Salt tectonics-sedimentation interaction providing space accommodation for clastics deposition: the Pyreneo-languedocian fan, Gulf of Lions - Western Mediterranean Sea

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Abstract

The Pyreneo-languedocian sediment body, located in the western secter of the Gulf of Lions, Western Mediterranean Sea, is an exmaple of a fan-like depositional system whose deposition is essentially controlled by salt tectonics. The area was subjected to a combined effect of overburden subsidence into the evacuated salt horizon and a significant distal salt thickening, due to a preferential basinward salt migration. This mode of salt migration impacted the Quaternary sea-bottom morphology by creating a large midslope topographic low, providing space accommodation for the Pyreneo-languedocian fan.

Introduction

In the Gulf of Lions – Western Mediterranean Sea, a complex network of Plio-Quaternary submarine canyons transferred an enormous volume of siliciclasts into the basin, notably during Quaternary glacio-eustatic fluctuations (Figs. 1 and 2). The turbidity currents funnelled by these canyons are both volume and time variable, resulting in the deposition of siliciclastic deep-water systems that exhibit distinct thickness and lateral continuity. These complexes evolved according to distinct depositional patterns, developing features of rather different surface morphologies, such as: the Pyreneo-languedocian sediment complex, the Rhône deep-sea fan, and the Marseille and Grand-Rhône sedimentary ridges (Fig. 2). The proposed deposition models for these sedimentary complexes are largely based on seismic stratigraphy that emphasizes the role of glacio-eustatic fluctuations as the major controlling factor of their stratigraphic architecture [e.g. Droz and Bellaiche, 1985; Bellaiche *et al*., 1989; Droz, 1991; Bellaiche and Mart, 1995; Droz *et al*., 2001). But unlike ancient deep-water depositional systems[1], modern depositional systems in deep-water basin margins are more difficult to study due to access limitations to establish the connections between facies distribution, sedimentary processes and stratigraphic architecture. As well as that, although salt tectonics has long been recognized in the study area, none of the above mentioned studies, have focused on salt-sediment interactions and their implications for the growth patterns of deep siliciclastic systems off Gulf of Lions.The purpose of our study is thus to discuss the impact of salt deformation on the Quaternary stratigraphic architecture of the Pyreneo-languedocian sedimentary complex, pointing to a rather distinc evolutionary scenario for this sedimentary complex, being essentially controlled by salt tectonics. This study is based on closely spaced multichannel seismic reflection profiles. Chronostratigraphy is controlled by three oil-exploration wells (Autan, GLP2 and GLP1) and the seismic sections grid.

Salt tectonics offshore Gulf of Lions

The Plio-Quaternary salt-structural evolution of the Gulf of Lions was primarily controlled by gravitational gliding over a Messinian detachment salt level. Gravity gliding produced three main tectono-stratigraphic provinces (Gaullier, 1993; Reis, 2001), as classically identified on passive margin basins: an uppermost Listric Faults Province, an intermediate Rigid Gliding Province and a lowermost Salt Domes Province. The Listric Faults Province is largely dominated by basinward-dipping faults and expanded stratigraphic wedges. Faults strike is dominantly parallel to subparallel with respect to the shelf break direction. Downslope, the Rigid Gliding Province is characterized by a rather tabular salt layer, and the overlying sediments remain parallel to the top of the salt. In the Salt Domes Province, salt diapirs increasingly break through the overlying sediments, forming local sediment thickenings. Our study area is located within the extensional zone (Reis, 2001).

The Pyreneo-languedocian Sedimentary Complex

The Pyreneo-languedocian sedimentary complex is a lobate sediment accummulation that reaches up to 1.000 m thick (Figs. 2, 3 and 4). Recent seimic investigation of this sediment body (CALMAR Mission, 1997) revealed successive layers displaying regular undulated parallel

[1] In the conceptual model of sequence stratigraphy, deep-water systems are deposited in lowstand system tracts, which are composed of prograding wedge complexes, slope fans and basin-floor fans (Posamentier and Vail, 1988). These systems can be classified into a series of models on the basis of grain size and sediment transport efficiency (Reading and Richards, 1994).

and continuous reflectors (Berné *et al*., 1999). The deposition model proposed for this complex is quite controversial. Berné *et al.* (1999) and Droz *et al.* (2001) interpret this sedimentary feature as a sedimentary ridge similar to the Var Sedimentary Ridge located along the Provençal margin. The wavy acoustic facies, consistent with sediment waves bedforms, was interpreted as the result of overflow of turbidity currents funneled by the Sète canyon-valley system. The resultant sediment body asymmetry would then be related to a preferential deposition of turbidity currents over the Sète valley western flank, due to the Coriolis effect and/or the counterclockwise circulation of the Liguro-Provençal geostrophic currents flowing along the margin (Figs. 3 and 4). However, the Sète canyon does not appear to be an importante feeder system nourishing this sediment accummulation. Seismic sections across the Sète valley clearly indicate that reflectors at the base of its western levee onlap the Pyreneo-languedocian sedimentary complex (fig. 4). The Sète levee deposit, prevailing along the valley full length, systematically onlaps the sedimentary complex eastern border. This spatial arrangement turned out in apparent depositional continuity between the Sète levee and the Pyreneo-languedocian complex (Fig. 4). This apparent continuity reinforces a deceiving external morphology of a single large levee thinning westerly from the Sète valley axis, being misleading in terms of the deposition model involved.

On the contrary, Reis (2001) and Reis *et al*. (2002-submitted), based on a denser data base, favours a fan-like depositional model, fed by the Pyrenean canyons (Fig. 2). These canyons are located directly upslope the sediment accummulation, exhibting features that indicate recent transport activity. Upslope the salt province, recently conducted swath-bathymetric mapping revealed modern narrow inner valley incisions, notably along the Lacaze-Duthiers and the Cap de Creus canyons (Berné *et al*., 1999). Seismic sections across the intercanyon regions also revealed shifting of High Amplitude Reflectors (HAR) that evidence systematic valley migrations and polyphased constructional activity (Berné *et al*., 1999). Downslope this area, already within the extensional zone, cross sections show flat-floored valleys that testify to a predominant depositional environment. Sesimic sections also show asymmetric acoustic units characterized by interbedded subparallel reflections, suggesting thick overflow levees deposition. Immediately basinwards, traces of channel-levee deposits are not at all observed and a wavy acoustic facies is thoroughly prevalent. The combined observation of systematic valleys migration and thick levee acoustic facies indicates the relevance of the Pyrenean canyons as active sediment conveyors to the adjacent basin, thus favouring the assumption that these canyons are the main feeders for the sedimentary accummulation located downslope. Furthermore, the significant change in the seismic facies from identifiable upslope channel-levee systems to downslope parallel reflectors is interpreted to reflect the change from channelized to sheetlike deposition. This variation in seismic facies conducted us to the interpretation of the Pyreneo-languedocian sediment accummulation as a submarine fan. However, this system is not a typical submarine fan, since at slope level where upper and middle fan features should develop, it is composed of continuous parallel acoustic facies. This abrupt downdip facies variation is a direct result of a strong structural salt-tectonic control (see section below). Stratigraphic correlations show that the fan deposition is synchronous with the Rhône fan Upper Series deposition. Thus, an age of Medium to Upper Pleistocene is estimated.

Salt tectonics: Depocenter creation involving salt-sediment interaction

The Pyreneo-languedocian Sub-basin Domain occurs as an isolated salt structural subsystem offshore Gulf of Lions (Fig. 3). Contrarely to the radial pattern of salt flow observed all over the gulf, this region is significantly affected by preferential basinward salt mobilization. In plan view, the subsytem limits are defined by steep faults running nortwest-southeastly. These faults roughly line up with either the lateral edges of the original salt basin (western subsystem limit) or with residual topography below the salt mass (most of its eastern limit) (Figs. 3 and 5). These faults acted essentially as thin-skinned transfer faults and hence, most of the system seems to be laterally constrained, inhibiting the salt mass from moving in all directions. We estimate that this configuration favoured preferential basinward salt migration, what led to significant salt accummulation into the distal system. This particular history of salt withdrawal is clearly reflected by changes in the degree of the structural development of successive stratigraphic levels. Quaternary active faulting is concentrated along closely spaced updip faults, while downslope faulting is restricted to the Pliocene sequence, not at all affecting the overlying Pyreneo-languedocian fan (Figs. 3 and 5). This structural framework results from diachronous intervening mechanisms acting through the Plio-Quaternary salt structural evolution of this domain (Reis, 2001; Reis *et al*., 2002-submitted).

During the Pliocene, the salt-structural system evolved by a combination of overburden translation and subsidence, testified by the stacking pattern of stratigraphic units. In the Early Pliocene, salt deformation operated by extension and block rotation, corroborated by the expanded growth wedges depicted along distal rollovers in Fig. 5. Toward the top of the Pliocene sequence, as salt was being progressively evacuated, distal rollovers subsided into the evacuated salt horizon. This overburden vertical movement resulted in the symmetric stacking pattern of hanging wall infillings, leading to the thickening of the distal Pliocene series as unequivocally illustrated in Fig. 5. This process is accompanied by considerable volume of basinward salt migration, pictured by midslope fault welds and thick salt accummulation in the form of salt-cored smooth anticlines in the deeper basin (Fig. 5).The combined effect of subsidence and distal salt thickening had a major impact on bottom morphology by imposing bathymetric highs over thickened salt and by creating a large midslope topographic low. The resulting structural effect of the this regional bottom back-tilting was the creation of a wide slope sub-basin, providing space accommodation for clastics (Fig. 5).

Subsequent Quaternary sediment influx was deposited in the salt-induced sub-basin that had been previouly created along the Pliocene salt tectonics. Quaternary units gradually filled up the midslope sub-basin, onlapping the distal uplifted sea-floor (smooth anticlines), which probably acted as a barrier for sediment dispersal (Figs. 3 and 5). Although this topographic barrier is not pervading through the entire sequence deposition, the general midslope sea-floor flattenning seems to have been sufficient to produce a sharp bottom gradient break (levelled deposition surface) able to stop massive Quaternary turbiditic influx, thus favouring unchannelized deposition (Fig. 5). On the other hand, the questian why this region is thouroughly affected by sediment waves remains opened. Apart from the counterclockwise Liguro-Provençal geostrophic currents, flowing along the margin and already suggested to explain such features (Berné *et al.*, 1999), the lack of direct measurement turns it difficult to asses the impact of the local bottom hydrodynamic regime on the sedimentation pattern.

Conclusions

Salt deformation and clastic sedimentation are intimately related processes offshore Gulf of Lions, having direct implications for the sedimentary architecture of the Pyreneo-languedocian depositional system. As well as that, this fan is a unique feature at the gulf scale. Depocenter location indicates that here unchannelized sedimentary environment occurs at slope level, thus in minor water depth in relation to all other deep-water sedimentary systems offshore Gulf of Lions. Slope unchannelized deposition finally argues for proximal retention of sandy facies. An interesting point about this area is that salt-sediment interaction is this case is not identifiable from the surface morphology of the sedimentary complex, since the external Pyreneo-languedocian fan morphology masks the intervention of salt deformation in its internal stratigraphic organization.

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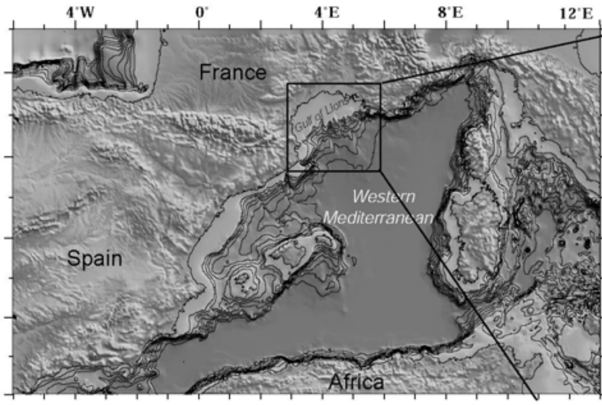

Figure 1: Regional map of the Western Mediterranean Sea (after GTOPO30, Smith and Sandwell, 1997).

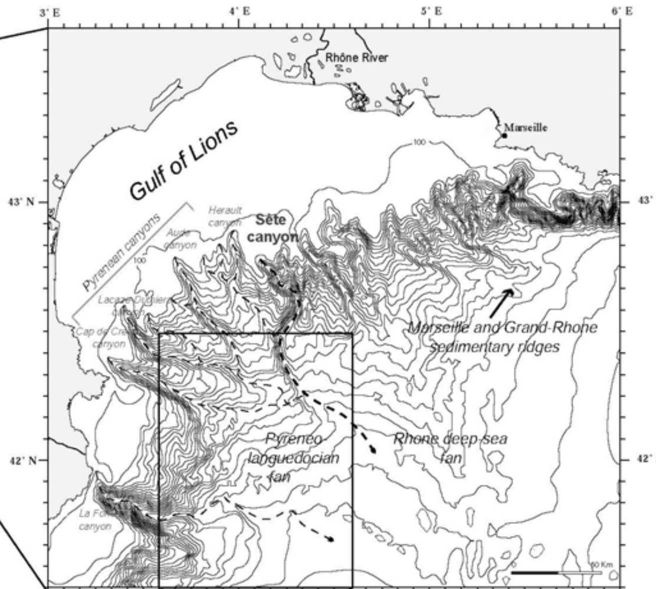

Figure 2: Location map of the area, showing the deep-water depositional systems offshore the Gulf of Lions.

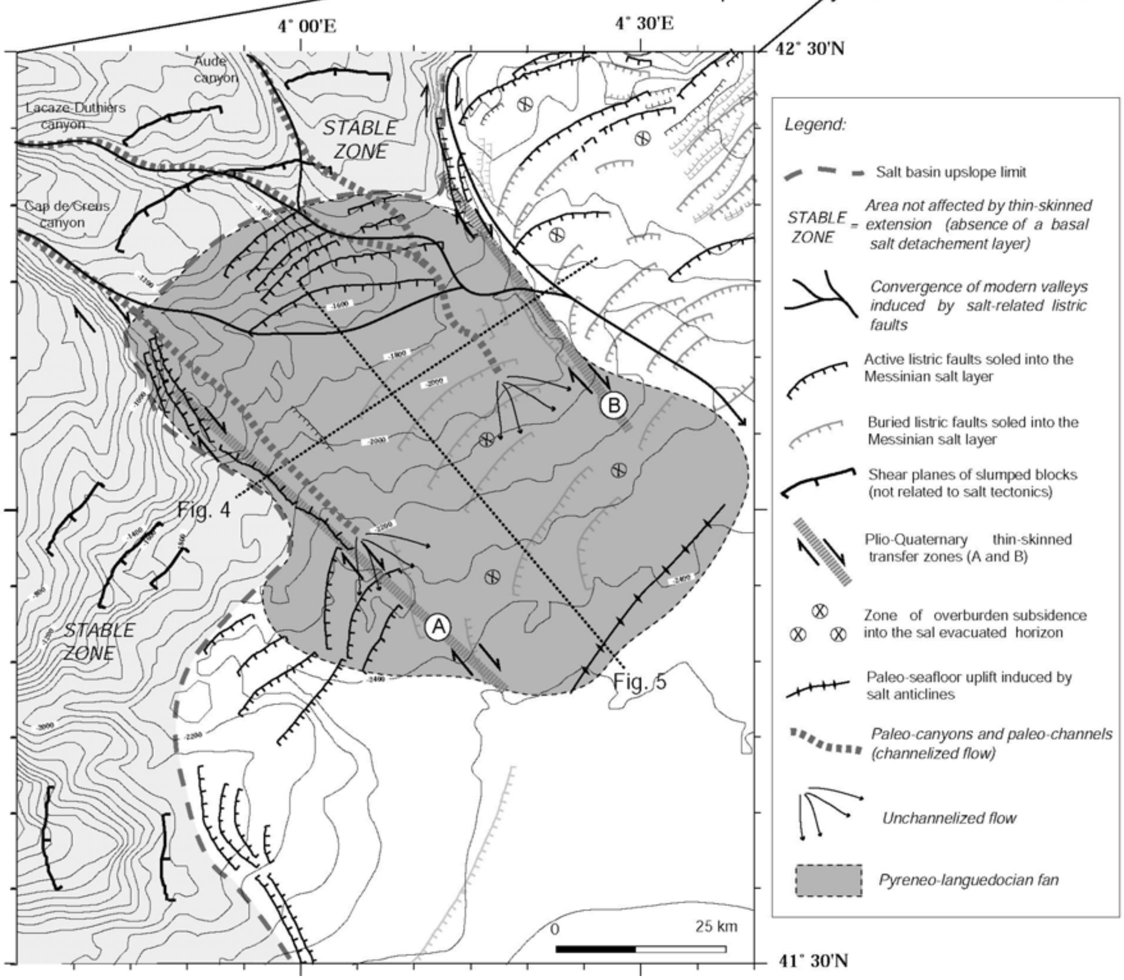

Figure 3: Summary sedimentary and salt-structural map of the Pyreneo-languedocian fan area, illustrating the fan feeder system and the major salt-related structures. The generation of the Pyreneo-languedocian fan depocenter at slope level is intimately related to salt-tectonic processes that operate in the area. The effect of Pliocene overburden subsidence into the evacuated salt-horizon provided space accommodation for Quaternary clastics deposition (the Pyreneo-languedocian fan).

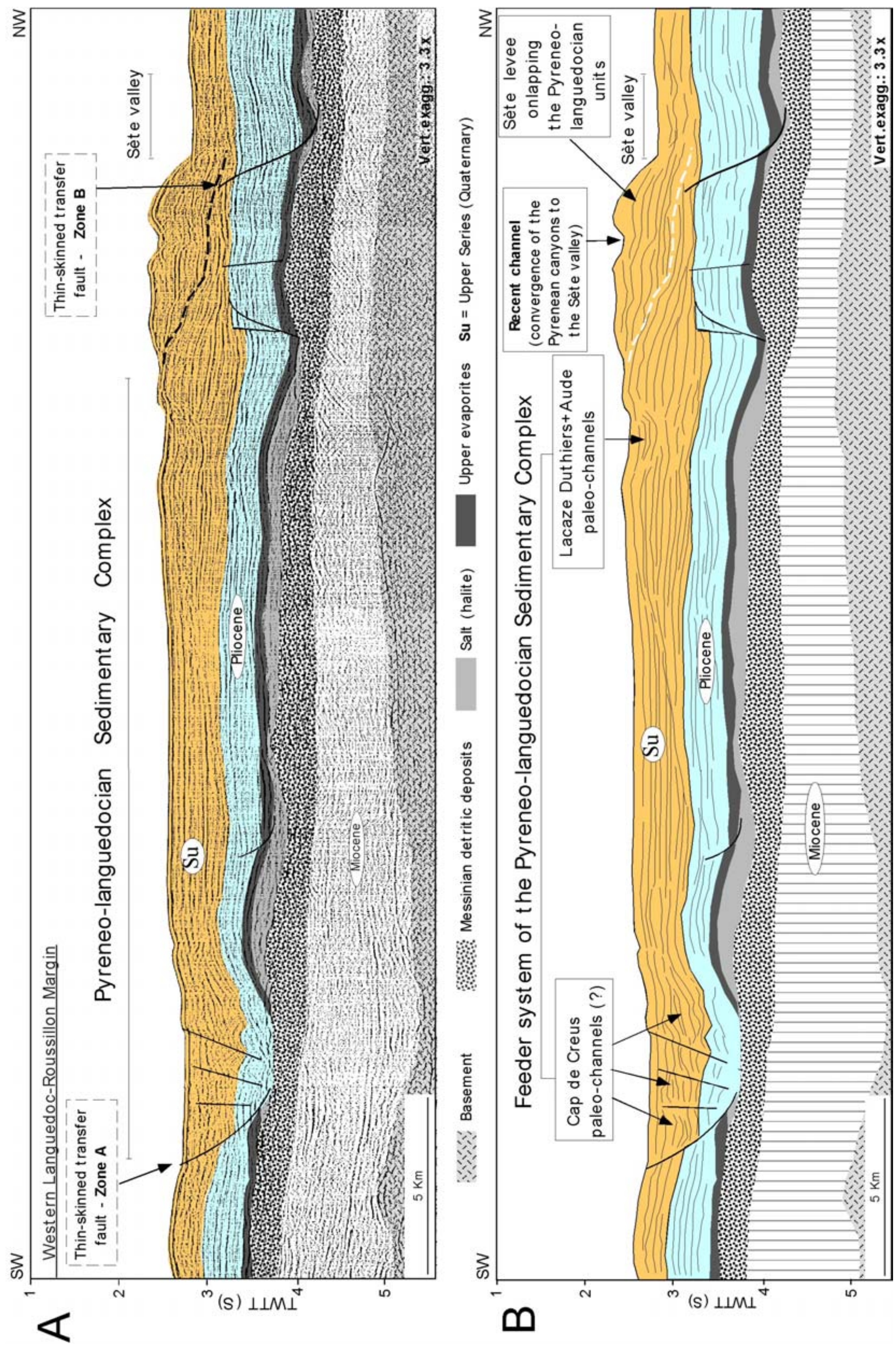

Figure 4: A - Interpreted seismic section across the Pyreneo-languedocian sediment complex. B - Line drawing showing distinct depositional features related to sediment funelling by the Pyrenean canyons and the Sète canyon. Seismic section location in figure 3.

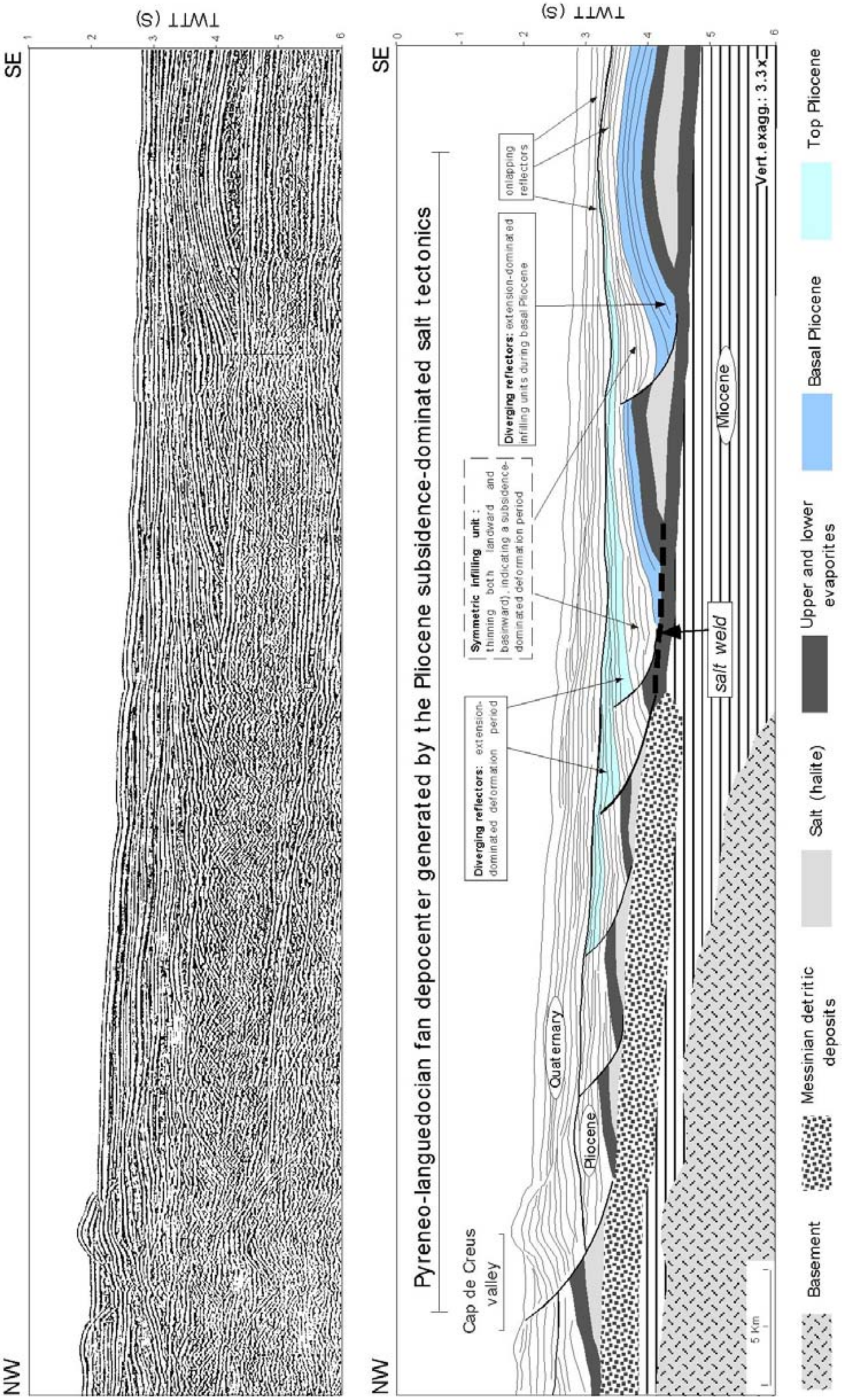

Figure 5: Uninterpreted seismic deep section (top) across the Pyreneo-languedocian Sub-basin Domain (LISA seismic line) and detailed line drawing (bottom) illustrating the main deformational phases involved in the generation of the slope sub-basin. Seismic section location in figure 3.