Tectonic evolution of the Triassic diapirs in the southern front of the Rif belt, Northern Morocco

Contexto tectónico de los diapiros triásicos del frente de deformación de la cordillera del Rif, Norte de Marruecos

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ABSTRACT

Located at the front of the external Pre-Rif, northern Morocco, at the edge between the Rif cordillera and the Saiss neogen basin, Triassic diapirs constitute one of the main features of this area, occurring within the Meso-Cenozoic allochthonous formations. In order to understand their geological setting and evolution during the Meso-Cenozoic times, we carry out a geological study based on structural analysis and fracturing field investigations. The obtained results are completed by previous geophysical and seismic works. The rising salt bodies (halite, anhydrite and gypsum) in those diapirs was controlled by the two NW-SE and NE-SW system faults from the Mesozoic to the Quaternary. The contacts between the Triassic material and the Miocene sedimentary marls are discussed. Some mapped tectonic contacts, considered as thrusting faults are in fact stratigraphic limits, which are characterized by polygenic conglomerates. These arguments allow us to review the whole history of these salt walls and to discuss their current geometry.

Key-words: *Structural analysis, Fracturing, Salt wall diapirs, Pre-Rif, Morocco.*

RESUMEN

La zona de estudio se ubica en el frente del Pre-Rif externo (norte de Marruecos), en el límite entre la cordillera del Rif y la cuenca neógena del Saiss, y se caracteriza por presentar diapiros triásicos dentro de las formaciones alóctonas Meso-cenozoicas. Para comprender su contexto geológico y su evolución durante el Meso-Cenozoico, realizamos un análisis estructural basado en medidas de fracturación en los materiales que rodean estos diapiros. Los resultados obtenidos se completan con trabajos geofísicos y sísmicos previos. El ascenso de material diapírico (halita, anhidrita y yeso Triásicos) fuo controlado por un sistema de fallas de dirección NW-SE y NE-SW desde el Mesozoico al Cuaternario. El análisis de los contactos entre el material del Triásico y las margas sedimentarias del Mioceno ha revelado que algunos de los contactos tectónicos cartografiados como fallas son en realidad límites estratigráficos caracterizados por conglomerados poligénicos. Este trabajo supone una revisión de la evolución de estos diapiros y un análisis de su geometría actual.

Palabras clave: *Análisis estructural, Fracturamiento, Muros de sal, Pre-Rif, Marruecos.*

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Introduction

Diapir structures involve flow salt with respect to the surrounding sedimentary rocks (Rowan et al., 2020). Horizontal and/or vertical movements of salt produce intense deformations both in the sedimentary hosting rocks and into the diapiric body itself (i.e.Vendeville and Jackson, 1992; Dooley et al., 2015; Alsop et al., 2016; Pérez-Valera et al., 2017; Escosa et al., 2018; Duffy et al., 2018). In this work, we describe salt tectonic deformation at the front of the external Pre-Rif, Northern Morocco. Specifically, we studied two Triassic diapirs and their host rocks, marly Miocene and the Plio-Quaternary limestones in order to propose an evolutionary model of their formation and growth. The Upper Triassic rocks are considered to be the detachment level responsible for the large allochthonous Alpine units in the Pre-Rif domain. Later, the Upper Triassic deposits were remobilized during the Miocene and Quaternary shortening phases. Their structural role has been already discussed, but a number of queries remain to be clarified, especially the tectonic/stratigraphic contact between the Triassic materials and their surrounding Miocene and the Plio-Quaternary strata.

Methodology

In order to infer the evolution of the two studied diapirs we did: (1) a lineament extraction and analysis from an area of 600km^2 containing both diapirs using a Landsat 8-OLI satellite image (free image from USGS database), (2) mesostructural analysis from field data, and (3) a geological description of the outer contacts of the Nzala des Oudaya diapir.

Geological setting of the Pre-Rif diapirs

The Rif fold-and-thrust belt (Northern Morocco) constitutes with the Betic chain (Southern Spain) an arc-shaped Alpine Orogen, related to the convergence between Eurasia and Africa. The studied area is located within the Prerif Nappe, the southern front of the Rif cordillera. The Prerif Nappe is composed by different lithologies that are mixed within Cretaceous to Middle Miocene marls. This tectono-sedimentary olistostrome constitutes the external part of the Rifian accretionary wedge and thrusted over the South-Rif foredeep basin during the late Tortonian (Chalouan et al., 2006). The studied Triassic outcrops are located north of Moulay Yacoub and near the Sidi Chahed dam. To the South of the studied area, the South Rifian Ridges appear (Figs. 1 and 2). We examine here two important diapirs, the Nzala des Oudaya (near the Sidi Chahed dam) and Douar El Harra (located north of Moulay Yacoub).

Nzala des Oudaya Diapir

The Nzala des Oudaya diapir is the most important structure in this region. It is elongated in a NE-SW direction (8 km-long and 2 km-wide), parallel to one of the main faults in the region, the Nzala des Oudaya fault system, trending NE-SW (The 1/50.000 map of Beni Ammar, Zizi et al., 2002; Del Ventisette et al., 2005; Sani et al., 2007).

It can be considered as a salt wall as demonstrated by seismic works (Sani et al., 2007). It is composed by Upper Triassic chaotic clays, salts, gypsum, anhydrite, halite and ophite rocks (Fig. 3). Two main units characterize the diapir; red clays in the southern part, and salts deposits in the northern one. They are separated by Oued El Maleh (Figs. 2 and 3).

Douar El Harra diapir

This diapir is oriented E-W (4 km-long and about 1km-wide). It is located 15Km to the north from Moulay Yacoub and along the Nzala des Oudaya fault. Its Triassic outcrops are mainly composed by salt rocks and red clays. Salt rocks are formed by gypsum and anhydrite with fragments of basaltic rocks, sandstones and dolomites. The Douar El Harra diapir was formed also as a salt wall (Figs. 2 and 3). At its northern border, Miocene white marls strata are superimposed over the diapiric gypsum and halite formations. At its southern border, Triassic rocks overlap highly fractured marly limestones, dipping sub-vertically.

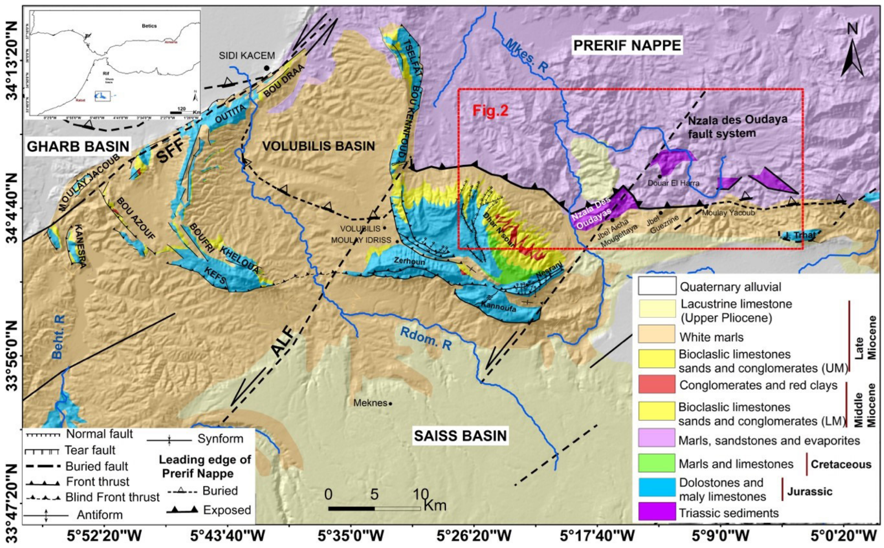

Fig. 1-Structural map of the southern front of the Rif (South Rifian Ridges and Miocene nappes, after Sani et al., 2007). SFF-Sidi Fili fault, ALF-Ain Lorma fault. See figure in colour on the web.
Fig.1-Mapa estructural del frente sur del Rif (Crestas Rifianas Sur y mantos del Mioceno, según Sani et al 2007). SFF-Falla de Sidi Fili, ALF-Falla de Ain Lorma. Ver figura en color en la web.

Results of field geological work

Lineament extraction and analysis

It is evident that the fracturing systems extracted from satellite imagen are dense near the studied diapirs and become rare to absent far from them. Around diapirs, fracture halos can be shown (Fig. 2). The NE-SW fractures appear to be the most dominant. It should be also noted that E-W and NW-SE NNW-SSE lineations are important in Jebel Guerzine and Jebel Aicha Mouguettaya, respectively (Fig. 3).

These fractures show a radial arrangement affecting the Miocene marls and the Plio-Quaternary limestones.

We consider that the NE-SW oriented lineaments constitute a systematic network. This system is the most abundant in terms of frequency and length of fractures. It is expressed in all geological formations outcropping in the area.

Mesostructural analysis

Some normal faults (N160-165, 50ENE and 50WSW) were observed in the Triassic red clays in the Nzala des Oudaya Triassic red beds. These normal faults determine horsts and grabens, sometimes accompanied by tilting blocks and some micro-breccias. In the Jebel Aicha Mouguettaya (the southern border of the diapir), the Upper Pliocene limestones are vertically dipping and sometimes even overturned to the NW and they suddenly become sub-horizontal few hundred meters southwards of the Saiss basin (Habibou et al., 2016). These limestones are affected by submeridian strike-slip faults, which have been interpreted as normal faults before folding (Ahmamou et al., 1988).

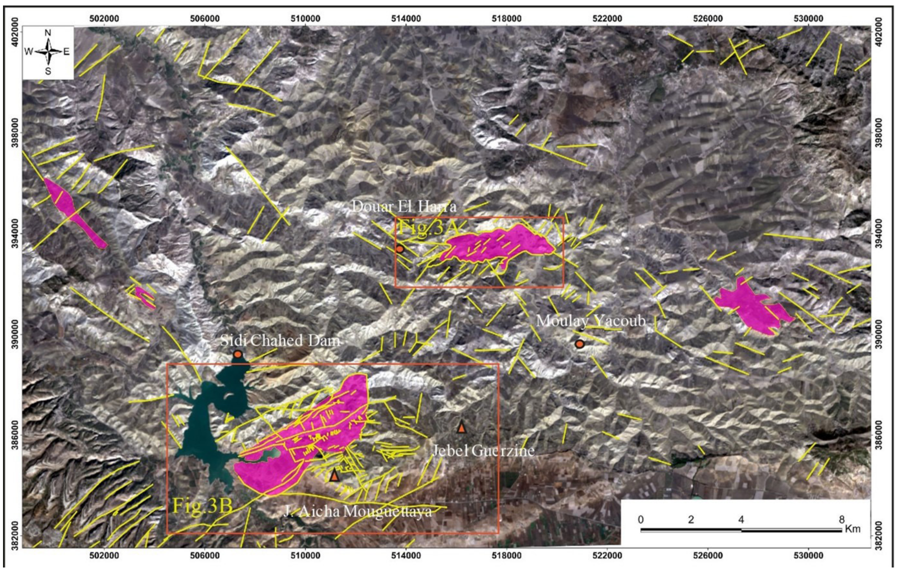

Fig.2 -Extracted lineaments from satellite image (Landsat 8-OLI) of the study area. See figure in colour on the web.
Fig. 2.- Lineamientos extraídos de la imagen satelital (Landsat 8-OLI) del área de estudio. Ver figura en color en la web.

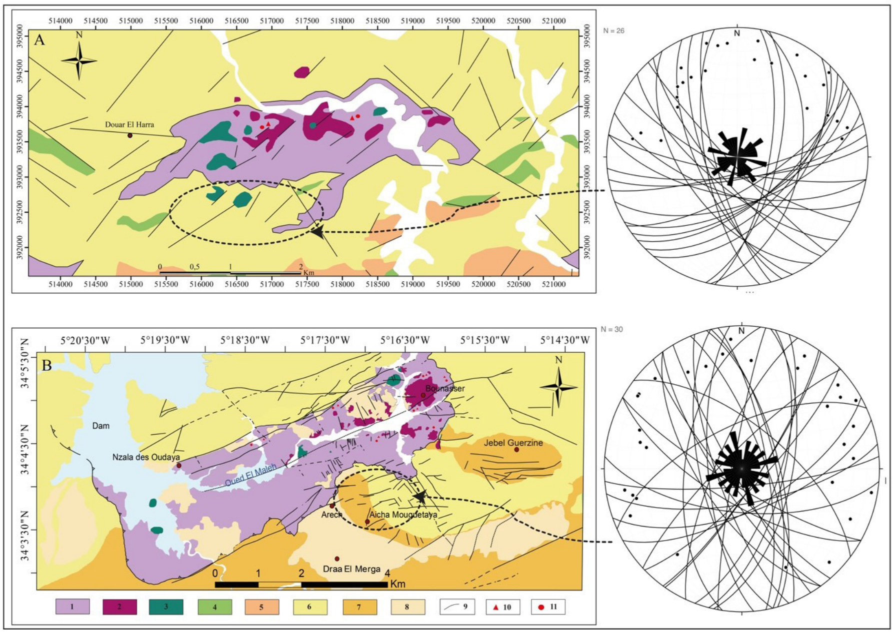

Fig. 3.- Geological maps of the El Harra (A) and Oudaya (B) diapirs with stereoplots of analyzed fractures (Stereonet software). 1. Triassic, 2. Anhydrite-Halite, 3. Ophite, 4. Cretaceous, 5. Paleocene, 6. Miocene, 7. Pliocene, 8. Quaternary, 9. Fracture, 10. Gypsum, 11. Salt. See figure in colour on the web.

Fig.3.- Mapas geológicas de El Harra (A) y Oudaya (B) diapiros. 1. Triasico, 2. Anhidrita-halita, 3. Ofita, 4. Cretácico, 5. Paleoceno, 6. Mioceno, 7. Plioceno, 8. Cuaternario, 9. Fractura, 10. Yeso, 11. Sal. Ver figura en color en la web.

Along the southern side of Douar El Harra diapir, the stratification is trending N120 to N140 with a dip of 40° to 60° NE. Sometimes, the stratification is vertical. Miocene white marly-limestones are in direct contact with the Triassic rocks and are highly fractured. Different sets of fractures have been found oriented N40, N70, N155 and NS (Figs. 2 and 3).

Geological description of the outer contacts of the Nzala des Oudaya diapir

In the Nzala des Oudaya diapir, the northern contact between the Triassic and Miocenestrata is sub-vertical and linear, but the southern part is sinuous and the Triassic rocks seems to be overlain by the Miocene marls and Plio-Quaternary lacustrine limestones. The NE contact zone shows a clear relationship between the Triassic and its Miocene surrounding rocks. Indeed, at the outcrop edge, we can observe subvertical (70-75°E) conglomerates of metric thickness, consisting of pebbles of different sizes and facies (Fig. 4). This polygenic and heterometric conglomerates is broken and marks the boundary between the Triassic and Miocene, while sometimes the conglomerate scraps can be found above the Triassic outcrops, a few meters further from the contact zone. This conglomeratic level is composed of pebbles of different origins (Jurassic limestones and sandy-limestones, fragments of quartzites, sandstone pebbles). The latter marks the cartographic limit between the Triassic outcrop and the Miocene marls and showing the beginning of the Miocene transgression on the earlier Meso-Cenozoic series and the Triassic materials that have already pierced their cover (Fig. 4). Along the SE border, the Plio-Quaternary limestones are vertical and sub-horizontal in few meters to the south. They are affected by decametric folds with ENE-WSW oriented axes (N60 to N70), sub-parallel to the Jebel Aicha Mouguettaya crest. Further south in Draa El Marga, similar folds, en echelon have been described by Sani et al. (2007) affecting the upper Pliocene limestones. The seismic works in this region (Zizi, 2002; Del Ventisette et al., 2005; Sani et al., 2007) detected a Triassic dome buried under these limestones that would be responsible, partially of these deformations that affect the Plio-Quaternary strata.

Interpretation and conclusion

Both the squeezed Nzala des Oudaya and Douar El Harra diapirs are typical salt walls, elongated in a NE-SW and E-W directions respectively. They are made up of at least three groups: i) red clays, ii) salt-bearing rocks corresponding mainly to halite and gypsum and finally iii) ophite volcanic rocks and dolomies. It's important to underline that when dealing with deformation patterns around salt structures, it is difficult to distinguish between structures resulting from regional stress and those related to salt flow itself. In literature, it's widely admitted that fracture density decreases away from diapir margin (Rowan et al., 2020). Starting from these considerations, we consider that the fracture halos around Triassic outcrops are the result of the active halokinesis in both diapirs.

The Oudaya diapir particularly shows poly-phased tectonic setting since the Mesozoic times until the Plio-Quaternary (Fig. 5). Indeed, the NE-SW trending Nzala des Oudaya system faults which delimit this Triassic outcrop, is inherited from the Paleozoic basement, and reactivated in normal faulting during the Triassic-Jurassic extension. It is at the origin of the initiation (doming stage) and the amplification of this diapir. The remobilization of Triassic salt in this region is widely demonstrated by seismic profiles that have concerned the Miocene Pre-Rif and the South Rifian Ridges (Sani et al., 2007; Roldan et al., 2014; Martín-Martín et al., 2016; Capela et al., 2017). The halokinesis was initiated and then amplified during these extensive movements, taking advantage of these dislocations affecting the Paleozoic basement and reactivated as normal faults during the Mesozoic extension.

The presence of a polygenic conglomeratic level marking the contact between the Triassic and the Miocene, suggests that the salt would have pierced the Mesozoic cover before the Miocene transgression (Miocence post-nappes). This diapiric movement obviously continued during the upper Miocene, Pliocene and the Quaternary, deforming surrounding strata. The Pliocene limestones show vertical and sometimes inverted dips along the southeastern edge of the diapir and correspond to flap structures that occur along the SE border. However, a part of deformation can be linked to the compressive regional tectonic events occurring during the Cenozoic.

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Fig. 4.- Photographs showing the transgressive conglomerate along the NE contact between the Triassic and Miocene marls. See figure in colour on the web.
Fig. 4.- Fotografías que muestran el conglomerado transgresor a lo largo del contacto NE entre las margas del Triásico y del Mioceno. Ver figura en color en la web.

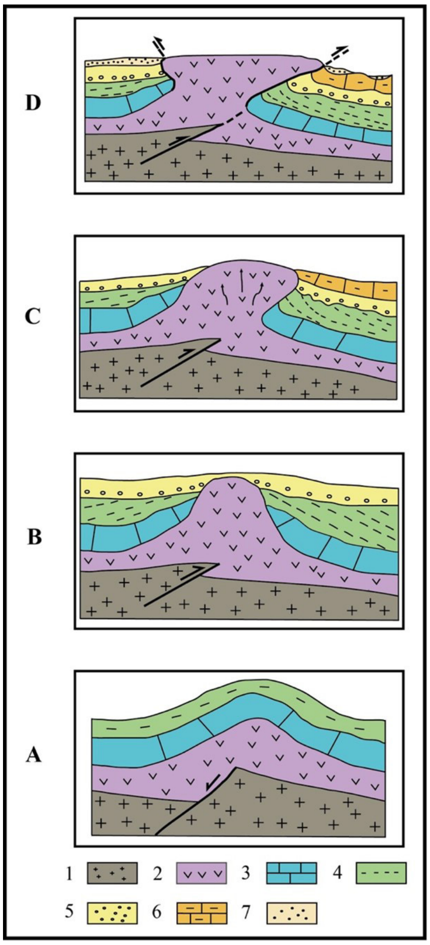

Fig. 5.- Evolutionary stages of the Triassic diapir of Nzala des Oudaya. A. During Jurassic-Cretaceous, B. During the Miocene, C. During the Pliocene, D. Quaternary-Present.1. Paleozoic, 2. Triassic, 3. Jurassic, 4. Cretaceous, 5. Miocene, 6. Pliocene, 7. Quaternary. See figure in colour on the web.
Fig. 5.- Etapas evolutivas del diapiro Triásico de Nzala des Oudaya. A. Durante el Jurásico-Cretácico, B. Durante el Mioceno, C. Durante el Plioceno, D. Cuaternario-Presente 1. Paleozoico, 2. Triásico, 3. Jurásico, 4. Cretácico, 5. Mioceno, 6. Plioceno, 7. Cuaternario. Ver figura en color en la web.

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Authors contribution

All authors executed the field work and interpreted the results. Hmidou El Ouardi, Maria Mazouar and Afaf Amine wrote the manuscript.

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