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Effects of Pyrenean contraction on salt structures of the offshore Parentis Basin (Bay of Biscay)

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Abstract: Structural analysis of old industrial 2D seismic surveys recently reprocessed from the offshore Parentis Basin reveal that salt tectonics played an important role in the basin evolution. Salt structures are mainly located in the edges of the basin, where Jurassic-Lower Cretaceous infill sequences are thinner and allowed salt anticlines and diapirs to form. Salt structures are more evolved in the east. Folds cored by Triassic evaporites and stocks created during Mesozoic times, absorbed almost all the shortening during the Pyrenean orogeny forming squeezed diapirs, salt glaciers, and welds, some of which were later reactivated as reverse faults. No new diapirs formed during the Pyrenean compression and salt tectonics ended with the termination of the Pyrenean orogeny in the middle Miocene.

Keywords: salt tectonics, Parentis Basin, Bay of Biscay, inversion tectonics, Pyrenees.

The Parentis Basin is an E-W oriented intra-continental Mesozoic basin bounded by the Armorican Margin to the north and the North Iberian Margin to the south (Fig. 1A). It is a deep basin with a V shape that opens westwards to the Biscay abyssal plain, which is floored by transitional to oceanic crust (Pinet *et al.*, 1987; Bois *et al.*, 1990; Bois and Gariel, 1994).

The formation of the Parentis Basin is strongly related to Iberian and European plate tectonics. The present shape of the basin was governed by two rifting episodes (Permian-Triassic and latest Jurassic-Early Cretaceous) and by the Pyrenean shortening (latest Cretaceous-middle Miocene).

The two rifting episodes are related to the break-up of Pangea and the opening of the Central Atlantic Ocean, which led to the development of a transtensional to extensional plate boundary between Iberia and Eurasia (Srivastava *et al.*, 1990). In this period, the Parentis Basin formed and was filled by a thick sequence of syn-rift Jurassic-Lower Cretaceous carbonate to terrigenous rocks that overlie lowermost Jurassic to Upper Triassic evaporites and Lower Triassic-Permian detrital rocks (Dardel and Rosset, 1971; Mathieu, 1986; Bitteau *et al.*, 2006).

From late Santonian to middle Miocene, the faster opening of the South Atlantic Ocean produced the northward drift of Africa, which caused 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 produced the Pyrenean orogen and the partial closure of the Bay of Biscay. Located immediately north of this orogenic belt, the southern part of the Parentis Basin tilted southwards and filled with uppermost Cretaceous-Cenozoic sediments as the north Pyrenean foreland basin (Deselgaulx and Brunet, 1990).

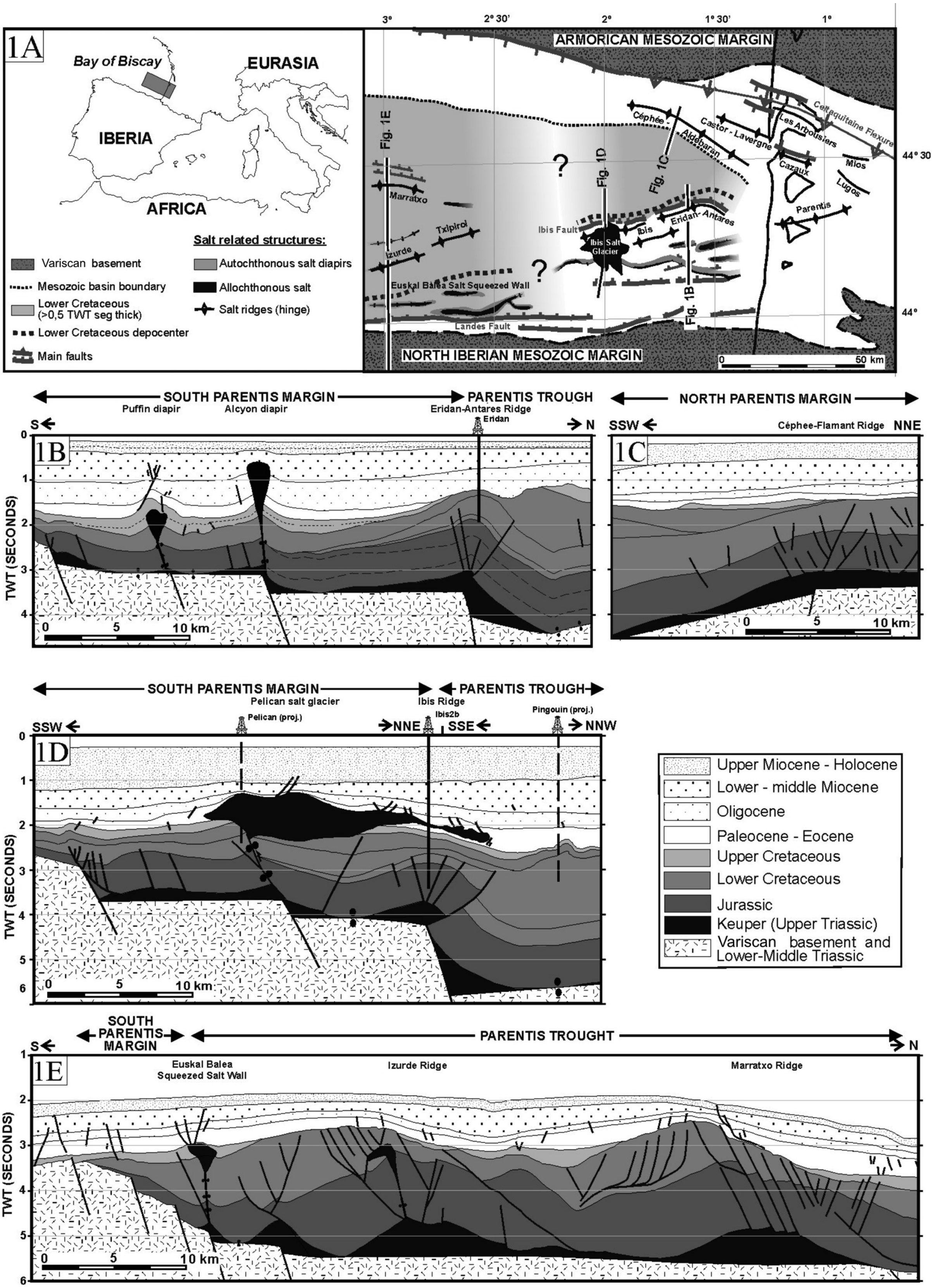

Figure 1. A) Cenozoic subcrop map of the Parentis Basin with the main salt structures and faults. Thick black lines show location of line drawing through the Parentis Basin displayed in figures 1B, 1C, 1D and 1E.

Using conventional seismic time surveys, wells and gravimetric data from the Parentis Basin, the purpose of this work is twofold: 1) to describe and date the main salt structures present in this basin and 2) to decipher the role played by these salt structures during the Pyrenean orogeny.

Dataset and methodology

The results presented in this work have been obtained using a seismic dataset composed of 12 industrial 2D seismic surveys recorded between 1976 and 1988 which have been reprocessed recently. Nearly 300 seismic lines located above the main salt structures have been completed with the ECORS and MARCONI deep seismic reflection surveys, covering practically all the offshore Parentis Basin except for its northern margin where seismic data are more scarce. Lamentably, the quality of the new reprocessed industrial seismic data has often not been sufficient to be able to delimit the roof and the base of the autochthonous salt or the top of basement, so interpretation is speculative in some cases.

Seismic horizons were interpreted using the data from 21 wells drilled in the eastern domain of the basin (Landes Plateau). The lack of well data in the western domain (marginal Landes Plateau) has been resolved by correlating reflectors from the eastern domain.

Description of salt structures

Keuper salt or its welded equivalent underlies the entire Parentis Basin within the study area. The deepest part of the eastern Parentis Basin is the Parentis Trough. The Céphée-Aldeberan Ridge forms the northern boundary of this trough. Southwards from this ridge, the Mesozoic basin fill thickens to a maximum at the Ibis Fault, where Lower Cretaceous sediments reach a two-way time thickness of >0.5 s. Having a displacement of 1.5 s TWT, this fault is the main structure in the eastern Parentis Basin and forms the southern boundary of a major half graben.

Salt structures of different geometry formed in the northern and southern basin boundaries. In the north, gentle WNW-trending salt anticlines deform all the Mesozoic sequences, which were mildly extended during flexure across the basin-margin hinge (Figs. 1A and 1C).

Conversely, in the southern margin, salt structures are much more complex, including ENE-trending salt anticlines, diapiric salt walls, isolated teardrop diapirs, stocks and allochthonous salt sheets (Figs. 1A, 1B and 1D). These salt structures affect Mesozoic and Cenozoic strata.

In the southern margin, the Ibis and the Eridan-Antares ridges are huge salt-cored anticlines along the Ibis Fault affecting only the Mesozoic series. Folded strata include uniformly thick Jurassic unit, a Lower Cretaceous unit that thickens northwards across the anticline, and an Albian-Upper Cretaceous unit that is clearly thicker north of the fold and has growth strata geometries in both fold limbs. These last synfolding deposits also fossilize a north-directed thrust, nucleated in the salt core of the anticline, cutting its northern limb.

To the south, other ENE-trending salt ridges appear to be squeezed salt walls (Alcyon, Puffin; Fig. 1B). They comprise small bulbs of diapiric salt having an inverted teardrop shape. The bulbs overlie apparent subvertical secondary salt welds, which we interpret as remnants of the diapiric stems. Lateral cutoffs of adjoining strata suggest that these salt walls grew as passive diapirs from Albian to early Miocene time. These diapirs are associated with minor north-dipping normal faults affecting the Jurassic and Lower Cretaceous series. The geometry of the Jurassic reflectors suggests that these faults are detached at the Upper Triassic level.

Some of these salt walls extruded large salt sheets (Fig. 1D). The Pelican salt glacier extruded from late Albian to Eocene times over a distance of 20 km. The salt glacier then became inactive and buried during the Oligocene probably due to orogenic closure of the feeding stem. The sedimentary roof of this structure was extended by many normal faults as the thin roof was stretched by flow of underlying salt.

The Parentis Basin (Fig. 1A) widens westward and is filled by thicker (3 s TWT) Jurassic-Lower Cretaceous sequences. Its southern boundary is the major Landes Fault, which shifted southward in relation to the master fault in the east.

The most important salt structures in the west are the ENE-trending Izurde and Marratxo anticlines defined by the Jurassic-Lower Cretaceous overburden and cored by Upper Triassic evaporites (Fig. 1E). These folds have a greater wavelength (up to 10 km), amplitude and lateral continuity (between 15 and 20 km) than the eastern basin ridges. Associated with these folds are mainly N-dipping listric extensional faults detached into the Upper Triassic evaporites. These faults are mainly in the northern flank of the anticlines, especially near the synclinal hinges (Fig. 1E). Here, diapirs are less well developed and are mainly located in the southern margin of the basin near the major Landes Fault, forming salt walls (Fig. 1E). All western diapirs are smaller than in the eastern Parentis Basin but they have the same inverted-teardrop bulb above a secondary near-vertical weld formed by later closing of the diapir stem.

Salt structures evolution

Despite the structural differences between both basin sectors, the seismic signature of the Parentis Basin infill successions (reflector geometry as well as thickness variations around salt structures) indicates that the growth of salt structures in the ensemble of the basin was similar.

During the Albian-Late Cretaceous, passive salt diapirs grew by downbuilding forming chains of massive salt walls. The wall-like geometry is compatible with initiation by regional extension as reactive diapiric walls. The actual faults that could have initiated reactive diapirism are not recognizable. However, this is to be expected with structures that are deep and small, especially on 2D time-migrated seismics. Nonetheless, some early extensional structures are preserved in the form of the large reactive diapir between Euskal Balea and Izurde ridges and abundant Late Jurassic-Early Cretaceous normal faults between diapirs (Fig. 1E). Once initiated by regional extension, the salt walls would have continued growing as passive diapirs once they pierced to the surface. Most diapirs show thickened peripheral sinks of Albian-Upper Cretaceous age around them (e.g. Puffin and Alcyon; Fig. 1B). But generally these local responses to salt expulsion were masked by large changes in regional thickness as the basin evolved.

The evolution of salt tectonics changed radically with the onset of the Pyrenean orogeny. Although the Parentis Basin as a whole was only mildly affected by regional compression, most salt structures responded readily to shortening because their ENE trend was favourably oriented to the N-S Pyrenean compression. Salt structures responded in the following ways. 1) Previously buried, dormant salt walls near the southern boundary of the basin were rejuvenated by squeezing, as the salt within them was displaced upwards and arched their previously flat-lying roofs (e.g. Euskal Balea Salt Wall, Fig. 1E); 2) salt walls of sufficient width extruded so much salt while being squeezed that salt extruded glacially, beginning in the latest Cretaceous and accelerating during Eocene-early Miocene times; 3) large anticlines due to buckling and thrusting formed the salt-cored Ibis and Eridan-Antares ridges above the Ibis Fault; 4) both extruding and buried salt walls became pinched off by regional compression to form subvertical secondary salt welds. Some of these welds acted like reverse faults when shortening continued during the last stages of the Pyrenean contraction (middle Miocene) (e.g. Pelican Salt Glacier, Fig. 1D or Puffin Diapir, Fig. 1B). After Pyrenean compression, salt diapirism ended in late Miocene times.

Conclusions

Structural analysis of seismic profiles from the Parentis Basin yields the characteristics described below for salt tectonics.

Chains of passive salt walls, which may have been extensionally initiated as reactive diapirs, began growing in the Albian. Although many of these walls stopped growing passively by the middle of the Late Cretaceous, some continued to grow passively until the Miocene.

During the collision of Iberia and Eurasia, which began to drive the Pyrenean orogeny in the Late Cretaceous, no major non-salt inversion structures formed in the Parentis Basin apart from uplift and erosion. In contrast, most salt structures responded readily to compression and absorbed practically all the Pyrenean shortening. During this period: 1) diapirs, some of which had become dormant, were rejuvenated by regional compression as their feeder stems began to close. In most of the diapirs this closure completely welded the diapir stem, isolating a teardrop-shaped salt bulb from its source layer; 2) upward expulsion of salt displaced from the squeezed walls arched up their sedimentary roofs to form shallow anticlines, 3) locally the pre-shortening salt walls were wide enough to expel so much salt under compression that the salt extruded glacially to form a salt sheet up to 20 km long; 4) after the weld formation, shortening was accommodated by inversion of pre-existing normal faults, by reverse fault welds or by the short-cut thrusts which nucleated in the salt pedestals.

Differences in the salt-tectonic style between the eastern and western domains could be explained by greater thickness of the synrift sequence, in the west. Because of faster aggradation in the west, salt tended not to reach the surface so readily and instead accumulated in the footwall of the extensional faults forming broad but low salt ridges.

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