Radial gliding evinced 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 offshore the Gulf of Lions is a shallow décollement layer that permits direct correlation of gravity-driven structures with those predicted by analogue models. Sub-salt relief is cleary depicted by high resolution seismic data. Subsalt relief and salt isopach maps indicate the occurrence of radial gliding at the scale of the entire Gulf of Lions. This pattern of gravity gliding is also indicated by the occurrence of salt-related structures of smaller scale (families of transverse faults). Transverse faults strike parallel to the regional dip direction, indicating strike-parallel extension. As well as that, our results also permit correlation between categories of residual subsalt relief (local irregularities) and rooting of faults along with, depending on their directions, there has been either strike-slip mouvement or weld-parallel slip.

Introduction

Experimental physical modellings and seismic interpretataion works have focussed attention on the links of subsalt relief and structural styles of thin-skinned tectonics driven by a basal salt décollement. Many of these studies have recognized, for instance, faults that lay obliquous or parallel to the regional dip direction as faults that sole into salt basement steps inherited from pre-salt tectonic processes (rifting structures and/or tectonic reactivation) (e.g. Gaullier, 1993; Rowan *et al.,* 1999; Reis, 2001; Maillard *et al.,* 2003; Reis *et al.,* 2004). Cobbold and Szatimari (1991), based on simple kinematic models, examined kinds of gravitational gliding (divergent or convergent) associating the regional shape of subsalt surface and the strike of salt-related features.

Nonetheless, the intervention of sub-salt relief on gravity-induced extension can not always be very easily addressed on mature passive margins as the mobile level (salt in this case) is usually very deep, buried by a rather thick sedimentary overburden. In this context, the Gulf of Lions, located on the northern border of the western Mediterranean (figure 1), is a quite interesting study case of salt-bearing passive margin because the entire Plio-quaternary section detaches above a shallow autochthonous salt layer. Evaporitic deposition in the Gulf of Lions was not related to a transitional tectono-stratigraphic phase but it took place as a consequence of the *Messinian Salinity Crisis* (5,96-5,33 Ma): a tectonic closure in the region of the modern Strait of Gibraltar, possibly augmented by a fall in sea level, led to the deposition of deep-water evaporitic sequences (Cita and Ryan, 1978; Clauson, 1996). This Messinian event *(*draw-down of water*)* makes up for the unusual stratigraphic position of the evaporitic deposits off the Gulf of Lions, lying at relative shallow depth (maximum of 3.600 m below sea-bottom) and sandwiched between deep-water marine sequences. Subsequent thin-skinned extension is brought about by gravitational movement of an essentially autochthonous salt mass, resulting in a less complex structural framework when compared to other marginal basins (Reis, 2001; Reis *et al.,* 2004; Reis *et al.,* in press).

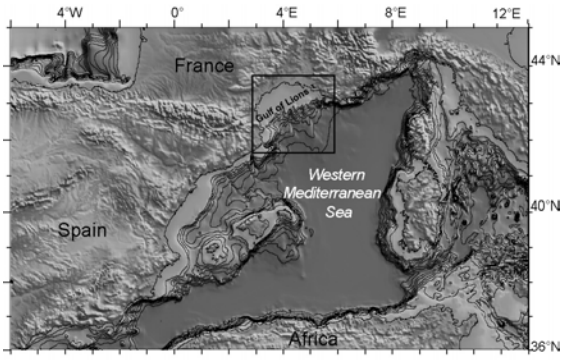

Figure 1: Location of the study area (after GTOPO3O data, Smith and Sandwell, 1997)

In this study, we analyse the salt basement surface and salt isopach maps to assess the links of subsalt relief and the structural framework of thin-skinned extension. This work is based on the interpretation of about 30.000 km of closely spaced multichannel seismic reflection profiles and oil exploration wells.

Salt tectonic framework of the Gulf of Lions

The Pliocene-Quaternary evolution of the Gulf of Lions was largely dominated by thin-skinned tectonics over the Messinian décollement salt level. Extension characterizes the upslope part of the system and contraction occurs basinward (Gaullier, 1993; Reis, 2001). Upslope

extension is characterized by faults that dip predominantly basinwards and strike parallel to subparallel with respect to the shelf break; while distal contraction is mainly characterized by salt-cored diapirs (figure 2)

Altough basinward-dipping faults predominate in the Gulf of Lons, faults that strike parallel to the regional dip direction (transverse fauts) are also recognized along the extensional domain. Transverse faults can occur at a regional scale, arranged either along the lateral salt pinch-out or segmenting extensional subsystems (figure 2). At local scale, transverse faults include also families of smaller faults arranged in symetric arrays with high angle to primary faults, forming local grabens which occur at the scale of basinward translation compartments (a few to tens kilometres large) (figure 3**,** faults not plotted in figure 2).

Subsalt relief and implied patterns of salt migration in the Gulf of Lions

The map in figure 4 presents the detailed morphology of the subsalt relief across the margin of the Gulf of Lions. Subsalt relief reveals a complex morphology below the Messinian salt layer that hints at modes of how salt might have migrated. Conical (divergent) and concave (convergent) shapes of subsalt morphology suggest preferential radial salt flow directions (*sensu* Cobbold and Szatimari, 1991). Such statement should obviously come from 3-D reconstruction of the overburden blocks, but the salt isopach map (figure 4) also indicates that the salt layer spreads radially, as the salt mass thins in the center and inflates in the outward parts of the basin. Salt mass is particularly inflated over the area of concave surface, probably as a result of convergent salt flow. Therefore, other than subsalt relief, salt distribuition seems another element pointing to a pattern of radial salt flow of the Messinian salt mass. Eventually, salt-related structures equally indicate radial gliding of the sedimentary cover in the Gulf of Lions (see next section)

Subsalt relief reveals as well local irregularities (residual relief, *sensu* Gaullier *et al*., 1993) of the subsalt basement. Residual relief is expressed by step-like or flat-ramp morphological features that strike either orthogonal or parallel to the regional dip direction (figure 5). Step-like features that strike orthogonal to the regional dip direction are the morphological expression of sedimentary wedges formed by Messinian detritic deposits that lay dicrectly beneath salt (these features result from the shelf-slope desmantling during the Messinian salinity crisis) (figure 5A). As well as that, basement transfer zones (e.g. the Catalan and Rascasse transfer zones in figure 2) impacted the susbalt relief in the form of NW-SE basement steps, running parallel to the regional dip direction (figure 5B). Another category of residual morphology are flat-ramp features that occur along the western portion of the Gulf of Lions (the Catalan margin). The Catalan margin corresponds to a rifting compartment relatively less stretched (depth of the top of the basement is about 2-3 km) in contrast to the central Gulf of Lions where depth to basement reaches up to 8-9 km (Mauffret *et al.,* 1995). Along a continent-basin profile, the thicker crust is still morphologically expressed as flat-ramp features at the subsalt relief (figure 5C).

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. In the Gulf of Lions, the association of seismic interpretation work and salt basement surface show that the subsalt relief have impacted the salt tectonic structural framework of the Pliocene-Quaternary section, as evinced by transverse faults and fault welds.

Transverse basement transfer zones (e.g. the Catalan and the Rascasse basement transfer zones, figure 2) form basement steps that impacted the subsalt relief. This kind of residual relief conditioned the emplacement of northwest-southeast faults that have rather steep fault plane and accommodate little extension. Disposition and geometry of their fault planes favour their interpretation as strike-slip faults, and finally as thin-skinned transfer zones (detached transfer faults) that define salt subsystems limits (figure 5B'). Strike-slip transfer faults are also recognized along the lateral salt pinch-out, this time conditioned by the boundary between translational and fixed sedimentary cover (absence of an underlying mobile salt) (figure 2). Salt basement step-like features, genetically related to sedimentary wedges with high frontal slope (Messinian detritic deposits) also favoured rooting of basinward-dipping faults, with local consequences for the Plio-Quaternary tectono-stratigraphic evolution of fault styles. In such a situation, deformation was initially dominated by basinward translation. With progressive salt evacuation, fault planes stepped down to the residual basement scarp and then rollovers underwent dominant vertical movement. Therefore, the structural system evolved by dominant overburden subsidence into the evacuated salt horizon (figure 5A'). Another particular relation between subsalt relief and extension style is observed along the western part of the Gulf of Lions. Flat-ramp subsalt features trending NE-SW, indirectly inherited from rifting structures, led to significant basinward salt mobilization, favouring weld slip (salt or fault welds). Such a context forms tectonic windows allowing direct connection between subsalt and suprasalt sedimentary units (figure 5C and C').

Our data set also revealed, probably for the first time, conspicuous families of transverse faults related to radial glidging. These transverse faults in the Gulf of Lions are comprised by secondary faults disposed at high angle to primary faults. Most of the time, these faults are arranged in symmetric arrays forming transverse grabens constrained between an upslope and a downslope primary fault that accomodate basinward extension (figure 3A and 3B). In the Gulf of Lions, these faults are active during the Pliocene deposition. The reason why these faults are restricted to the Pliocene remains opened (inactivated by the progradational load of the Quaternary section ?) (figure 3A). A link can be established between the developement of such fault style and the subsalt

relief, since their occurrence is resctrited to sectors of the Gulf of Lions where the morphology of salt basement is marked by a regional conical surface. Radial faults developing over a conical subsalt surface indicate that gravitational gliding followed a pattern of radial divergent salt flow, pointing thus to a deformation style kinematically related to strike-parallel extension (figure 3A and B). Transverse grabens developped in such context, although limited to the scale of individual structural compartments (as large as a few kilometers) can very probably control sediment pathways directions, with consequences for the architecture of distal turbidite systems. On the other hand, contrarily to what analogue models predict (e.g. Cobbold and Zsatimari, 1991) no compressive structures (reverse faults) were reported in the sector of the Gulf of Lions where the subsalt relief has a concave shape. In fact, this area is dominated by buckle folds (salt-cored pillows). The lack of compressive structures may quite probably stem from insufficient seismic resolution.

Conclusions

Mapping of subsalt relief is an important tool for the understanding of the structural evolution of gravity-driven tectonics induced by a basal salt décollement. In the Gulf of Lions, the association of subsalt relief and salt distribution maps attests to the occurrence of radial salt flow. This pattern of salt migration is reflected in the upslope extensionsal province by extensional fault families formed by basinward translation, associated with secondary fault families related to strike-parallel extension

Residual subsalt relief also influenced the structural framework of salt tectonics in the Gulf of Lions. Residual salt basement steps (either of structural or sedimentary nature) can control the emplacement/strike of faults and the kinematics involved:

- strike-slip faults develop along salt basement scarps parallel to the regional dip direction (NW-SE). These faults function as thin-skinned transfer faults/zones that define salt subsystems limits;

- normal listric faults soled along step-like residual accidents transverse (SW-NE) to the regional dip direction. In this situation, deformation experiences a combination of extension- and subsidence-dominated phases. Block subsidence along normal faults has the final effect of providing accommodation space for clastic sedimentation, creating isolated sub-basin;

- Ramp features favours significant weld slip, forming tectonic windows that allow connection between subsalt and suprasalt sedimentary units.

Acknowledgements

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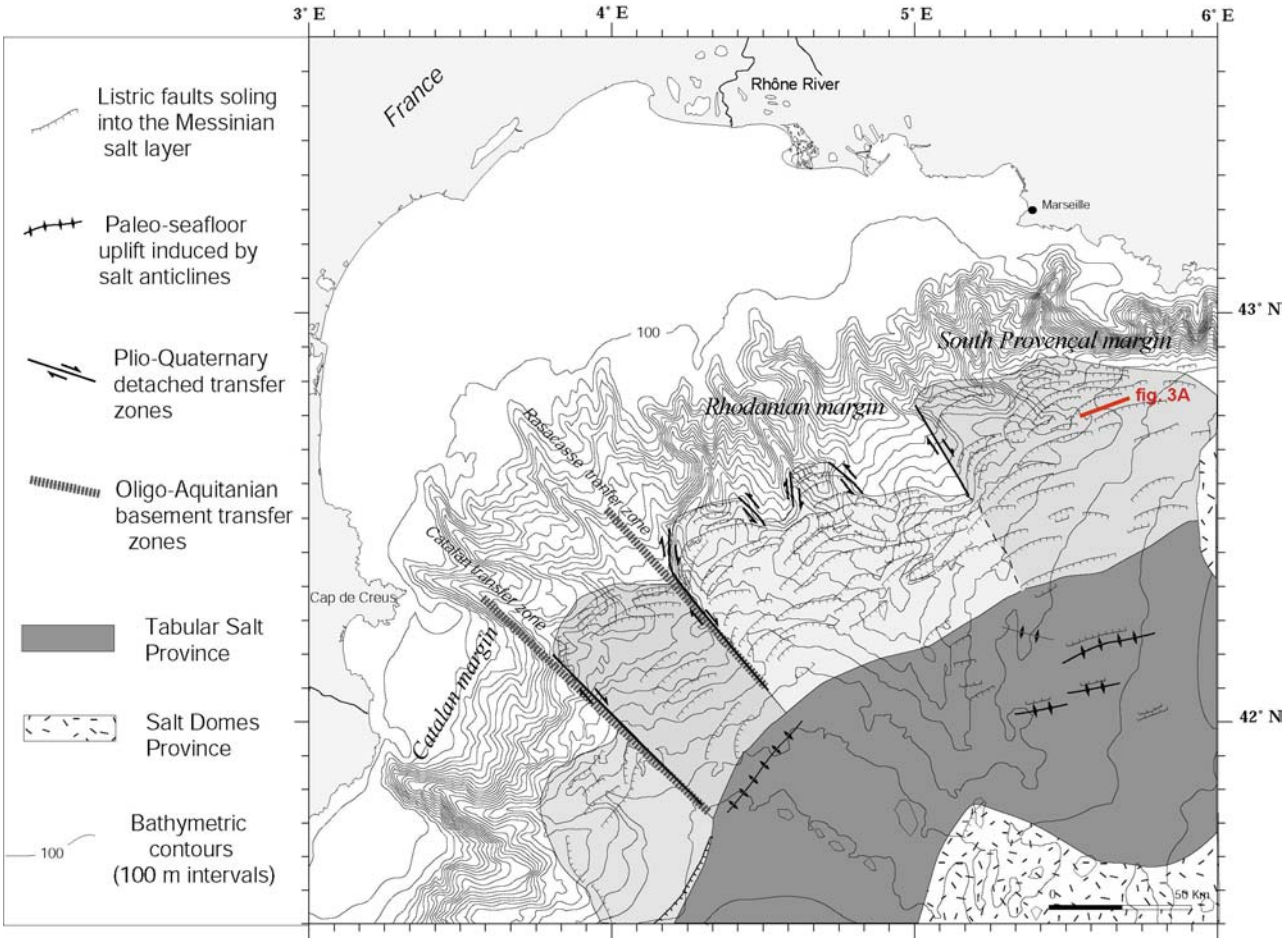

Figure 2: Structural summary map of Plio-Quaternary salt-related structures offshore the Gulf of Lions (from Reis, 2001).

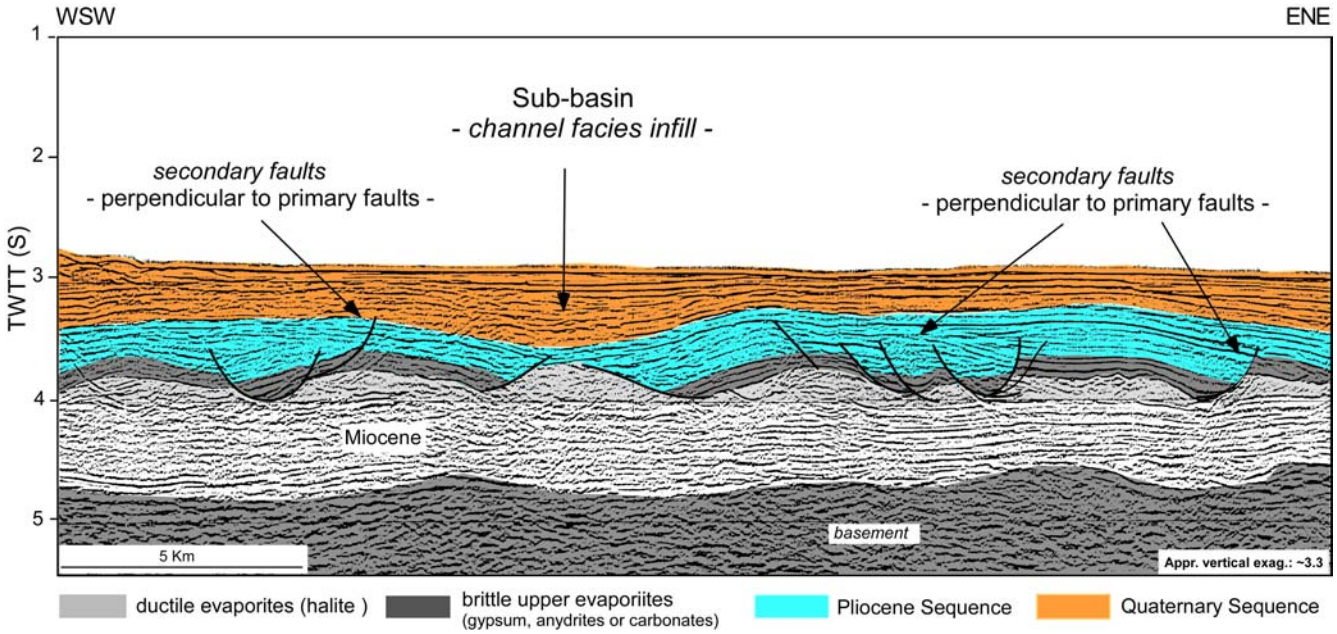

Figure 3A: Along-strike seismic line offshore the South Provençal margin-Gulf of Lions, illustrating secondary transverse faults disposed at high angle to primary faults. Location in figure 2 (faults depicted in this seismic line are not represented in figure 2) and schematic representation in figure 3B

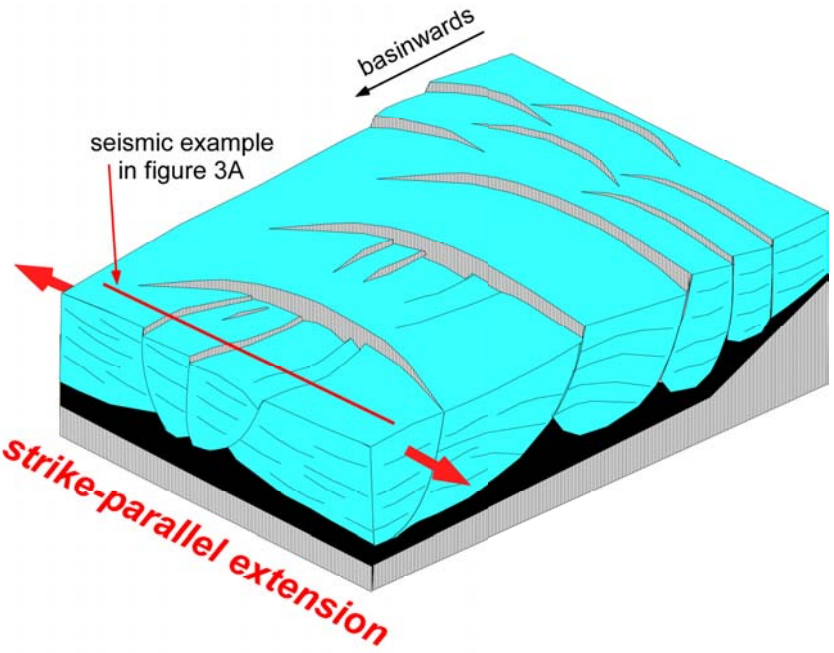

Figure 3B: 3-D block diagram illustrating a simplified geometrical model of strike-parallel extension that occurs in areas of conical subsalt surface in the Gulf of Lions.

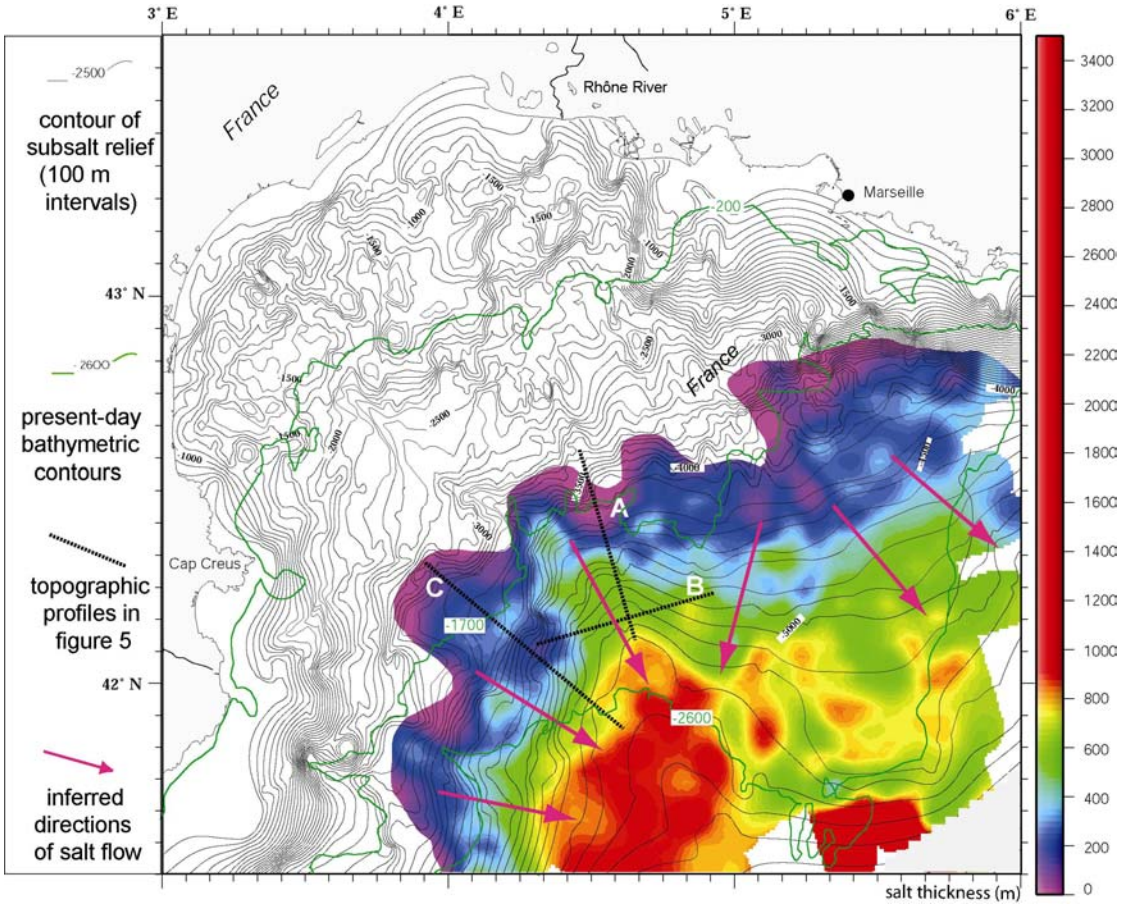

Figure 4: Conjugated map of subsalt morphology and salt thickness offshore the Gulf of Lions.

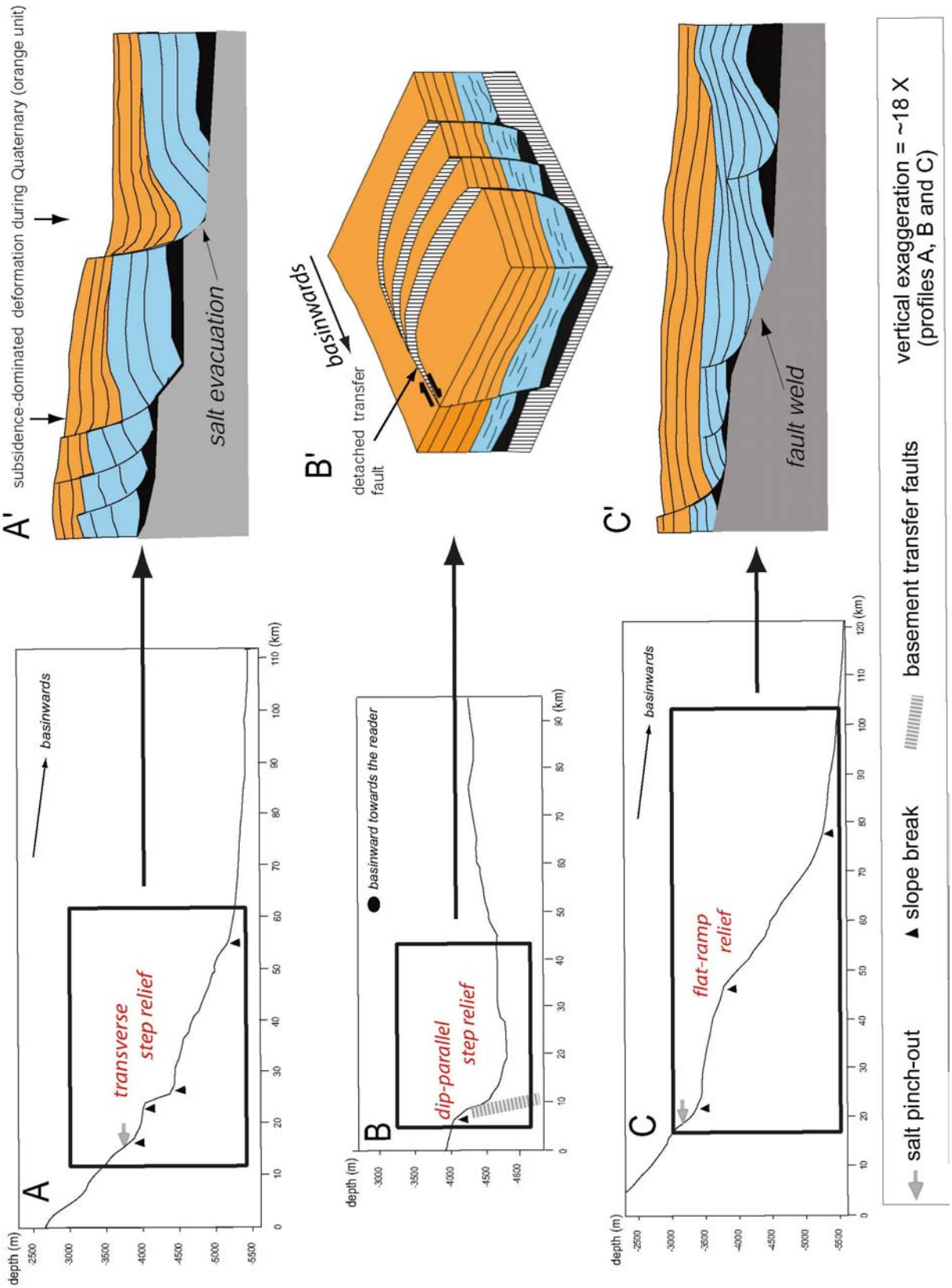

Figure 5: Topographic profiles of subsalt relief (A,B and C) and their implications for the deformation of the sedimentary cover and the kinematics of salt-related structures (A', B' and C').