelle and Marco, 1983; Mathieu, 1986; Mediavilla, 1987; Masse, 1997).

The two rifting episodes that generated the Parentis basin, Permian-Triassic and latest Jurassic-Lower Cretaceous in age, are related to the break-up of Pangea and the opening of the North Atlantic Ocean which led to the development of a transtensional to extensional plate boundary between Iberia and Eurasia (Srivastava *et al.*, 1990). From late Santonian, the faster opening of South Atlantic Ocean produced the northward drift of Africa and, as a consequence, the convergence and later collision between the recently individualised Iberia and Eurasia plates (Rosenbaum *et al*., 2002). This drastic change in the relative motion of Iberia generated the Pyrenean orogen and northwards, in the Parentis Basin area, compression and the development of a portion of the northern foreland basin of this orogen. This contractional regime continued until Middle Miocene when relative motion between Iberia and Eurasia ceased or became imperceptible (Srivastava *et al*., 1990).

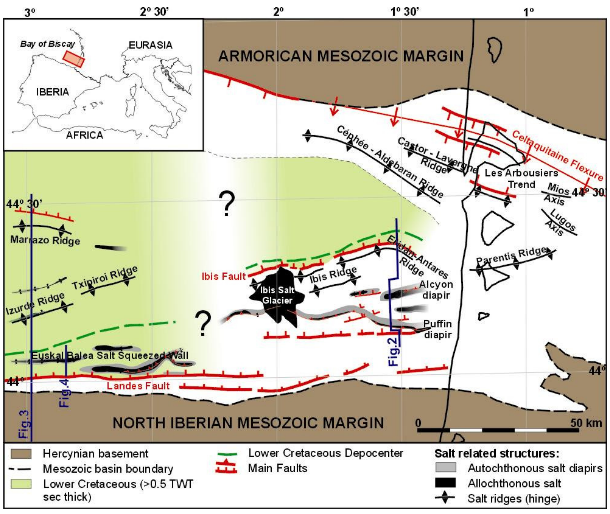

FIGURE 1. *Cenozoic subcrop map of the Parentis Basin with the situation of the main saline structures. Thick black lines and framed numbers show location of seismic profiles given in Figs. 2, 3 and 4.*

The present paper aims at illustrating the main features of the salt tectonics in the Parentis Basin from the description and interpretation of available subsurface data. Salt structures have been identified, dated and the relationships between their evolution and the processes that governed the evolution of the Bay of Biscay-Pyrenees realm deciphered.

SALT TECTONICS IN THE PARENTIS BASIN

In the eastern part of the Parentis Basin, salt structures only occur at the margins of the major half graben located on the centre of the basin which is characterized by very thick lower Cretaceous successions (>0.5 TWT sec.). On the contrary, in the basin margins, the Jurassic-Lower Cretaceous successions are thinner than 1-1.2 TWT sec (Fig. 2).

Salt structures differ in both margins. In the northern margin, they are strongly fractured WNW-trending salt ridges which only affect the Mesozoic sequences. In contrast, south of the Ibis major fault which is the southern boundary of the half graben, salt structures are more complex including salt ridges, but also extruding isolate finger-shape diapirs, salt walls and glaciers. A typical image from this last area is showed in Fig. 2, where three halokinetic structures in different evolutionary stages are showed. The Eridan-Antares ridge developed on top of the Ibis fault. It constitutes the largest diapiric structure recognized in the eastern Parentis Basin. The Alcyon and Puffin diapirs developed on top of minor north-dipping normal faults affecting the Jurassic series. The deep geometry of these normal faults is not well defined seismically, although geometry of Jurassic reflectors suggests that they are detached at the Upper Triassic.

Formation and evolution of the diapiric structures in this southern margin is rather well constrained by the seismic signature of the studied profiles. The thinning of the Albian-Late Cretaceous packages towards the diapir-related anticlines and salt ridges, together with the convergent pattern of the reflectors of this age (Fig. 2), demonstrates that diapir emplacement and the partial rise of these diapir structures took place during the Albian-Late Cretaceous post-rift stage. However, the geometry of the Cenozoic reflectors denotes that these diapiric structures were reactivated during the development of the north-Pyrenean foreland basin. Observed growth strata geometries indicate that diapir related anticlines grew above the pre-existing ridges and diapirs during the Late Eocene-Early Miocene and, afterwards, in some cases, older diapirs were reactivated as reverse faults. These structural features are consistent with the contractive squeezing of older diapiric structures that forced the viscous diapiric rocks to extrude upward generating: a fast growth of the anticlines on top of the diapirs; the formation of new extruding diapirs; and sudden increase of the surface extrusion of viscous material along the diapirs generating widespread overhangs. An example of this last process is well recorded by the asymmetrical salt-glacier located in the central part of the Parentis Basin, (Fig. 1). This saline extrusion, formed during the Albian-Late Cretaceous, clearly expanded during the Eocene and became quickly inactive during the Oligocene probably due to the closing and emptying of the feeding stem.

The Parentis Basin is wider in its western part with a south-bounding major fault (the Landes Fault) clearly shifted to the south in relation to the master fault observed in the eastern domain (Ibis Fault). Furthermore the Jurassic-Lower Cretaceous synrift successions are thicker (3 TWT sec.) and overlie a flat Triassic cover and Hercynian basement. These lasts units only appear slightly tilted to the North close to the Landes Fault where they are also affected by some synthetic normal faults (Fig.3). Above, the Jurassic-Lower Cretaceous synrift successions are affected by ENE-trending folds, diapirs and a large amount of faults that are present in the entire basin. This structural difference between the basement and the cover denotes the presence of a major detachment that should be located in the Upper Triassic mudstones and evaporites.

In this western part of the Parentis Basin, the predominant diapiric structures are salt ridges that constitute the above described ENE-trending folds. In contrast to those observed in the eastern sectors, they show greater wavelength (up to 10 km), amplitude and lateral continuity (between 15 and 20 km). Also, they are not associated to basement-involved extensional faults but to the motion of north-dipping listric extensional faults detached into the Upper Triassic evaporites.

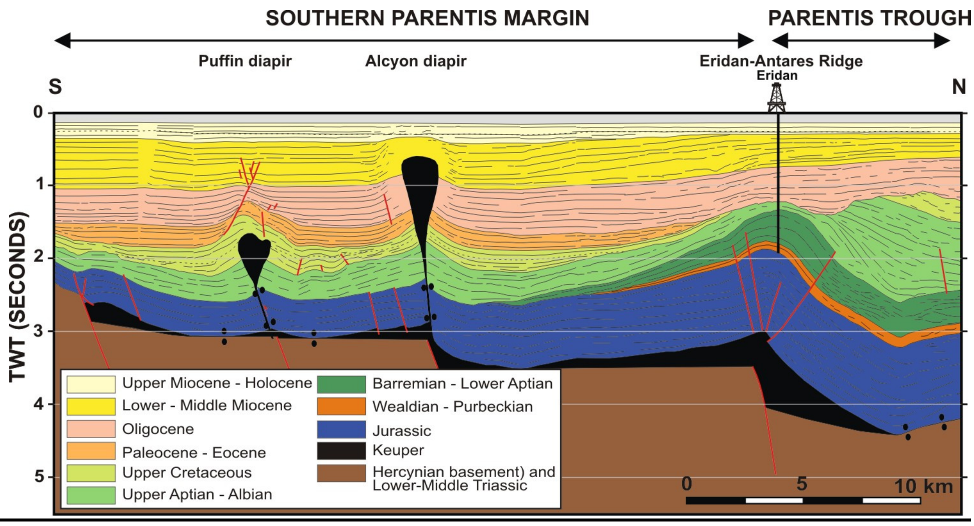

FIGURE 2. *Line-drawing throught the eastern sector of Parentis Basin (see figure 1 for location).*

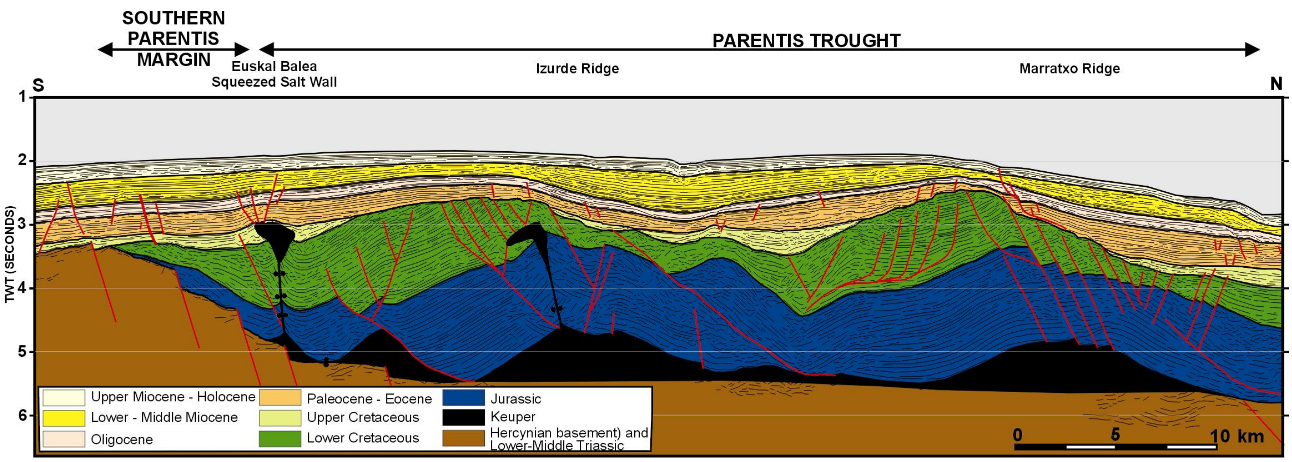

FIGURE 3. Line-*drawing throught the western sector of Parentis Basin (see figure 1 for location).*

These faults produced a significant thinning of the Jurassic-Lower Cretaceous overburden in their footwalls where such salt ridges developed.

The diapirs are less developed than in the eastern sector. They are concentrated close to the Landes Fault along the southern edge of the basin; although they could be also present northwards piercing the salt ridge hinges (Fig. 3). In comparison with the eastern diapirs, their size is clearly smaller and they consist of long narrow salt walls in which diapiric rocks show a near-vertical inverted teardrop shape. All diapirs of the western domain are isolated from its source layer by secondary near-vertical welds (Fig.4).

Despite these structural differences, the seismic signature of the Parentis Basin infill successions (reflector geometry as well as thickness variations around the diapirs) indicates that all the diapiric structures present in the western domain also developed during the Albian-Upper Cretaceous, which is coevally with those observed in the eastern domain.

Similarly, the pre-upper Miocene successions are also folded over the diapiric structures and include growth strata geometries that allow dating a renewed extrusion of diapiric rocks as Late Eocene-Early Miocene. This extrusion was related to Pyrenean compression which closed and emptied the feeding stem of the pre-existing diapirs creating secondary near-vertical welds that isolated the diapir bulb from its source layer. Often it has been observed that this secondary weld acted like a thrust fault after the diapir was completely squeezed during the last stages of the Pyrenean contractional deformation (Middle Miocene) (Fig. 3).

DISCUSSION AND CONCLUSIONS

Analysis of available subsurface data denotes that salt tectonic deformation played an important role in the evolution of the Parentis Basin. Most of the structures observed in the basin are diapiric in origin and consist on salt ridges and diapirs developed on top of the extensional faults affecting the basin fill. These faults affect the Hercynian basement close to the southern edge of the basin but not in the rest of the basin where they are listric and detached into the Upper Triassic evaporites.

The normal faults, and the associated salt ridges, are only developed in the basin areas in which the basement is horizontal or slightly tilted. Its steep geometry and obliquity to the basin margins suggest a transport direction towards the deepest part of the basin; this is, towards the Bay of Biscay oceanic crust. In accordance with these features, we suggest that most listric faults and associated salt ridges were triggered as a consequence of a gravity gliding mechanism developed on the eastern slope of the Bay of Biscay.

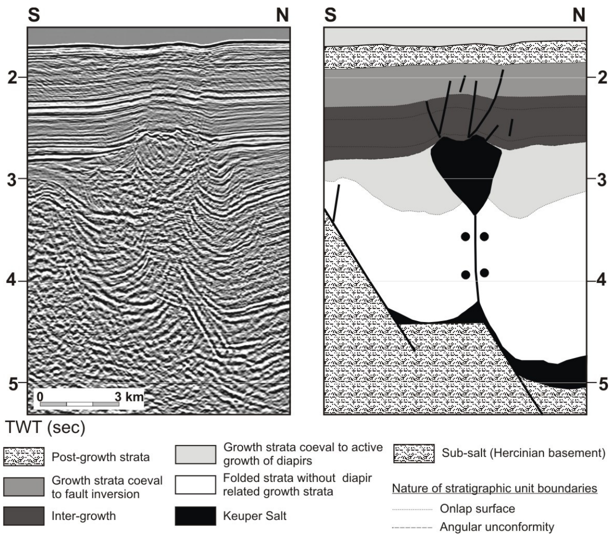

FIGURE 4. *Time-migrated seismic profile and adjoining interpretation showing a squeezed diapir close to the Landes Fault (Western sector; see Fig.1 for location).*

Referring to the differences in the salt tectonic style between the eastern and western domains, they could be explained from the major thickness that shows the syn-rift successions in the western domain. Diapiric rocks have more difficulties to pierce the overlying overburden if it is thicker and, since they do not extrude, they accumulate in the footwall of the extensional faults forming huge salt ridges.

Finally, strata geometries around the diapiric structures clearly indicate that all of them were formed during the Albian-Late Cretaceous; this is during the last extensional stages of Parentis Basin formation and coevally with the accretion of oceanic crust in the Bay of Biscay. Also they denote that, later on, these diapiric structures were reactivated and squeezed during the last stages of the development of the Pyrenees, between the Late Eocene and the Middle Miocene. In relation to this contractional deformation, it is should be noted that the Parentis salt bodies absorbed practically all the shortening transmited from the Pyrenees. There are not inverted normal faults as observed westwards in the Bay of Biscay Abyssal Basin.

ACKNOWLEDGEMENTS

This work was carried out under the financial support of the MARCONI (REN2001-1734-C03-02/MAR) and the MODES-4D (CGL2007-66431-C02-01/BTE) projects as well as the “Grup de Recerca de Geodinàmica i Anàlisi de Conques” (2005SGR-00397). The authors are indebted with Hidrocarburos de Euskadi for providing the seismic and well data used in this work. Comments from J.L. Alonso improved the quality of this work.

REFERENCES

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

Dardel, R.A. and Rosset., R. (1971): Histoire géologique et structurale du bassin de Parentis et de son prolongement en mer. En: *Histoire Structurale du Golfe de Gascogne.* (J. Debyser, X. Le Pichon, and L. Montadero, eds.). Publication de l’Institute Français du Pétrole. Technip, Paris, Vol. I : IV.2.1. - IV.2.28.

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*. (Mémoires de la Societe Geologique de France ed.). 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.

Rosenbaum, G., Lister, G.S. and Duboz, C. (2002): Relative motions of Africa, Iberia and Europe during Alpine orogeny. *Tectonophysics* 359: 117-129.

Srivastava, S.P., Schouten, H., Roest, W.R., Klitgord, K.D., Kovacs, L.C., Verhoef, J. and Macnab, R. (1990) Iberian plate kinematics: a jumping plate boundary between Eurasia and Africa. *Nature*, 344: 756-759.