Structure and kinematics of the Ayora-Cofrentes Diapir (eastern Betics). Role of basement faulting in the salt and suprasalt deformation of the Mesozoic cover.

Estructura y cinemática del diapiro de Ayora-Cofrentes (Béticas orientales). Rol de las fallas de basamento en la deformación salina y suprasalina de la cobertera mesozoica.

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Abstract: *The Ayora-Cofrentes Diapir is a 34 km long N-trending salt wall cutting the Valencian Domain that is made by Middle to Upper Triassic salt. On both sides, it is flanked by parallel half grabens offsetting the subtabular strata of the Jurassic to Cretaceous suprasalt carbonate successions. Based on detailed geological mapping and cross-sections, one of them supported by a new magnetotelluric profile, this study analyses the structure and kinematics of this salt wall with the purpose of establishing the role played by the subsalt structure in its development; and, thus, help in the interpretation of diapirs currently incorporated in fold and thrust belts. In this regard, the study evidences the presence of a subsalt basement fault (the Ayora Fault), active as extensional during the Early Jurassic, and reactivated with a reverse throw sometime between the latest Cretaceous and middle Miocene. Both motions are older than the salt wall growth (middle-late Miocene). This strongly suggest that the Ayora-Cofrentes Diapir was not triggered by the vertical motion of the underlying Ayora basement fault but by thin-skinned processes for which this pre-existing basement fault appears to have played a crucial role as salt/suprasal strain localizer.*

Keywords: *salt wall, salt tectonics, décollement, thick- vs. thin-skinned tectonics, eastern Betics.*

Resumen: El diapiro de Ayora-Cofrentes es una pared salina N-S de unos 34 km de longitud que atraviesa el Dominio Valenciano. Está formado por sal del Triásico Medio y Superior; y, a ambos lados, está flanqueada por semi-fosas que afectan las capas del Jurásico y Cretácico. En este estudio se ha analizado su estructura y cinemática en base a cartografías geológicas de detalle y cortes compensados. El objetivo ha sido establecer el papel que ha jugado la estructura infrasalina en su desarrollo; y así ayudar a interpretar diapiros similares actualmente incorporados en los sistemas orogénicos. En este sentido, el estudio muestra que, por debajo de la pared salina, hay una falla extensiva de basamento (la Falla de Ayora) de edad Jurásico Inferior que, posteriormente, se reactivó con una componente vertical inversa en algún momento entre el Cretácico superior y el Mioceno medio. Ambos movimientos son previos al desarrollo de la pared salina (Mioceno medio a superior). Por ello, la pared salina de Ayora-Cofrentes no parece haberse generado por el movimiento de la falla de basamento subyacente sino por deformaciones de piel delgada para las que esta falla preexistente jugó un papel crucial como localizador de la deformación salina y suprasalina.

Palabras clave: pared salina, tectónica salina, *décollement*, tectónica de piel gruesa vs. tectónica de piel fina, Béticas orientales.

INTRODUCTION

Although salt diapiric structures are widespread in the eastern part of the Iberian Peninsula, significant challenges still remain about their driving mechanism. One of the most prominent is to determine if the extension driven diapirs of Triassic salt are related to a thin- or thick-skinned tectonics. Most of these diapirs are involved in younger thin-skinned folds and thrust systems (Pyrenees, External Betics and Iberian Chain) that, detached in the salt, translated them far away from their original position. Consequently, their relationships with the initial subsalt structure must be stablished indirectly, mainly on the basis of the structure/thickness variations of the suprasalt successions; data that very often do not lead to a straightforward answer.

In this scenario, the Valencian Domain and the scarcely deformed cover of the Iberian Massif located westwards (SE Spain) appear as particularly favorable regions to recognize relationships between the basement (subsalt) structure and the diapirism. Both are the only places in *the Iberian Peninsula with outcropping diapirs of Triassic salt that have been little (less than 3 km) or not displaced from their original position.*

This work analyses the structure and kinematics of one of the largest diapir of this sector (the Ayora-Cofrentes Diapir) with the purpose of establishing the role played by the subsalt structure in its development, and, thus, help in the interpretation of similar diapirs currently incorporated in fold and thrust systems. It is a study based on detailed geological maps and several cross-sections, one of them supported by a new magnetotelluric profile.

GEOLOGICAL SETTING

Located northwestwards of the External Prebetic Zone, the Valencian Domain is the outermost unit of the eastern Betic Cordillera (Roca et al., 2006). It is a thin-skinned thrust sheet around 50 km wide made up by a 1,000-1,500 m thick Jurassic-Upper Cretaceous succession. To the north, it is bounded by a NNW to ENE-trending arcuate thrust front (Fig. 1) whose structure and lateral extend indicates a small (less than 3 km) NW to N directed displacement that diminishes westwards to be nearly null west of the Ayora-Cofrentes Diapir. To the south, the Valencian Domain is delimited by ENE-trending folds and minor thrusts (Fig. 1) traditionally defined as the External Prebetic Front (Vera, 1983; De Ruig, 1992). These folds and thrusts are detached at the Upper Triassic salt and they develop over a strip in which the salt detachment dips to the SE and the thickness of the Mesozoic to Cenozoic increases in the same direction. These features are compatible with the presence of a major ENE-trending and SSW-dipping subsalt fault offsetting the top of the Variscan basement with a throw of about 1,300-1,500 m.

The internal structure of the Valencian Domain, like in the rest of the External Betics, is controlled by the presence of the weaker Middle-Upper Triassic evaporitic units between the stronger Variscan basement and Jurassic-Cretaceous suprasalt cover. These weak layers (Keuper and middle Muschelkalk) decouple the deformation promoting two different styles of deformation above and below them. Thus, beneath these salt layers, the subsalt rocks appear to be offset by few planar extensional faults with predominant ENE-WSW and N-S trends that bound rigid polygonal blocks with limited internal deformation. In contrast, the suprasalt Jurassic-Cretaceous cover constitutes a large subhorizontal tabular platform that, bounded by detachment folds and thin-skinned thrusts, is cut by a pervasive set of salt-detached extensional faults and salt walls with N-S, ENE-WSW and NNW-SSE trends.

THE COFRENTES SALT WALL

One of these suprasalt structures is the prominent N-trending Ayora-Cofrentes Salt Wall. This structure, around 34 km long, traverses the entire Valencian Domain, and is flanked on both sides by parallel half grabens that offset the Jurassic to Cretaceous carbonate succession and are filled by Miocene to Pliocene continental sediments.

The salt wall is made up of a layered evaporite sequence of Middle to Upper Triassic evaporites (halite and anhydrites), carbonates and fine-grained detrital sediments. Detailed geological mapping carried out in the Cofrentes and Ayora areas, indicates that its overall internal structure belongs to a global anticlinorium with a roof deformed by synforms and antiforms. These secondary folds involve the Middle Triassic Muschelkalk carbonates up to the uppermost Keuper unit (the so-called K5; Ortí, 1974), and, in general, are westwards inclined detachment folds cut at the diapir edges. They are cored by salt located beneath the Middle Triassic carbonates (upper Muschelkalk) which is inferred to correspond to the middle Muschelkalk.

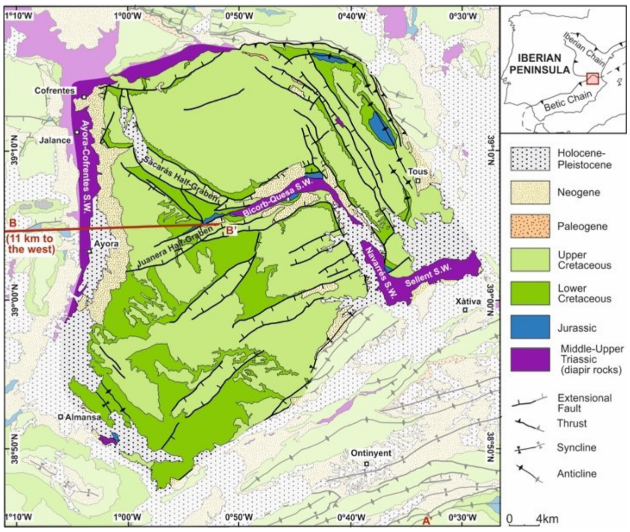

FIGURE 1. Geological map of the Valencian Domain and adjoining Iberian Chain and Prebetic fold-and-thrust belts. SW: salt wall. Solid colors, frames and lines represent the Valencian Domain. B-B': location of the cross-section and magnetotelluric profile shown in Figs. 3 and 4.

The well exposed surface geology also reveals that the long salt wall is elsewhere flanked by suprasalt half grabens bounded by the extruding salt and, in the opposite side, by extensional faults dipping towards the salt wall axis. These asymmetric basins are filled by Neogene deposits, comprising, from base to top: 1) a middle to upper Miocene detrital fluvial to alluvial syndiapiric unit; and 2) a Plio-Quaternary lacustrine marly to limestone postdiapiric unit (Santiesteban et al., 1990).

The middle-upper Miocene sediments lie unconformably on the highly deformed diapiric succession and are affected by the marginal extensional faults. Their syn-diapiric character is defined by: a) the growth-strata geometries shown by the Miocene detrital sediments at the diapir edges where tabular halokinetic sequences have been recognized; and, b) the widespread presence of re-sedimented bipyramidal quartz crystals derived from the K4 Upper Triassic diapiric unit. Those crystals, locally *designated as "jacintos de Compostela", have a diagenetic origin and denote the extrusion and erosion of the salt in the Ayora-Cofrentes Diapir.*

By contrast, the uppermost Miocene to Plio-Quaternary sediments onlap and truncate the marginal extensional faults, and, with a rather constant thickness, lies unconformably over the diapir rocks. They are undeformed except over the salt incised by the fluvial network. Here, mainly above the K4 unit, they appear affected by collapse structures that locally generated some minor secondary minibasins (Fig. 2).

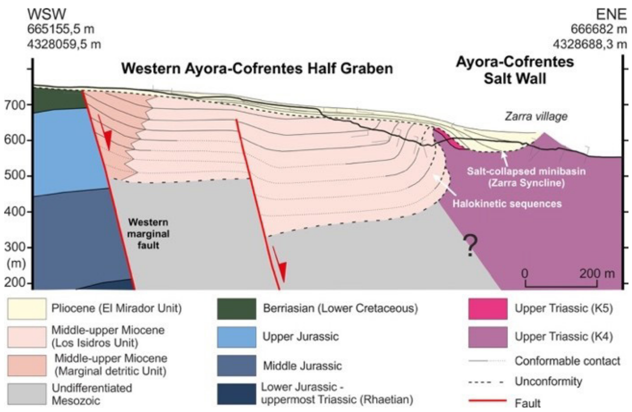

FIGURE 2. Schematic cross-section of the western margin of the Ayora-Cofrentes Salt Wall at the Zarra village. Note the salt-collapse structure at the Zarra village where thickened Pliocene show a growth-strata geometry with beds downlaping a troughshaped unconformity developed over the Keuper K4 unit.

Subsalt (basement) structure

New magnetotelluric data (Fig. 3), the Carcelen-1 well and thickness variations in the outcropping Jurassic and Cretaceous rocks reveal the existence of a c. 30 km long N-trending basement fault beneath the salt wall. This fault, designated as the Ayora Fault, is interpreted to be planar and dipping to the west according to the thickness differences and the regional horizontal attitude of the suprasalt cover on both fault sides. The thickness variations are restricted to the Lower Jurassic which is much thicker in the western block of the fault (Fig. 4). They are not present in the overlying Jurassic and Cretaceous successions which display similar thicknesses on both fault sides.

These data evidences that the Ayora Fault is a W-dipping basement fault that moved as extensional during the Early Jurassic and did not have significant activity during the sedimentation of the Middle Jurassic to Upper Cretaceous successions. The magnitude and orientation of the fault displacement vector during the Early Jurassic is difficult to stablish with the available data. However, from thickness variations, it can be estimated that it generated a throw of the mechanical basement top decreasing from 1,020-1,390 m at the Ayora area to c. 300 m at the Jalance-Cofrentes sector.

After this extensional history, the higher elevation of the base of the Upper Cretaceous (green line in Fig. 3) in the hangingwall denotes that the Ayora Fault reactivated with a reverse throw. The age of this reactivation was older than the Plio-Quaternary whose base has a similar elevation at both sides of the fault (yellow line in Fig. 3). Such uniform elevation of the Plio-Quaternary indicates that the Ayora Fault has not experienced any appreciable throw after the late Miocene. In this sense, the dip-slip normal faulting observed in some late Pleistocene to Holocene fluvial terraces of the Xúquer river are probably linked to dissolution processes of the salt wall along the fault trace.

Considering that the Ayora-Cofrentes Salt Wall and related half grabens developed during the middle-late Miocene, this implies that the formation of these last structures was not linked to the motion of this basement fault but to a thin-skinned stretching of the suprasalt Mesozoic cover. In this scenario, the pre-existent Ayora basement fault acts as a strain localizer of this middle-late Miocene thin-skinned deformation by: 1) shifting the elevation of the décollement (Middle-Upper Triassic salts); and 2) changing suddenly the thickness, and therefore the mechanical behavior of the overburden.

CONCLUSIONS

From the magnetotelluric, structural and stratigraphic data, we can draw the following concluding points regarding the kinematics of the Ayora-Cofrentes Diapir and the associated basement and suprasalt structures:

- *Underlying the salt wall, there is a basement fault (the Ayora Fault) active as extensional during the Early Jurassic and reactivated as a reverse sometime between the latest Cretaceous and middle Miocene.*
- *The passive diapiric rise of the Ayora-Cofrentes Salt Wall took place during the early (?)-late Miocene, contemporaneously with the development of the fringing half grabens. The precise age is not well constrained with the available data but can be expected to happen before the deposition of the first sediments in the two half grabens; this is, during the early-middle Miocene.*
- *Both salt inflation in the Ayora-Cofrentes Salt Wall and fault activity in the fringing half grabens ended at the latest Miocene-earliest Pliocene just before the sedimentation of the Plio-Quaternary deposits.*
- *The Ayora-Cofrentes Salt Wall, consequently, was not driven by thick-skinned stretching but by thin-skinned processes in which a pre-existing basement fault (in this case the Ayora Fault) played a crucial role as salt/suprasal strain localizer.*
- *From the Pliocene, in those areas with fluvial incision, some small minibasins and extensional structures have been developed over the salt wall, apparently related to the halite dissolution of the Upper Triassic K4 unit.*

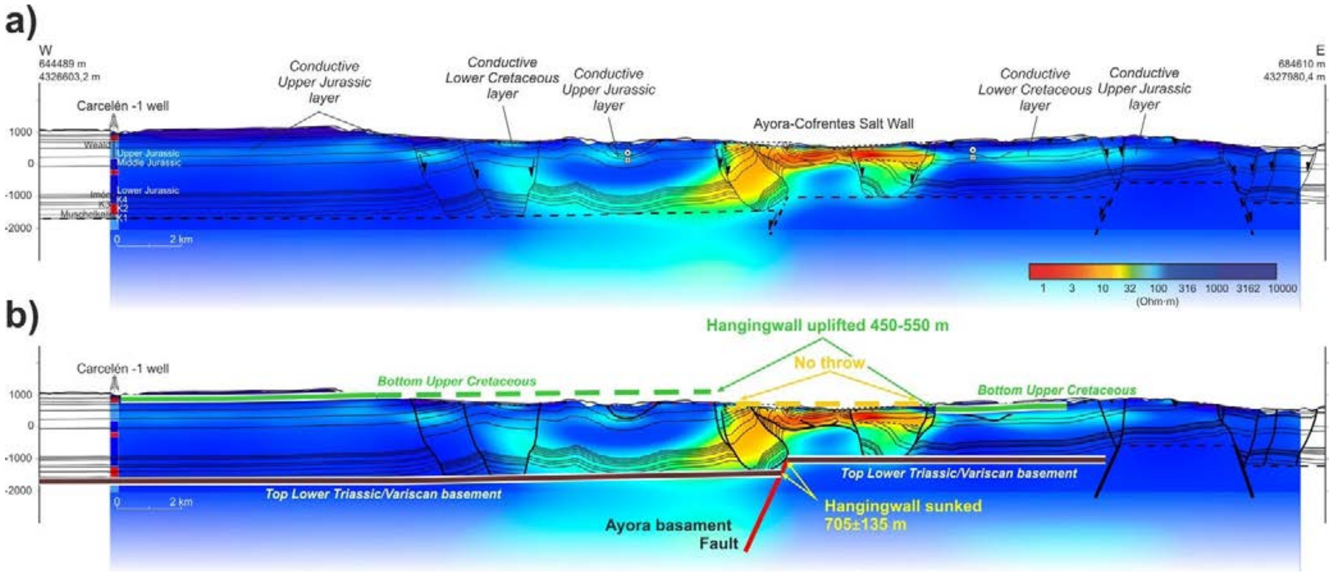

FIGURE 3. a) 2D magnetotelluric model of the Carcelén-1 - Juanera Half Graben transect with the faults and stratigraphic contacts depicted in the cross-section of the Fig. 4; b) Elevation of the top of the Lower Triassic/Variscan basement (thick continuous brown line), bottom of the Upper Cretaceous (continuous to dashed green line) and bottom of the Pliocene (dashed yellow line) on both sides of the Ayora Fault. For cross-section location see Fig. 1

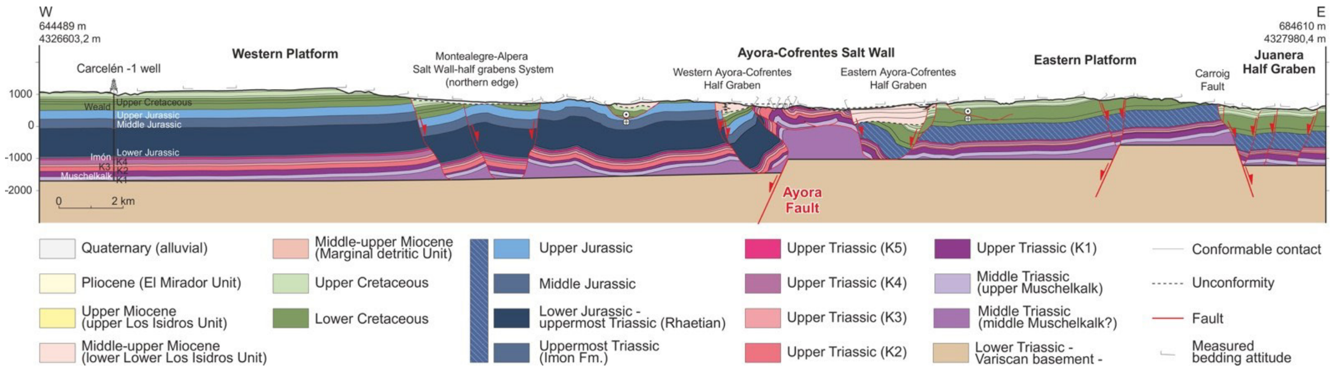

FIGURE 4. Geological cross-section through the central part of the Ayora-Cofrentes Salt Wall extending from the vicinity of the Carcelén-1 exploratory well to the Juanera Half Graben. Subsurface structure constrained by field data, the Carcelén-1 well and the results of the 2D MT model. The dip of the basement faults is speculative. For cross-section location see Fig. 1.

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