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RADIAL GRAVITATIONAL GLIDING INDICATED BY SUBSALT RELIEF AND SALT-RELATED STRUCTURES: THE EXAMPLE OF THE GULF OF LIONS, WESTERN MEDITERRANEAN

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ABSTRACT. The young Messinian salt basin offshore the Gulf of Lions comprises a shallow *décollement* layer (maximum of 3.6 km deep) that allows the seismic imaging of the subsalt relief and the correlation between the shape of subsalt relief and gravity-driven structures. The subsalt relief reveals a variable morphology below the salt layer, characterized by both convex and concave shapes, indicating the occurrence of radial gravitational gliding at the scale of the entire Gulf of Lions. Radial gravitational gliding is equally illustrated by the distribution of the Messinian salt layer. The salt isopach map shows overthickened salt mass overlying subsalt relief of concave shape, pointing to a pattern of convergent gliding, and areas of salt thinning (over convex shape of subsalt relief) indicating divergent gliding. Radial gravitational gliding is also reflected by salt-related structures. Families of normal transverse faults striking parallel to the regional dip direction attest the control exerted by components of strike-parallel extension over areas of convex shape of subsalt relief, whereas widespread buckle folds overlying concave shape of subsalt relief indicate the occurrence of a convergent pattern of salt migration and associated translational gliding. The Gulf of Lions provides then an interesting geological setting to focus on gravity tectonics as well as a model to correlate mapped salt-related structures with those predicted by analogue models.

Keywords: salt tectonics, radial gravitational gliding, passive margin evolution, basin analysis, marine seismic reflection, Gulf of Lions-France.

RESUMO. A bacia evaporítica Messiniana do Golfo de Lion constitui um nível basal móvel bastante raso (∼3.6 km de profundidade), o que facilita o imageamento sísmico da superfície de *décollement* e a correlação entre tipos de estruturas gravitacionais e a forma do relevo subsalífero. O relevo subsal revela morfologias convexas e côncavas, sugerindo direções radiais regionais de fluxo gravitacional. O deslizamento radial é ainda indicado pelas variações de espessura da camada de sal. Enquanto zonas de superespessamento do sal recobrem regiões côncavas do relevo subsalífero, e indicam padrão de deslizamento convergente; zonas de afinamento da camada de sal recobrem porções convexas da superfície de *décollement*, indicando um padrão de deslizamento divergente. O padrão de deslizamento radial reflete-se ainda no arcabouço estrutural pela presença de falhas normais transversais e dobramentos nucleados pelo sal. Falhas paralelas à direção de mergulho regional da bacia afetam a cobertura sedimentar sobrejacente a áreas côncavas do relevo subsalífero, atestando a intervenção de componentes de extensão paralela ao *strike* da margem. Além disso, uma grande concentração de estruturas compressionais afeta a cobertura sedimentar sobrejacente a porções côncavas do relevo subsalífero, atestando um padrão convergente de deslizamento translacional. O Golfo de Lion oferece, deste modo, um interessante cenário para estudos de tectônica gravitacional, assim como um modelo para correlação entre estruturas mapeadas da tectônica de sal e aquelas previstas em modelos analógicos.

Palavras-chave: tectônica salífera, deslizamento gravitacional radial, evolução de margens passivas, análise de bacias, sísmica de reflexão marinha, Golfo de Lion-França.

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INTRODUCTION

Since the 1980's several works based on physical models and seismic interpretation have focussed attention to the links between the basal slope geometry of a salt-bearing margin (subsalt relief) and the resulting structural styles of gravity-driven tectonics, both at local and regional scales (e.g. Vendeville et al., 1987).

At local scale, a few studies have recognized that normal faults striking obliquely or parallel to the regional dip direction can be conditioned by salt basement steps (residual morphology after Gaullier et al., 1993) inherited from syn- and/or post-rift tectonic processes or even from pre-salt sedimentary constructional features (e.g. Gaullier, 1993; Rowan et al., 1999; Maillard et al., 2003; Reis et al., 2004a; Reis et al., 2005a; Loncke et al., 2006).

At regional scale, the scale of observation discussed in the present work, analogue models show that when a viscous salt layer decouples near an ideal perfectly planar surface below salt, salt-related structures strike perpendicular to the regional dip direction as a result of parallel gravitational gliding (e.g. Vendeville & Cobbold, 1987; Vendeville & Cobbold, 1988; Cobbold & Szatmari, 1991; Gaullier et al., 1993). But as natural margins do not have ideal perfectly-straight planar basal salt morphologies, Cobbold & Szatmari (1991), based on simple kinematic models and on physical experiments (analogue models), examined patterns of gravitational gliding associating the regional shape of subsalt surface and the strike of salt-related features. They demonstrated that when the salt basal slope is shaped like a circular cone, salt spreads radially producing structural features of rather different orientation in comparison to those observed in sliding overburdens detaching on a planar *décollement* surface. On the other hand, in the case of a convex shape of subsalt relief, basinward salt displacement follows a radial divergent pattern. Divergent gravitational gliding in this case produces an uppermost domain of strong vertical salt thinning balanced by extension in all horizontal directions. Conversely, in the case of a concave shape of subsalt relief, salt displacement follows a radial convergent pattern. Convergent gravitational gliding produces a lowermost domain of strong vertical salt thickening balanced by contraction in all horizontal directions.

In spite of what these kinematic or physical experiments show, the intervention of subsalt relief on gravity-induced systems can not be easily addressed on mature passive margins where the mobile level (salt in this case) is usually very deep, buried by a rather thick sedimentary overburden several kilometres thick, like, for instance, the Jurassic and Cretaceous evaporitic basins in the Atlantic margins (e.g. Summer et al., 1991; Demercian et al., 1993; Schuster, 1995; Cobbold et al., 1995; Diegel et al., 1995). In such a context, the Gulf of Lions, located on the northern border of the western Mediterranean Sea (Fig. 1), is an interesting example of a salt-bearing passive margin where the entire Plio-Quaternary section detaches above a shallow Messinian salt layer, so that the subsalt relief can be clearly depicted by conventional 2D multichannel seismics (Gaullier, 1993; Reis et al., 2004a; Reis et al., 2004b; Reis et al., 2005a, Reis et al., 2005b). Subsequent sliding of the sedimentary section took place along an essentially autochthonous salt mass, resulting in a less complex structural framework when compared to those of mature marginal basins (Worrall & Snelson, 1989; Peel et al., 1995; Mohriak et al., 1995).

DATA AND METHODS

In this article, we focus on the morphology of the basal salt surface to investigate links between subsalt relief, salt migration patterns and the structural framework of the Plio-Quaternary gravity-driven system offshore the Gulf of Lions. Our analysis is based on a series of thematic maps, including a subsalt relief map, an isopach map of the Messinian mobile salt layer and a regional structural map. The interpretation is also based on structural and stratigraphic analysis of salt-related features observed in seismic profiles.

The available seismic data (Fig. 2) comprises about 30,000 km of closely spaced 2D multichannel seismic reflection profiles (between 2 to 5s penetration) and chronostratigraphy data from three oil-exploration wells (Autan, GLP2 and GLP1) located in the central part of the Gulf of Lions (Cravatte & Suc, 1981).

GEOLOGICAL SETTING

The Gulf of Lions is a passive margin, located on the northern part of the Ligurian-Provençal Basin. This basin evolved in a back-arc position in the tectonic framework of the slow convergence between Africa and Europe, due to a combined effect of the north-westward subduction of the African plate (and its associated slab retreat) and the west-to-east migrating Apenninic arc system (Le Pichon et al., 1971; Montigny et al., 1981; Olivet, 1996; Gueguen et al., 1998). The rifting phase is represented by a short-lived Oligocene-Early Miocene (Aquitanien) crustal thinning, followed by the onset of oceanic crust in response to the counterclockwise rotation of the Corsican-Sardinian continental block, circa between 21 and 15 Ma (Réhault et al., 1984; Gorini et al., 1993; Mauffret et al., 1995; Olivet, 1996; Speranza et al., 2002).

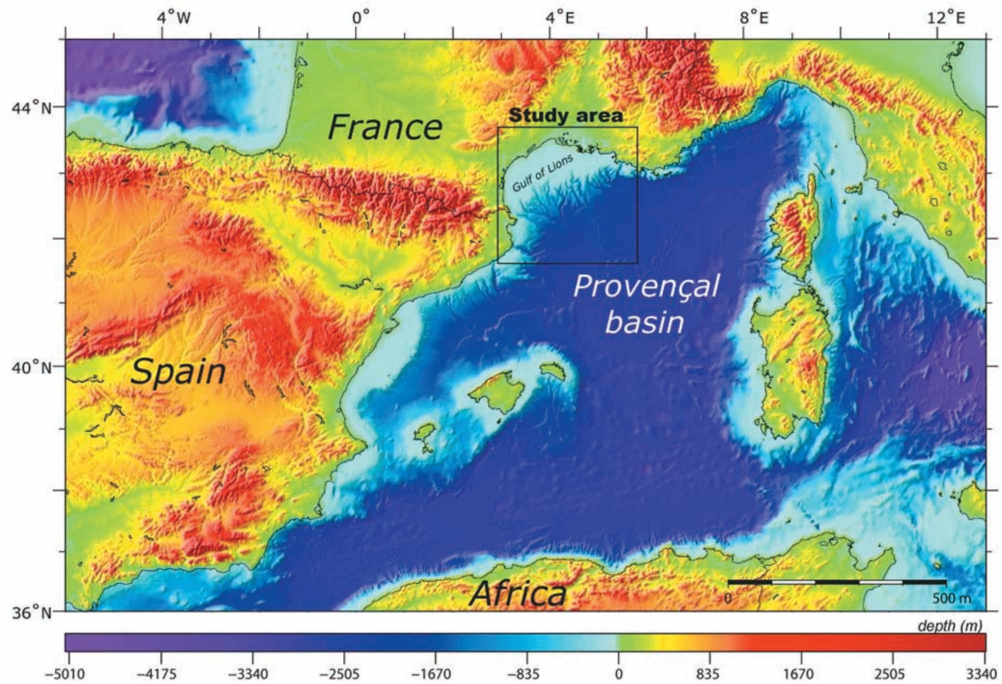

Figure 1 – Regional bathymetric map of the Western Mediterranean Sea with location of the study area – the Gulf of Lions (after GTOPO1 Global Relief High Resolution Model, Amante & Eakins, 2008).

The evolution of the margin led to deposition of thick marine deposits (several kilometres) since the end of the Miocene (Gorini et al., 1993; Mauffret et al., 1995). The sedimentary marine series can be simplistically subdivided into three major sedimentary events (Fig. 3). Burdigalian-Tortonian marine series make up the pre-salt sequence deposited on a subsiding margin (Gorini et al., 1993). Marine series were interrupted by the Messinian Salinity Crisis that took place between 5,96-5,33 Ma (Hsu et al., 1973; Ryan, 1973; Ryan & Cita, 1978; Cita, 1980; Clauzon, 1996; Krijgsman et al., 1999; Lofi et al., 2005) leading to an important episode of lowering of relative sea level (of the order of 1000 m), favouring evaporitic conditions in the deep Mediterranean basins, which resulted in widespread deposition of a continuous and thick evaporitic layer (2 km) from the European to the African margins, composed of the lower evaporites, the salt layer (the mobile level) and the upper evaporites (Réhault et al., 1984) (Fig. 3b) (for further discussion about the Messinian Salinity Crisis, see Lofi et al., 2005). The subsequent emersion of the Mediterranean margins resulted in intense erosion on the shelf and slope (the Messinian Unconformity), truncating the pre-salt marine series (Fig. 3a), and in the incision of land-connected deep canyons on the continental shelf and upper slope, which funnelled products of erosion towards the basin (Droz, 1991; Gorini et al., 1993; Gorini et al., 2005; Lofi et al., 2005). The Messinian event makes up for the peculiar stratigraphic level of evaporitic deposits of the Gulf of Lions (comparing with that of the Atlantic offshore basins), lying at relative shallow depth (maximum of 3.600 m below sea-bottom) and sandwiched between deep-water marine sedimentary sequences (Fig. 3b). This major event was followed by the re-opening of the Gibraltar Straight (Early Pliocene) that, together with the Plio-Quaternary global sea-level variations, allowed the transfer of an enormous volume of siliciclastic sediments into the basin through a complex network of Plio-Quaternary submarine canyons, notably during the Quaternary high-frequency glacio-eustatic fluctuations (Droz, 1991; Berné et al., 2002; Reis et al., 2005a; Droz et al., 2006). Terrigenous sediment input resulted in the deposition of Plio-Quaternary siliciclastic deep-water systems (the post-salt series) having distinct thickness, lateral extent and depositional architecture (Reis et al., 2005a; Droz et al., 2006) such as, the Rhône deep-sea fan, the Pyreneo-Languedocian submarine sedimentary complex, and the Marseilles and Grand-Rhône sedimentary ridges (Fig. 4).

The Plio-Quaternary sedimentary architecture of the slope and deep-water depositional systems is affected by salt tectonics induced by the Messinian salt migration. The degree and nature of salt-sediment interactions varied from the Pliocene to the Quaternary as turbidite deposition and salt tectonic mechanisms changed through time (Reis et al., 2005a; Weibull et al., 2006).

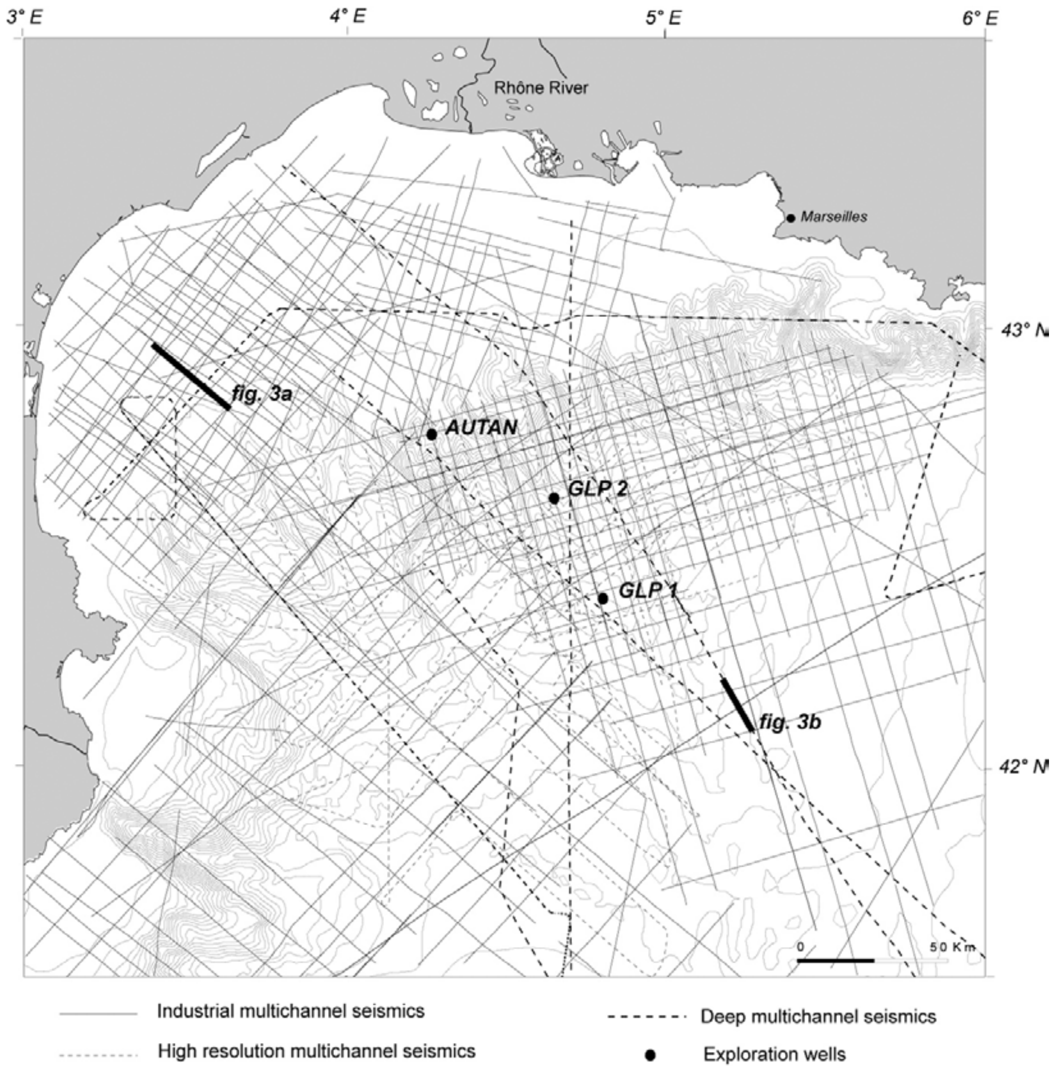

Figure 2 – Seismic data grid and location of exploration wells used in this study.

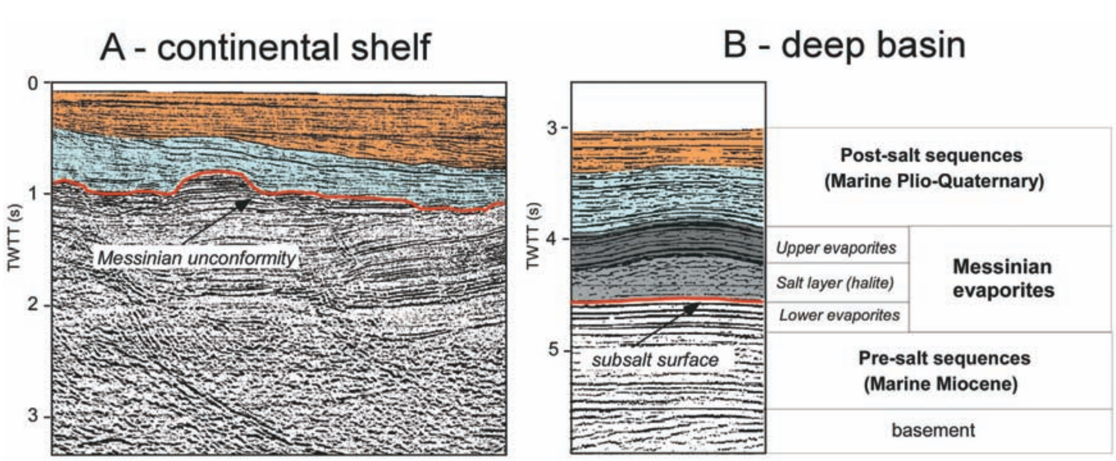

Figure 3 – A – Messinian unconformity on the proximal margin of the Gulf of Lions (LRM seismic section, from Reis et al., 2005a). B – Seismostratigraphic sequences in the deep basin (ECORS section, after Réhault et al., 1984). See Figure 2 for location.

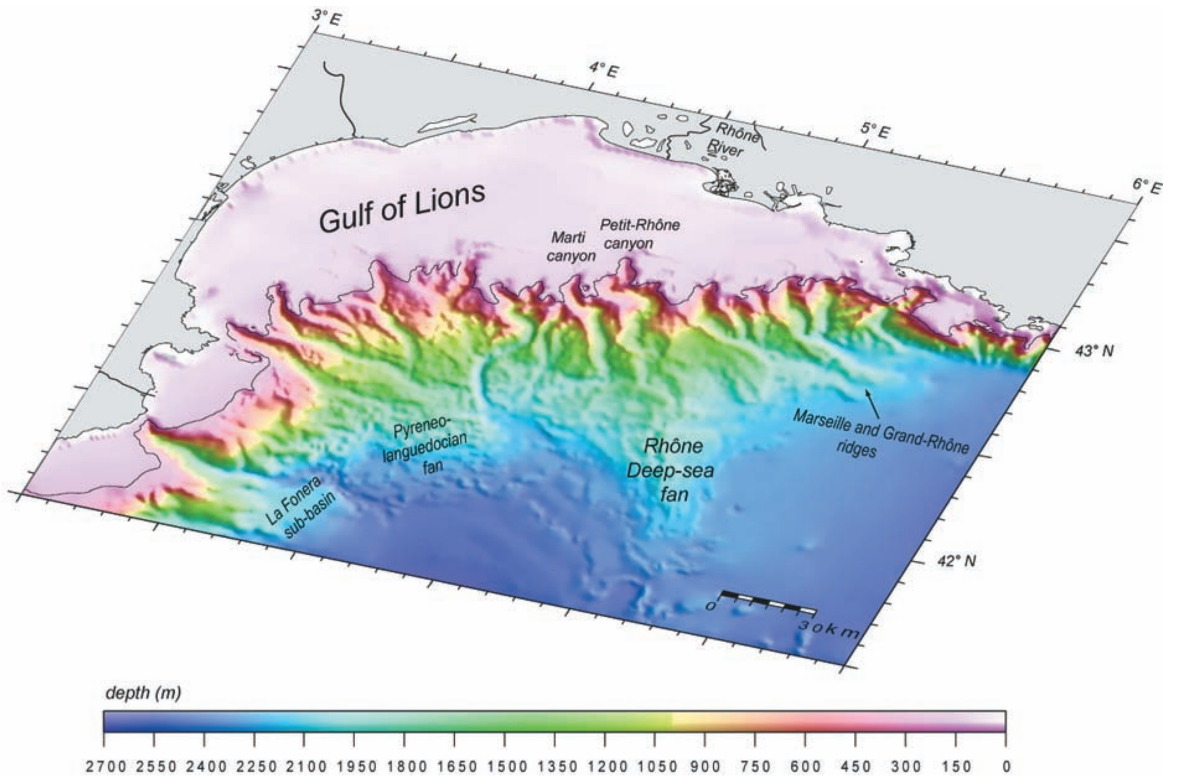

Figure 4 – Bathymetric map illustrating the dense network of submarine canyons and the main Plio-Quaternary deep-water depositional systems offshore the Gulf of Lions (IFREMER swath bathymetric data, France).

The organization of the Plio-Quaternary turbiditic deposition was influenced by a variety of mechanisms like, for instance, syn-depositional vertical salt movements and/or compression (buckle folds or distal salt diapirs); and by salt withdrawal along flat-ramp-flat morphologies, forming syn-kinematic syncline basins in the overlying sedimentary cover. At the same time, seafloor topography created by faulting influenced sediment transport pathways and so controlled the location and configuration of distal turbidites (for further details, see Reis et al., 2005a and Weibull et al., 2006).

SALT TECTONIC FRAMEWORK OF THE GULF OF LIONS

The Plio-Quaternary evolution of the sedimentary section offshore the Gulf of Lions was largely dominated by gravity gliding-spreading of the Messinian *décollement* salt level. Basinward salt migration produced a characteristic structural zonation, typical of salt-bearing marginal basins (Gaullier, 1993; Reis et al., 2005a). Upslope extension (mid to lower continental slope) is characterized by faults that dip predominantly basinwards and strike parallel to subparallel with respect to the shelf break (Figs. 5 and 6); while distal contraction is mainly composed of salt diapirs, barely represented in the study area (Figs. 7 and 5). Extensional and compressional structural provinces are connected by an intermediate translational domain (Fig. 6).

The translational domain is relatively little deformed in relation to both the extensional and the contractional domains, and is characterized by a rather tabular salt layer where the overburden strata remain parallel to the top of the salt layer (Fig. 7). For this reason, this domain was originally regarded as a rigid gliding province, simply connecting the landward extension to the basinward contraction (Gaullier, 1993; Reis et al., 2004a; Reis et al., 2004b; Reis et al., 2005a). However, analysis of a larger set of seismic data show the occurrence of widespread salt-cored anticlines along the previously considered rigid gliding domain. Basinwards of the eastern part of the Gulf of Lions, salt-cored anticlines (buckle folds) occur as a narrow zone adjacent to the distal salt diapirs, forming a E-W belt south of 42°, while westwards of 5° they are widespread in a large area of the southwestern gulf (Figs. 5 and 8).

Buckle folds are halokinetic deformations related to a mechanism of ductile layer-parallel shortening (Vendeville & Gaullier,

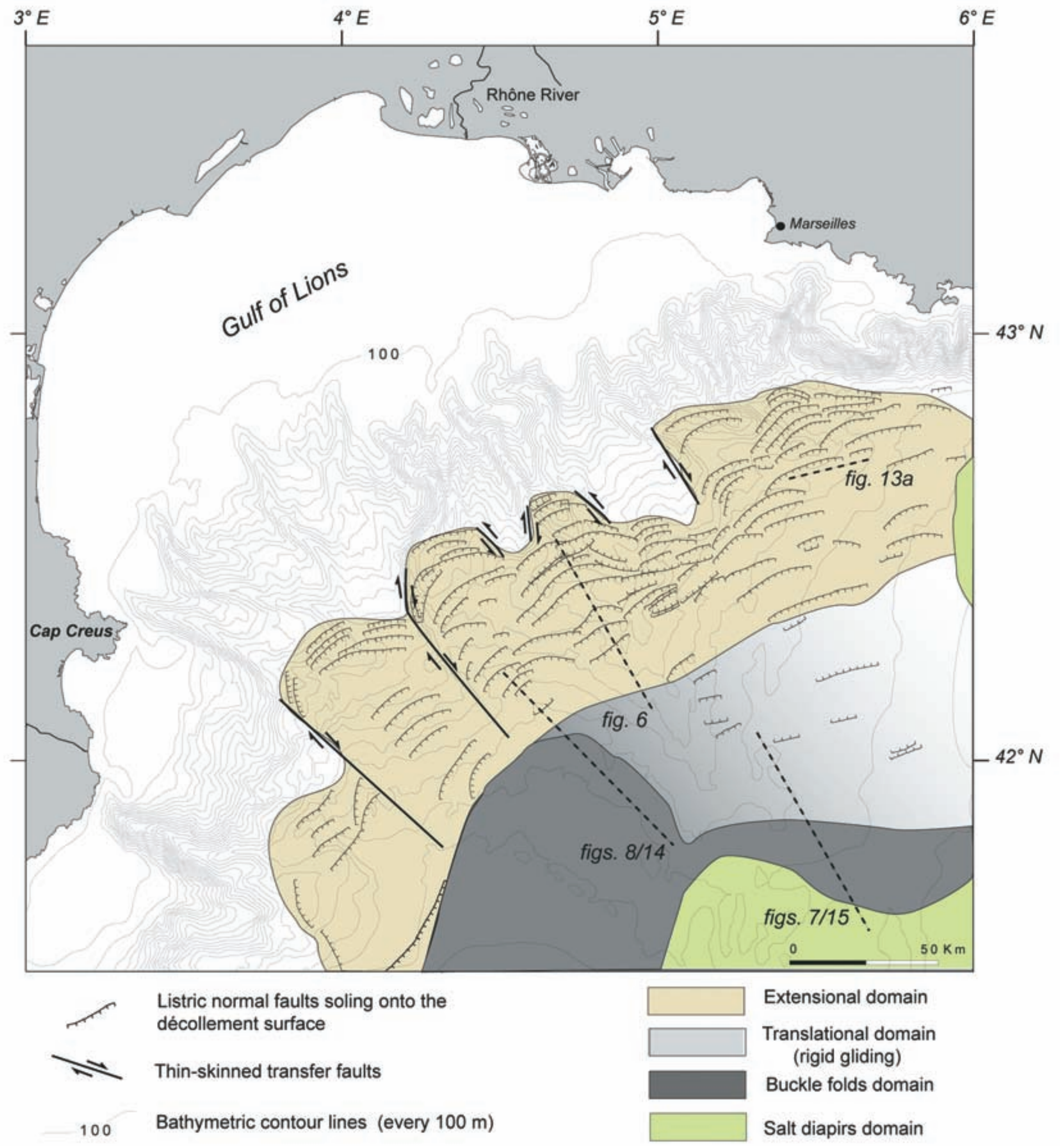

Figure 5 – Simplified map of Plio-Quaternary salt-related structures and structural provinces of the Gulf of Lions (modified from Reis et al., 2005a).

2005). Vendeville & Gaullier (2005), examining buckle folds in the Western Mediterranean Sea, argue that shortening or buckle folds can be an answer for the formation of large piercement diapirs (Fig. 9). Considering that the Western Mediterranean Sea is a closed salt basin (Letouzey et al., 1995), continued downward translation of sedimentary overburden from both the European and African margin would cause increasing tightening and buckle folds formation in the deeper basin. Continued tightening of the folds would force salt to flow into the fold cores, resulting in buckle folds and the evolving diapirs to migrate upslope (Fig. 7).

As for the extensional domain, although basinward-dipping faults predominate along the mid to lower slope, faults that strike parallel to the regional dip direction (transverse faults) are also recognized along this domain. Transverse faults can occur at regional scale (Fig. 5), arranged either along the lateral salt pinch-out or segmenting extensional subsystems, acting as NE-SW trending transfer faults (Reis et al., 2005b).

SUBSALT RELIEF AND IMPLIED PATTERNS OF SALT MIGRATION OF THE GULF OF LIONS

The map in Figure 10 presents the detailed morphology of the subsalt relief across the margin of the Gulf of Lions, without any backstepping correction for subsidence due to overloading since

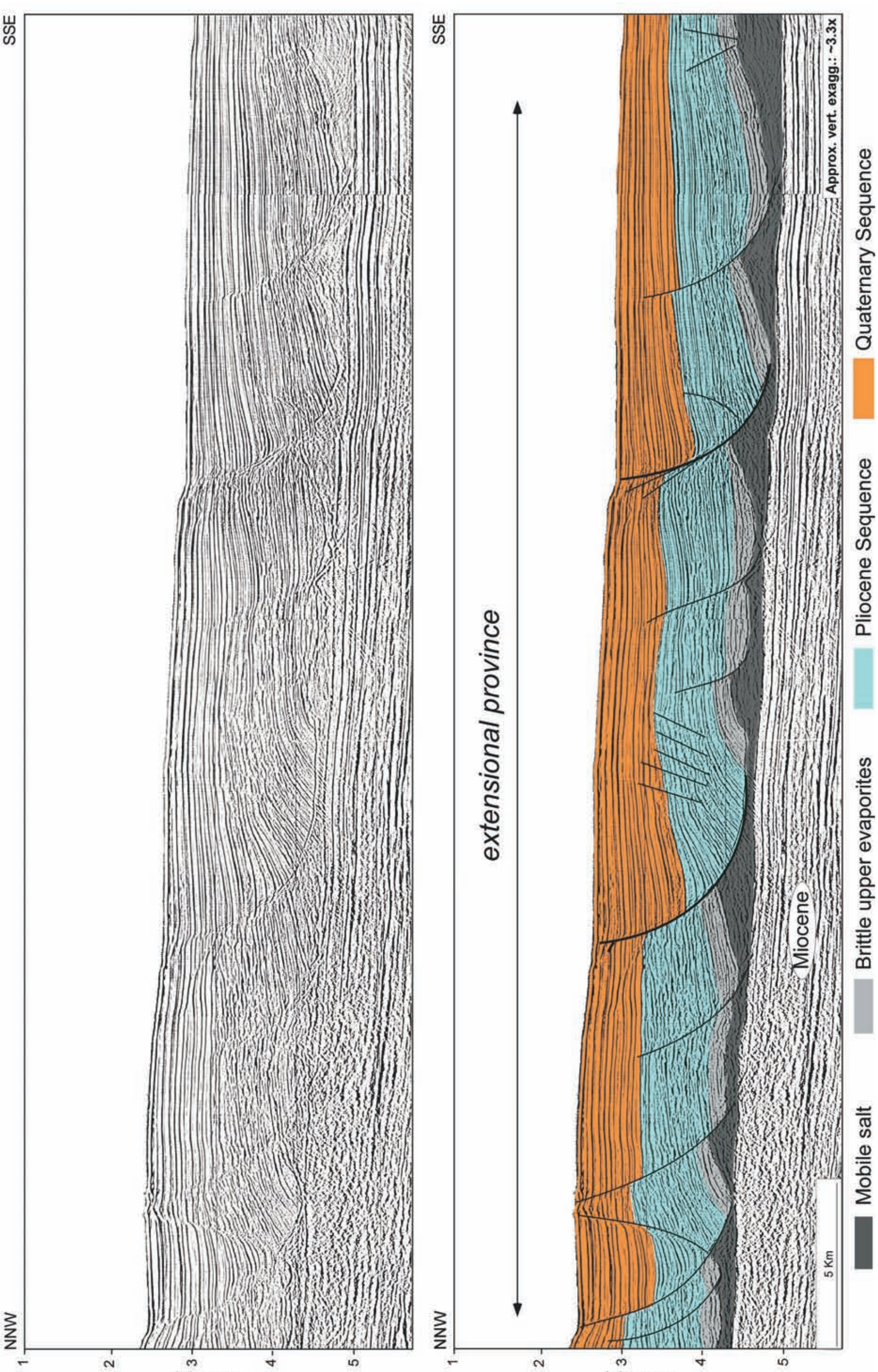

Figure 6 – Uninterpreted (top) and interpreted (bottom) dip seismic section across the Listric Faults Province offshore the Gulf of Lions (CEPM multichannel seismics, France). See Figure 5 for location.

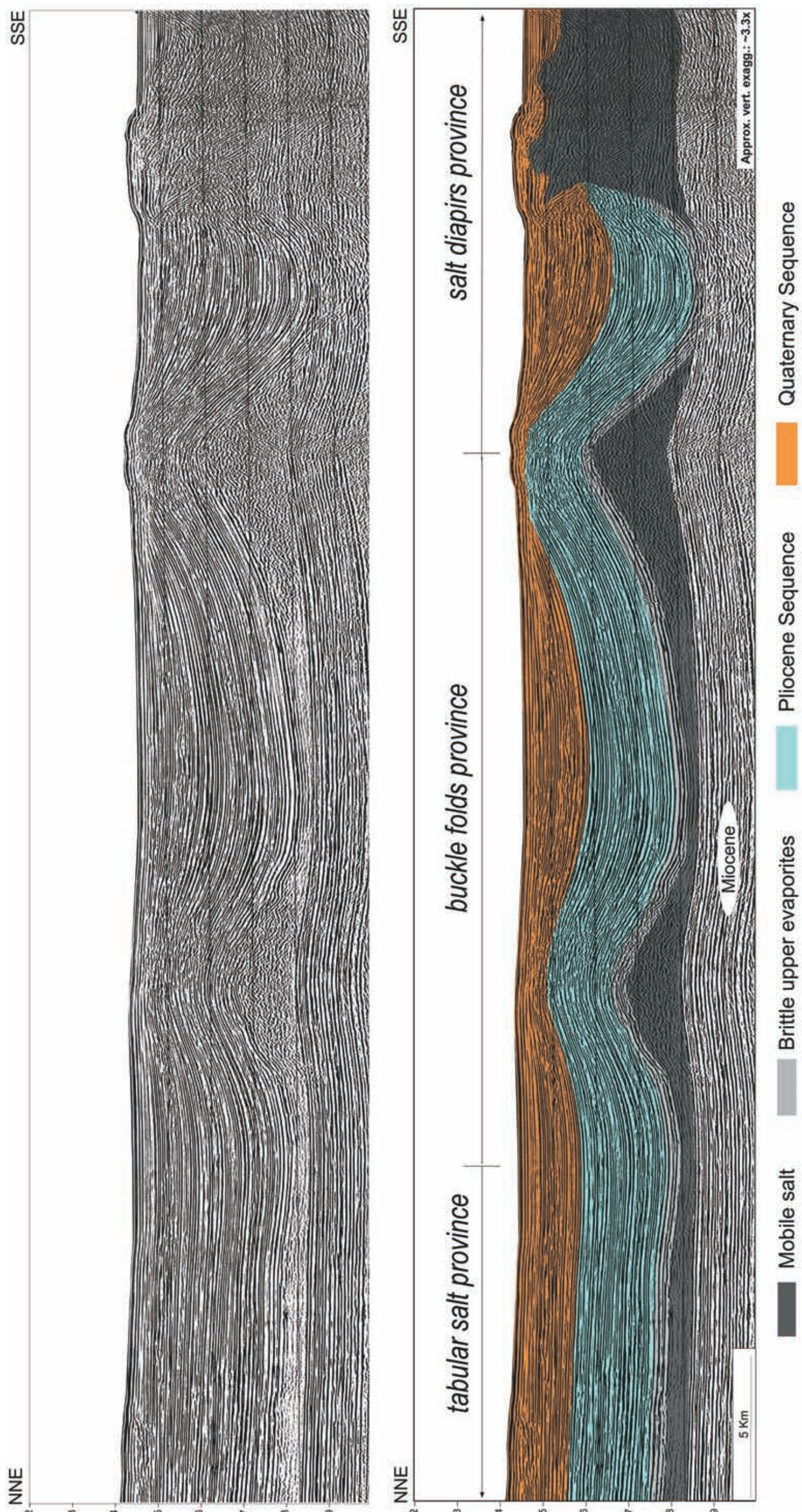

Figure 7 – Uninterpreted (top) and interpreted (bottom) dip seismic section showing the Rigid Gliding Province, the Zone of Buckle Folds and the Salt Domes Province offshore the Gulf of Lions (CEPM multichannel seismics, France). See Figure 5 for location.

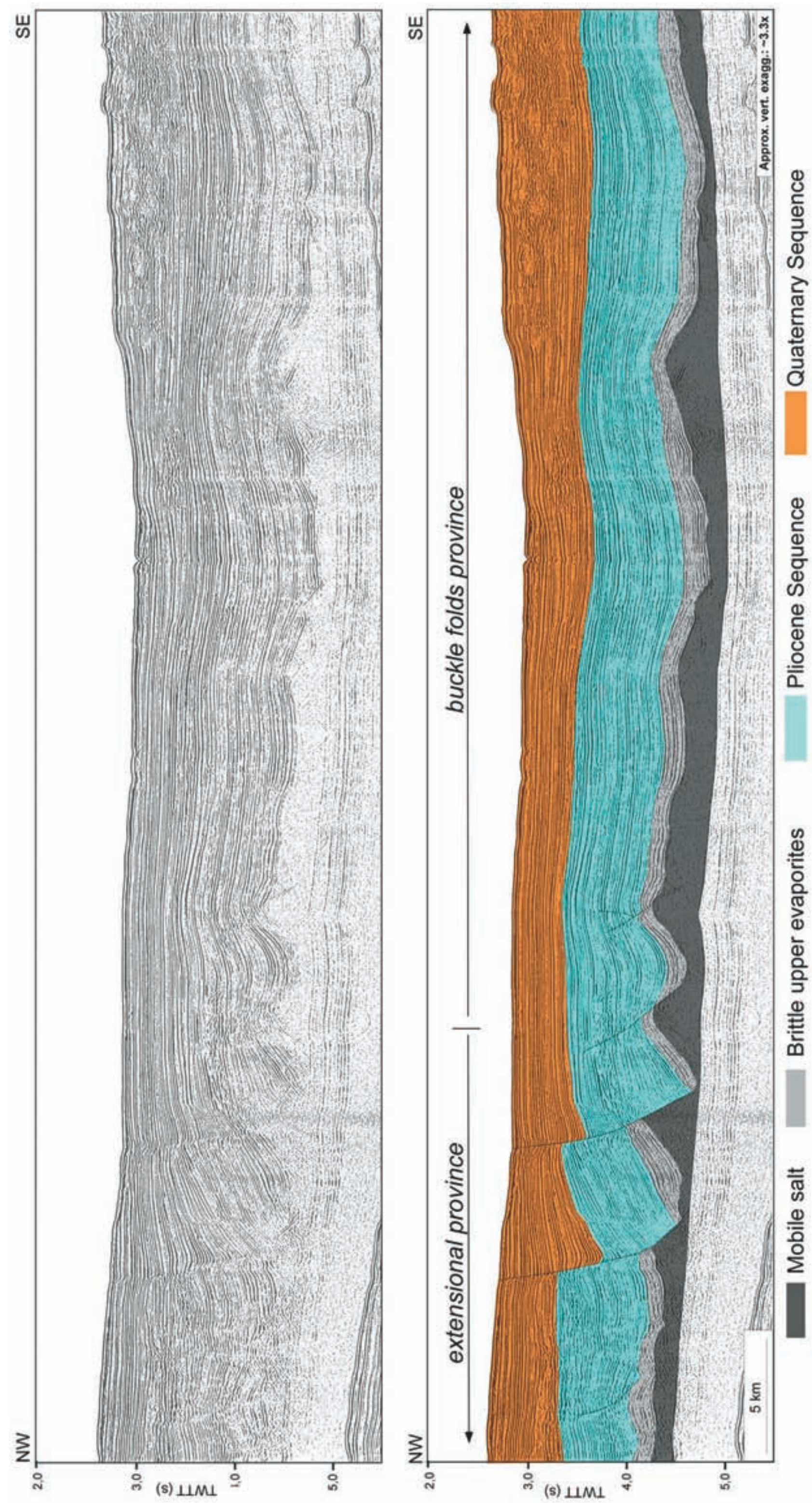

Figure 8 – Uninterpreted (top) and interpreted (bottom) dip seismic line across the wide Zone of Buckle Folds in the southwestern Gulf of Lions (Calmar seismic line). See Figure 5 for location.

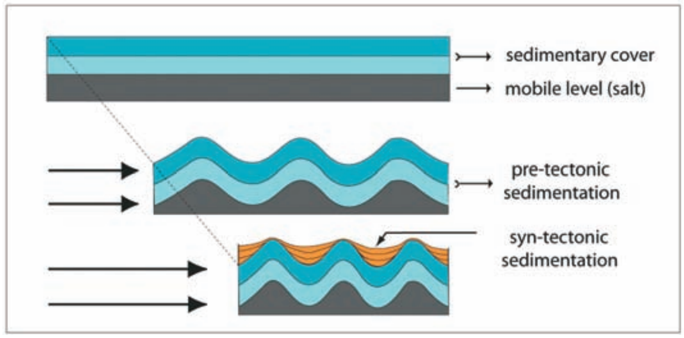

Figure 9 – Conceptual geometric model of buckle folds formation. Ductile layer parallel shortening forms salt-cored buckle folds due to downward translation of sedimentary overburden to the deeper basin, in the context of a closed salt basin as is the case in the Western Mediterranean Sea (modified from Vendeville & Gaullier, 2005).

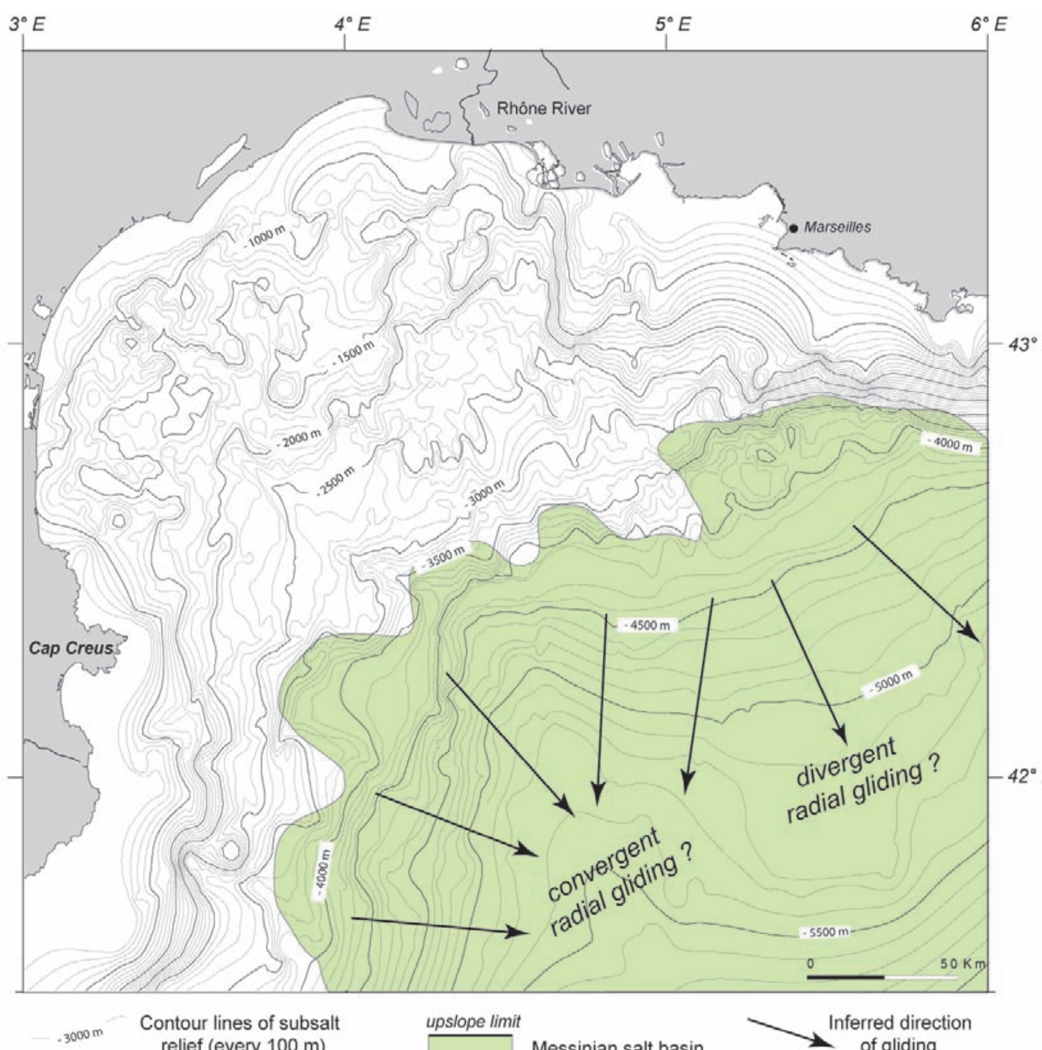

Figure 10 – Morphology of the present-day subsalt relief of the Gulf of Lions. Depth conversion considered ESP layer velocities of Pascal et al. (1993) for stratigraphic levels represented in Figure 3. Corrections for overloading subsidence were not taken into account.

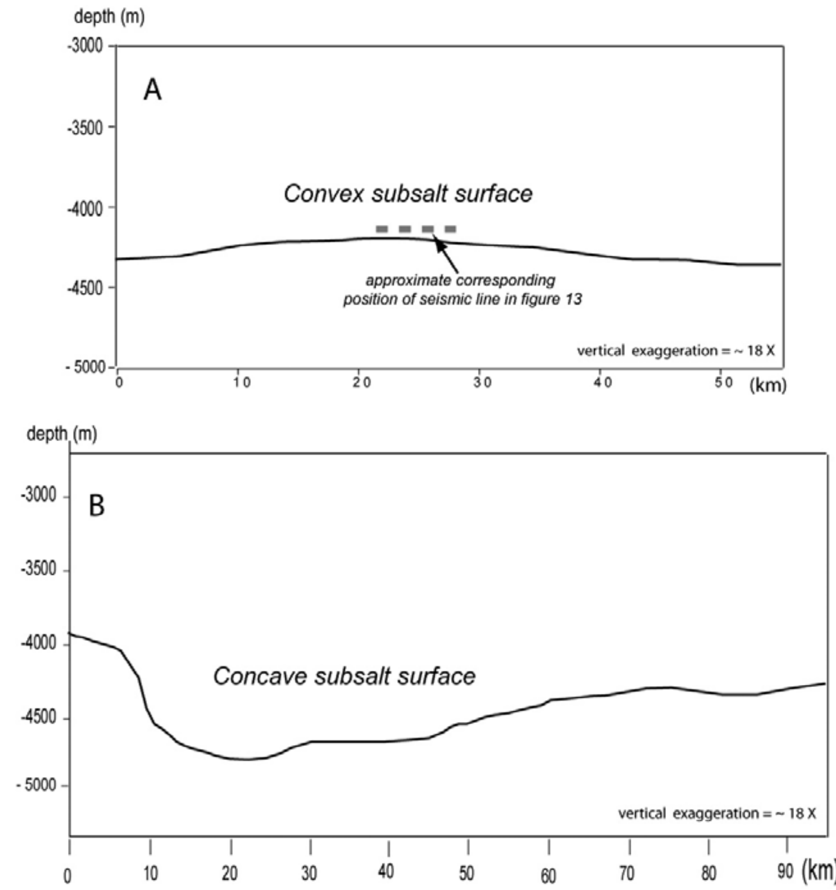

Figure 11 – Morphological profiles illustrating convex (A) and concave (B) shapes of the subsalt relief across the Gulf of Lions. See Figure 10 for location.

the Messinian. The surface represents then the present-day subsalt morphology of the pre-salt sequence (marine Miocene), considering ESP layer velocities of the overlying salt and marine Plio-Quaternary sedimentary units (Fig. 3) from Pascal et al. (1993).

The subsalt relief reveals a variable morphology below the Messinian salt layer that hints at modes of how salt might have migrated. Convex (Fig. 11a) and concave (Fig. 11b) shapes of subsalt morphology suggest preferential radial salt flow directions (*sensu* Cobbold & Szatmari, 1991), that is to say, following divergent and convergent directions, respectively. Such statement should obviously come from 3D reconstruction of the overburden blocks, but the salt isopach map also indicates that the salt layer spreads radially, as the mobile salt mass thins in the center (with salt thickness between 0-200 m; violet to blue colours in Fig. 12) and inflates in the outward parts of the basin (with salt thickness exceeding 1000 m; red colours in Fig. 12). The salt mass is particularly overthickened over areas of concave subsalt surface (reaching a maximum of about 3.500 m thickness), probably as a result of convergent salt flow (Fig. 12). Therefore, other than subsalt relief, salt distribution seems another element pointing to a pattern of radial salt flow of the autochthonous Messinian salt mass.

Considering the subsalt relief, a question that arises is since when such morphology persists. Bessis (1986) and Burrus et al. (1987) estimated small subsidence rates for the Gulf of Lions during the Plio-Quaternary. However, a recent study indicates that crustal tilting seems to have been quite significant offshore the Gulf of Lions during the Late Quaternary (Rabineau et al., 2005). This study, based on stratigraphic models applied to the shelf break area, estimates some 25 m of subsidence per 100 kyr for the last 540 kyr only, due to the margin tilting, which resulted in the creation of large amount of accommodation space for sediments during the period. Nonetheless, though tilting must probably have constantly changed the gradient slope at the salt base, there seems to be no reason to believe in significant changes in the shape of such surface. Then, salt movement and the downslope overburden translation should have evolved under the influence of the variable morphology of the *décollement* surface as depicted in Figure 12.

IMPLICATIONS OF SUBSALT RELIEF ON THE THIN-SKINNED TECTONIC FRAMEWORK OF THE GULF OF LIONS

In gravity-driven deformation of a sedimentary section over an autochthonous salt mass, faults dip primarily basinwards following the regional dip direction, thus corresponding to synthetic faults. This is the case of the salt system offshore the Gulf of Lions were most of the extensional faults, here referred to as primary faults, strike parallel to the shelf break, indicating that salt flows dominantly basinwards, with differential movement of the overburden blocks accommodated by NW-SE transfer faults perpendicular to the shelf-break (Fig. 5). However, the integration of seismic analysis and morphological map of the salt basement shows that the radial subsalt relief has impacted the salt tectonic framework of the Plio-Quaternary section.

Other than the regional transverse faults (NW-SE transfer faults) that segment salt subsystems in the Gulf of Lions (Fig. 5), there are also families of several smaller transverse faults of local expression, here referred to as secondary transverse faults (Fig. 13a). Secondary transverse faults stand out as conspicuous

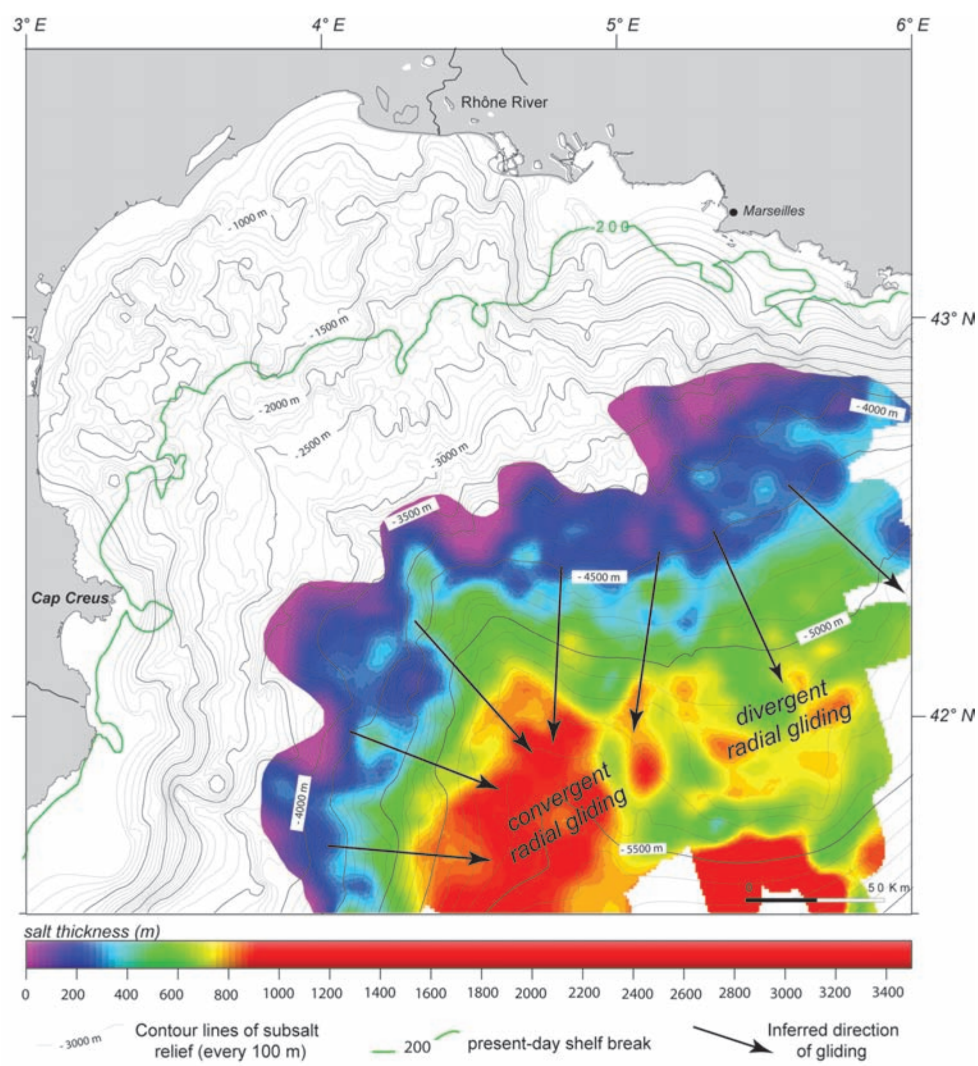

Figure 12 – Conjugated subsalt morphology and mobile salt isopach map offshore the Gulf of Lions (layer velocity for the mobile salt = 4.5 km/s after Pascal et al., 1993).

features in the Gulf of Lions. They comprise normal faults disposed at high angle to primary faults, arranged in symmetric arrays forming transverse grabens constrained between an upslope and a downslope primary fault that accommodate most of the basinward extension (Figs. 13a and 13b). A link can be established between the development of such fault style and subsalt relief, since their occurrence is restricted to sectors where the underlying salt basement is depicted by a surface of convex shape. Radial faults developed over a convex subsalt surface indicate a deformation style kinematically related to strike-parallel extension, attesting thus to a pattern of radial divergent gravitational gliding (Figs. 11a and 13b).

On the other hand, contrarily to what experimental physical models predict (e.g. Cobbold & Szatmari, 1991) compressive salt-related structures in the form of transverse reverse faults were not reported in the sedimentary cover of the Gulf of Lions where a convergent gravitational pattern of salt movement is suggested by the morphology of subsalt relief. This may quite possibly stem from insufficient seismic resolution and seismic data coverage. But instead, buckle folds are widespread along the whole area between the upslope extensional faults and the distal diapirs in the southwestern Gulf of Lions, so that a typical salt tabular province (rigid gliding domain?) is not at all represented in the region (Figs. 5 and 11b). Seismic data coverage did not allow us to map the strike of these salt-cored anticlines, so that we are not certain if they correspond preferentially to structural lineaments perpendicular to the margin. However, at the regional scale of the Gulf of Lions, buckle folds are indeed preferentially developed in the southwestern part of the Gulf of Lions, where subsalt relief is markedly concave in shape (Figs. 5, 8, 11b and 12). So an answer to this widespread occurrence of buckle folds may quite probably lay in the shape of subsalt relief. This statement is also supported by stratigraphic interpretation, as seismic analysis shows that buckle folds in this part of the Gulf of Lions are deformational structures formed earlier in comparison to those laying to the East, adjacent to distal salt diapirs. Salt-cored anticlines formed by progressively younger upslope migration of folding in the eastern part of the gulf (Fig. 14); while in the western part of the gulf abundant pillows and salt anticlines are relatively older compressional structures, formed as early as the Early Pliocene (Fig. 15). They seem to have been caused by the subsalt relief that induced the gravitational translation gliding of the sedimentary cover to converge to the bathymetric low, leading thus to compression and folding in a large area at the toe of the slope since the Early Pliocene. This scenario differs from buckle folds disposed to the East, formed by compression that started in the deeper basin and then migrated upslope, due to the closed shape of the Western Mediterranean salt basin.

CONCLUSIONS

Mapping of subsalt relief is an important tool for understanding the structural evolution of gravity-driven tectonics induced by a basal salt *décollement*. Offshore the Gulf of Lions, salt movement and downslope overburden translation have evolved under the influence of a variable morphology of the *décollement* surface.

The integration of subsalt relief and salt isopach maps, together with seismic interpretation of salt-related structures attest the occurrence of radial gravitational gliding at the regional scale of the Gulf of Lions basin (Figs. 10 and 12). This pattern of gravitational gliding is illustrated by both extensional and compressional salt-related structures, reflecting divergent and convergent directions of salt flow and the overburden gliding, as predicted by analogue models (Cobbold & Szatmari, 1991):

- in the upslope extensional province, transverse normal faults displayed at high angle to basinward-dipping normal faults developed in the sedimentary cover that overlies areas of convex morphology of the subsalt relief. These transverse faults are related to strike-parallel extension as a consequence of a radial divergent pattern of gravitational gliding (Figs. 12 and 13);
- the downward translation of the sedimentary overburden is also affected by compression in the form of buckle folds in areas where the underlying salt basement has a concave morphology. Buckle folds in this scenario reflects a radial convergent pattern of gravitational gliding (Figs. 12 and 14).

Conversely, radial gravitational gliding impacts the thin-skinned structural framework offshore the Gulf of Lions with consequences for the sedimentary architecture of deep-water depositional systems. As an example:

- transverse grabens developed in a context of strike-parallel extension, although limited to the scale of individual structural compartments (as large as a few kilometers, Fig. 13b) can generate sediment pathways, with possible consequences for sediment dispersal and the architecture of distal turbidite systems (Fig. 13a). In the study area, transverse grabens are active only during the Pliocene deposition, suggesting that patterns of salt migration changed from the Pliocene to the Quaternary (from radial pattern to an essentially basinward pattern). The reason why

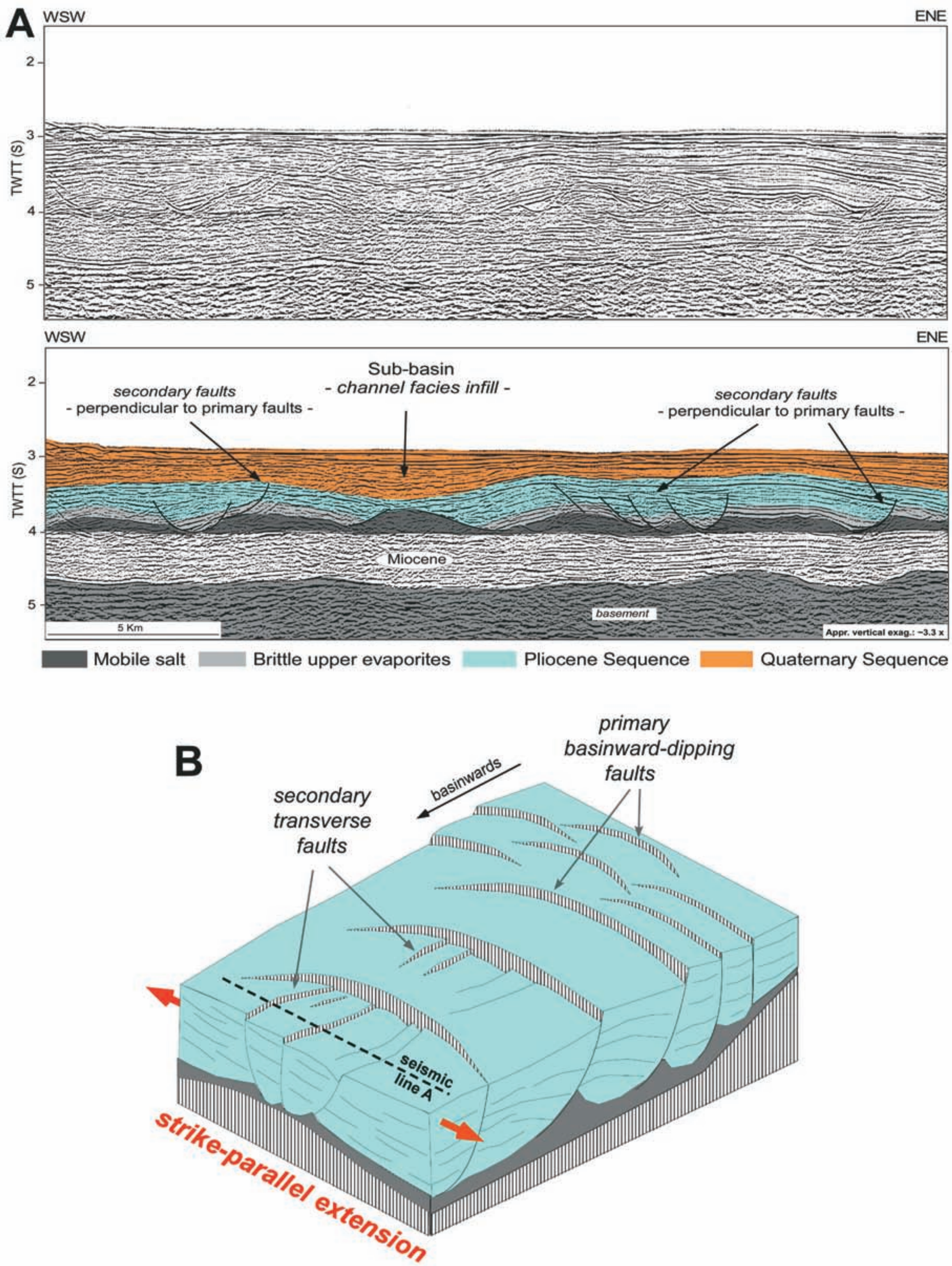

Figure 13 – A – Along-strike uninterpreted (top) and interpreted (bottom) seismic line offshore the South Provençal margin-Gulf of Lions, illustrating secondary transverse faults disposed at high angle to primary seaward-dipping faults. These transverse faults affect the sliding sedimentary cover overlying areas of convex shape of subsalt relief (CEPM multichannel seismics, France). See Figure 5 for location. B – 3D block diagram illustrating a simplified geometrical model of strike-parallel extension due to divergent gravitational gliding.

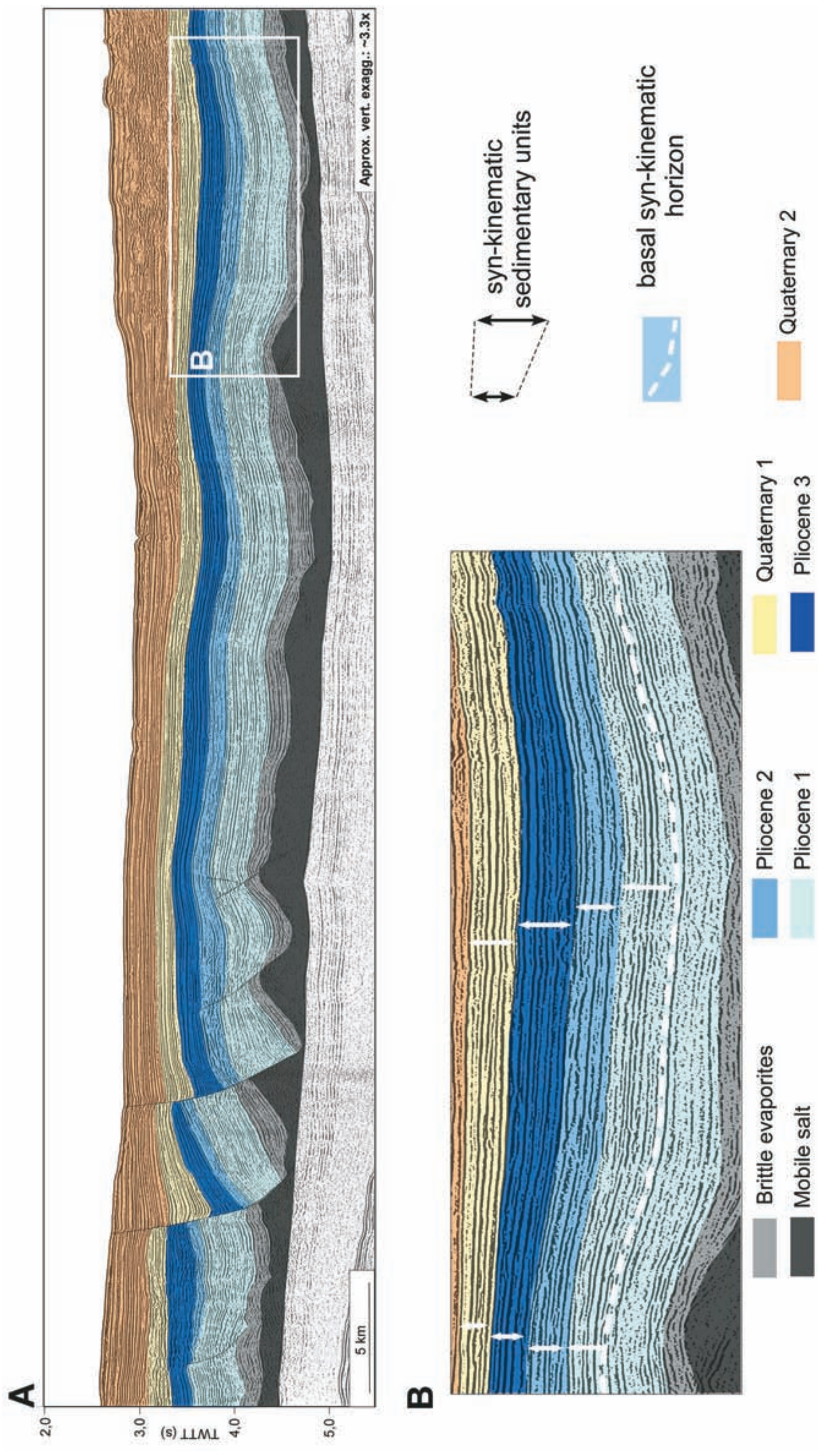

Figure 14 – A – Dip-oriented seismic line (Calmar seismics) showing the zone of widespread buckle folds formed as a result of the sedimentary cover slide toward the concave bathymetric low at the salt basement surface, as depicted by the seismic line and by the morphological map of the subsalt surface shown in Figure 10. B – Zoom-in of the seismic line above to stress the syn-kinematic sedimentary units (represented by white arrows) that occur in the area affected by halokinesis since the Early Pliocene (age of the basal syn-kinematic horizon). See Figure 5 for location.

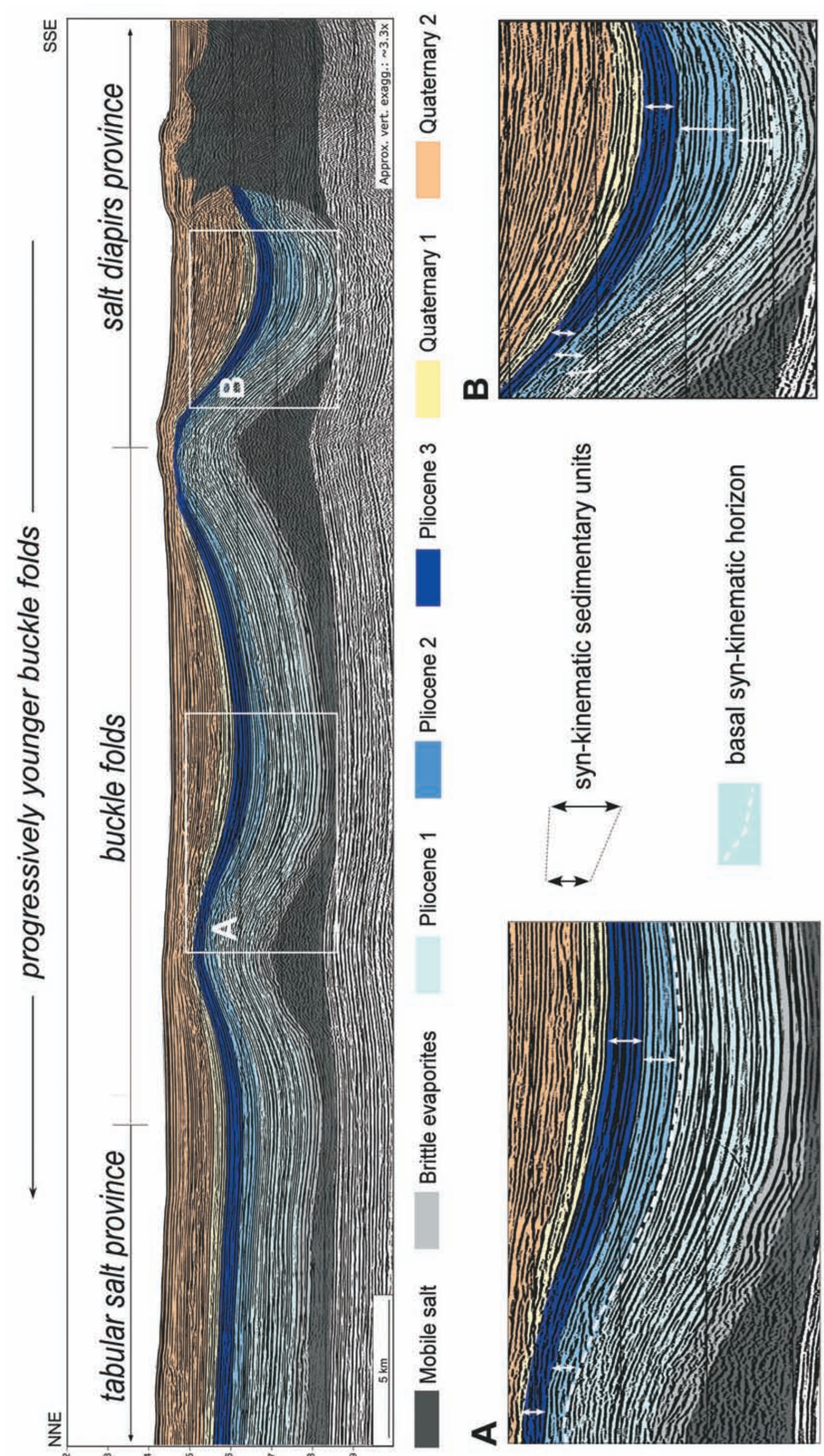

Figure 15 – Dip-oriented seismic line (CEPM multichannel seismics, France) crossing the Rigid Gliding Province (tabular salt), the Buckle Folds Province and the distal Salt Diapirs Province. A and B – Zoom-in showing that compression gets progressively younger upslope (Early Pliocene in A and Middle Pliocene in B). See Figure 5 for location.

these faults are restricted to the Pliocene sequence remains open, but the set of Pliocene secondary transverse faults may quite probably have been inactivated due to the intense progradational overload of the Quaternary sedimentary section in the area;

- the syn-depositional vertical salt movements associated with formation of buckle folds, or growth of distal salt diapirs, generated a series of topographic highs that controlled the Pliocene sediments dispersal in the western Gulf of Lions, providing accommodation space as a series of minibasins. This pattern of salt-sediment interaction prevailed during deposition of the entire Pliocene deep-water sedimentary system (see Weibull et al., 2006, for details).

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