Journal of Materials and Environmental Sciences
ISSN : 2028-2508
CODEN : JMESCN

J. Mater. Environ. Sci., 2018, Volume 9, Issue 2, Page 336-343

http://www.jmaterenvironsci.com

Influence of Mesozoic distension on the triggering of halokinesis in the Prerifan ridges (Morocco, southern Rif): contribution of seismic and well data

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Received 01 Jul 2017,
Revised 16 Sep 2017,
Accepted 18 Sep 2017

Keywords
- ✓ The Prerifan ridges,
- ✓ seismic,
- ✓ extension,
- ✓ salt tectonics,
- ✓ post-rift stage.

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Abstract
The seismic analysis has shown that the area of the Prerifan ridges is marked by the superposition of three major geological events: the Triassic-Liassic extension, salt tectonics and Miocene-Pliocene compression. These events have created the fold-faulted structures which show a saliferous heart and which are located at the top of the normal faults. This study based on the subsurface data shows that the area was marked by a very active phase of salt tectonics prior to the Miocene-Pliocene compression. A detailed analysis of the sedimentary markers, tectonic markers and halokinetic markers of the post-rift series shows that the halokinetic movements were triggered by the reactivation of normal faults and were increased with sedimentation and with the Miocene-Pliocene compression. The analysis showed that the halokinetic movements were not synchronous for all salt structures identified in the area; the first ones were recorded prior to the Domerian. This research shows also that most of the salt diapirs are pre-orogenic, and possibly had a prominent role in determining the location of folds during the Alpin orogeny.

1. Introduction
The external Rif, which is part of the North African margin, recorded the effects of divergence between Africa and America as he recorded the effects of convergence between Africa and Europe. The Prerifan ridges are the frontal part of the external Rif (Figure 1). They are formed by a set of reliefs made of Jurassic deposits framed by Neogene marls. The Meso-Cenozoic tectonics-sedimentary history recorded by the sedimentary cover is characterized by two periods of different tectonic regimes [1-6]:
- A Mesozoic period marked by an extensive tectonic regime,
- A Cenozoic period marked by a compressive tectonic regime.

A basal detachment at the level of the Triassic salt have been supposed by Daguin [7] and Durand-Delga & al. [8]. This detachment was confirmed by the studies based on the subsurface data [3-6]. Consequently the basement faults could not have influenced the Cenozoic compressive phase. The seismic studies have also confirmed the existence of the salt tectonics prior to the compressive tectonic phase [3-6].

2. Objectives and Methodology
The previous studies based on subsurface data showed that the structures of Prerifan ridges are complicated by the extensive tectonic inheritance and halokinetic movements [3-6]. In this study based on seismic reflection and well data, a detailed analysis of the salt structures identified in the studied area was carried out taking into account several local factors. So, the objectives of this study are multiple:
- produce an isopach map, which allows identifying the different salt structures in the area,
- determine the timing of triggering halokinetic movements in the area,
- determine the normal fault / salt structure relationship,
- determine the inverse fault / salt structure relationship,
- propose a model explaining the current architecture of salt structure in the area.

Figure 1: Simplified geological map of Rif chain (according to Suter [9]; location of the study area)

For the working methodology, a hundred seismic profils coorresponding to 1400 km have been interpreted (Figure 2). The geological interpretation of the seismic profils requires the calibration of certain seismic horizons which delimit the main seismic sequences.

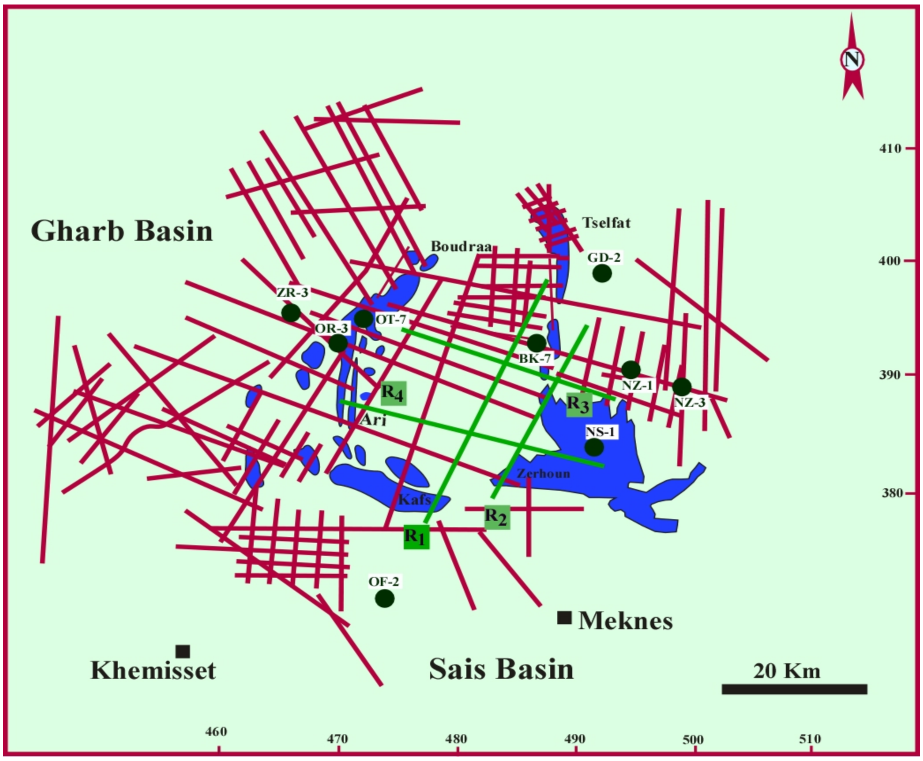

Figure 2: position plan of seismic profiles interpreted in the study
OR-3, ZR-3, OT-7, OF-2, NS-1, BK-7, GD-2, NZ-1, NZ-3 : wells used in the study
R_1, R_2, R_3, R_4 : seismic profiles presented in this paper

The calibration carried out in this study by using data from nine wells (Figure 2) allows to find the relation between, the seismic profiles which present the geological events in time scale, and the well data which present the same events in metric scales. To find this relation we must establish the relation T = f (p). In the first stage, we started the calibration by certain key sections that are intersected, at least, by a well where the formations traversed are dated and where the data of seismic velocities are available. The combination of the seismic reflection and the boreholes data allowed us to distinguish seven horizons on the seismic sections :

- roof of the Paleozoic basement,
- roof of the Tiassic,
- roof of the Domerian,
- roof of theToarcian,
- roof of the Aaleno-Bajocian,
- base of the Prerifan nappe,
- roof of the Prerifan nappe.

The different horizons are then correlated on all the seismic profiles through the seismic mesh of the study area. The second stage is the correlation and the mapping of the normal faults in order to determine their directions in space. The last stage is to produce an isopach-time map of saliferous series inorder to identify the salt structures in the area. We noted the difference between the time values of the two horizons that delimit the triassic saliferous series.

3. Stratigraphy of the post-rift series

In Morocco, the age of syn-rift series is Trias to basal-Lias [10, 11]. The basalts of the Prerif to whom the study area belongs give an age which corresponds to the Hettangian (185 Ma) [12]. The study area is one of the basins characterized by a powerful syn-rift halitic series that overcomes detritic deposits [13]. The drill data allowed recognizing the Triassic series in the area that generally comprise five formations: 1- infra salt detritic formation, 2- lower Clay-salt formation, 3- volcanic formation (basalts), 4- upper Clay-salt formation, 5- upper detritic formation. The well OR-3 that crosses the Triassic series shows that this series begins with the basalts that rest directly on the Paleozoic (Figure 3).

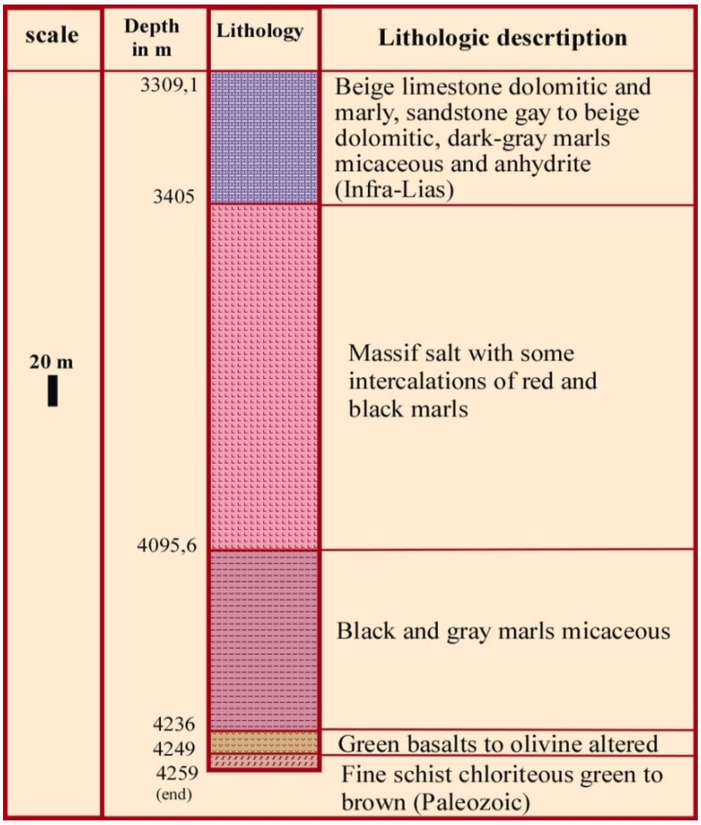

Figure 3: Lithostratigraphic Log of Triassic of Prerifan ridges (well OR-3, see location in Figure 2 and Figure 4)

The post-rift stage begins in the area of the Prerifan ridges at Lias with the installation of the carbonate platform and ends with the first inversion's index of the tectonic regime at the Tortonian. The post-rift series is composed of the three series: Jurassic series, Cretaceous-Paleocene series and Infra-nappe Miocene series.

3.1. Jurassic series

Jurassic terrains largely outcop in the study area. Faugères groups these terrains into three series [2]:
- Reduced series formed essentially of carbonate facies of Lower and Middle Lias.
- Intermediate series composed of carbonate deposits of internal platform of the Lower and Medium Lias, overcome by marl and marl-limestone deposits of Toarcian then by sandstone deposits of the Bajocian.
- Thick series which include marly and sandstone-marly facies of Toarcian and Bajocian.

3.2. Cretaceous-Paleocene series

The Cretaceous and Paleocene formations were limited to the eastern part of the study area [2]. Only the boreholes carried out at the oriental ridges crossed these formations which are made up essentially of marls and marl-limestones.

3.3. Infra-nappe Miocene series

The series are formed of deposits previous to the installation of the Prerifan nappe at the Tortonian. According to the end-of-poll reports, we can distinguish from the bottom to the top: the series of gray marl of lower Vindobonian, the gray-sandy-limestone series of the Burdigalian, and the series of Aquitanian made up of marl and marly- sandstone limestones that rest on crystalline limestones.

4. Extension phase and salt tectonics: Interpretation of seismic profiles

The interpretation of the seismic reflection data allowed us to elaborate an isopach-time map of the Triassic-Liasic salt series (Figure 4). This map highlights the different salt structures revealed by the seismic sections in the study area. A global analysis of the map shows that all salt structures, except the Ari ridge, are associated with normal faults and extend in two same directions, namely E-W and NNE-SSW. These results indicate that the extension must have controlled the diapirism of the Prerifan ridges (Figure 4).

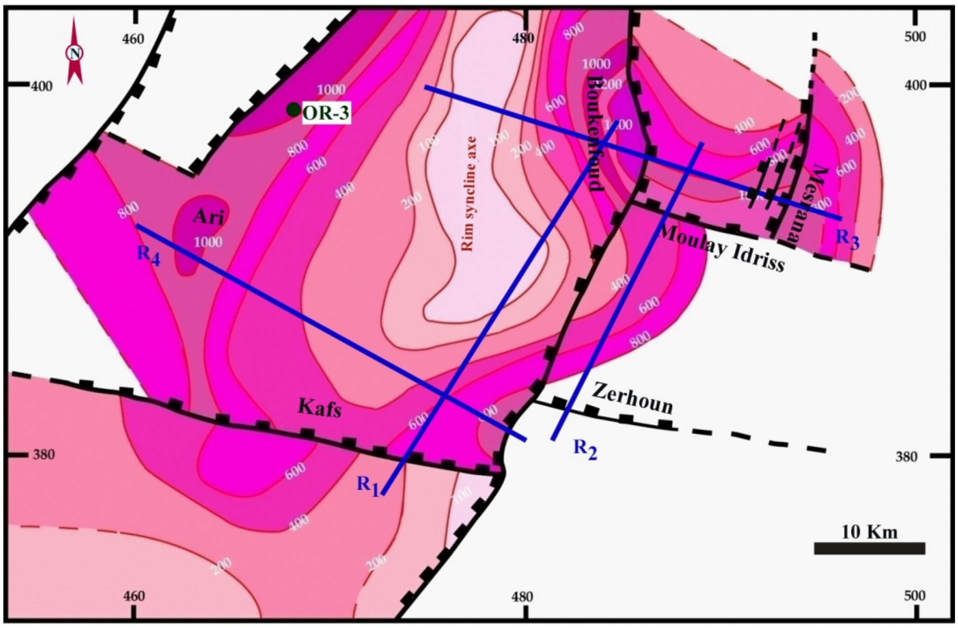

Figure 4: Isopach-time map of the Triassic-Liasic salt series (location of the profiles illustrating the salt structures)

In the following paragraphs, we will describe and analyze four seismic profiles (see location on Figure 4):
- Seismic profile R_1 which crosses the Kafs and the Boukenfoud ridges,
- seismic profile R_2 which crosses the Zerhoun and the Moulay Idriss ridges,
- Seismic profile R_3 which crosses the Boukenfoud and the Mesrana ridges,
- Seismic profile R_4 which intersects Ari ridge.

4.1.The salt structure of Kafs

The R_1 seismic profile and the Isopach-time map show that the Kafs salt structure is clearly related to the Kafs normal fault F_k (Figures 4 and 5). The analysis of the seismic facies of the supra-salt sequences shows that the Domerian sequence presents a thinning near the ridge. Indeed, some reflectors of this sequence end in "Onlap" against the roof of the salt series (Figure 5). The "Onlap" within the Domerian sequence indicates that the movement of the salt was triggered before the Domerian.

The sequence representing the Toarcian also shows that certain reflectors end in "Onlap" against the roof of the Domerian serie. On the other hand, the sequence representing the Aaleno-Bajocian shows a thinning at the approach of the Kafs ridge with a Toplap truncation that coincides with the Miocene uncomformity (Figure 5). These data indicate that the halokinetic movements were triggered before the Domerian and were very active during the Jurassic period. These movements resulted in salt ridge whose summit was eroded before the Miocene.

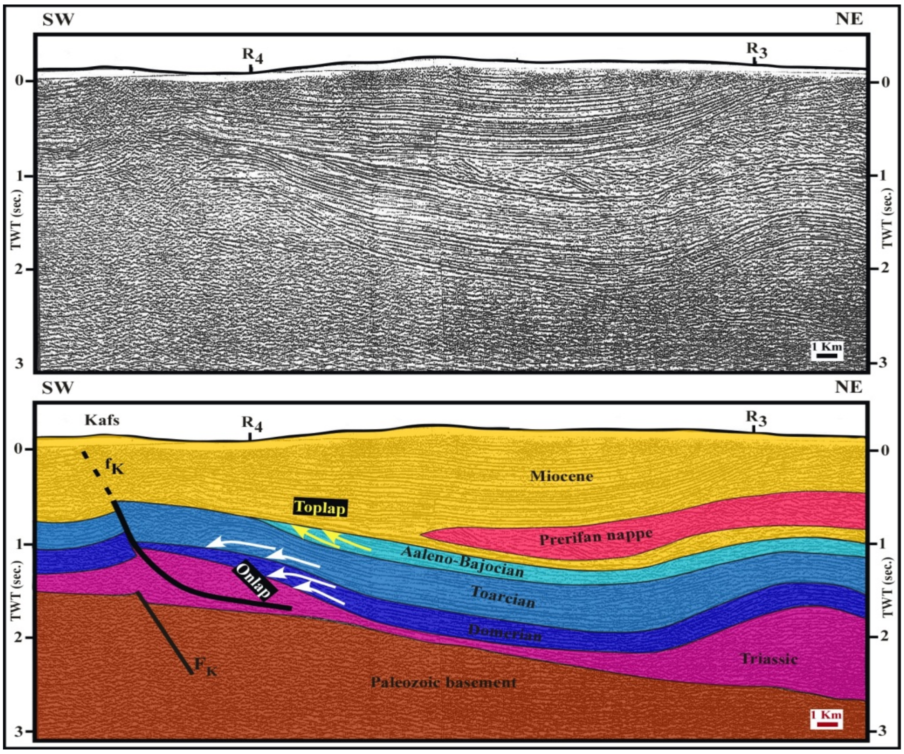

Figure 5: Seismic profile R_1 illustrating the salt structure of Kafs (see location in Figure 4)

4.2.The salt structures of Zerhoun and Moulay Idriss

The seismic profile R_2 shows that these two salt structures form the cores of two fold-faults which are located respectively at the top of the two normal faults of Moussaoua (F_M) and Moulay Idris (F_{MI}) (Figure 6). The Jurassic series show no real variations in thickness. This observation allows us to deduce that the movement of the salt at these two ridges was not triggered during the Jurassic.

On the other hand, the syn-compression series shows an important thinning at the approach of the two ridges. The halokinetic movements of these two structures are therefore largely related to the compressive movements. The seismic profile R_2 shows the pull up structure (Figure 6) which is an anomaly of the seismic wave propagation velocity induced by the presence of salt [14].

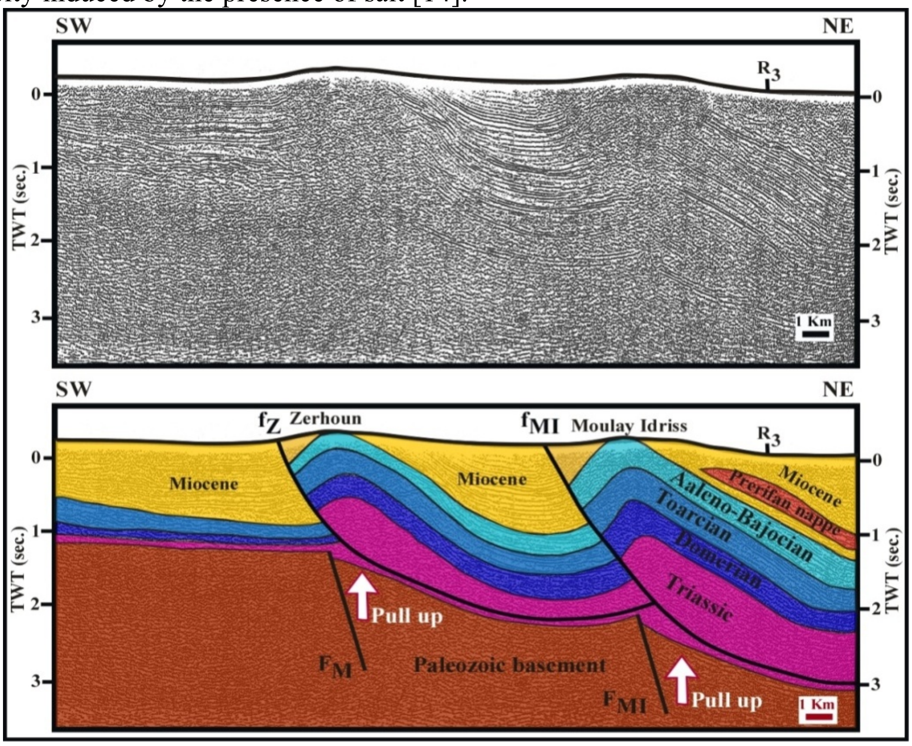

Figure 6: Seismic profile R_2 illustrating the salt structures of Zerhoun and Moulay Idriss (see location in Figure 4)

4.3.The salt structures of Boukenfoud and Mesrana

These structures are illustrated by the R_3 seismic profile (Figure 7). The analysis of the seismic facies of the Domerian sequence shows no change in thickness, which means that the halokinetic movements have been triggered after the Domerian. The presence of reflections belonging to the Toarcian with onlap terminations, indicate that the halokinetic movements were triggered prior to the Toarcien (Figure 7). The Downlap structures illustrated by the seismic profile R_3 are related to the total shrinkage of the salt. On the ESE side the seismic profile R_3 illustrates the Mesrana ridge, which is located at the top of two normal faults. The profile shows that this salt structure did not reach the piercing stage.

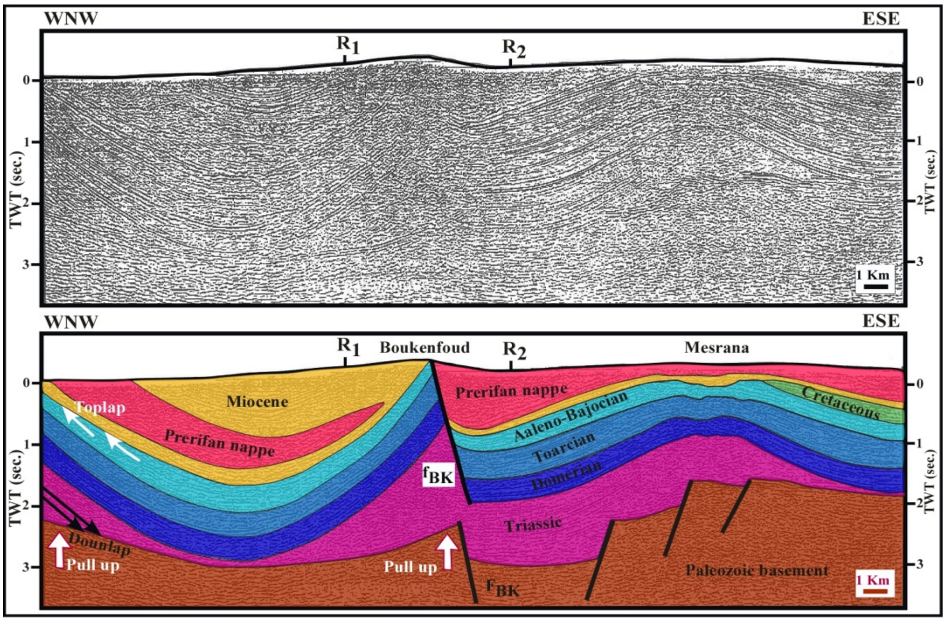

Figure 7: Seismic profile R_3 illustrating the salt structures of Boukenfoud and Mesrana (see location in Figure 4)

4.4.The salt structure of Ari

The Ari structure is the unique one that is not linked to a fault in the study area. This structure shows no salt movement during the Jurassic period (Figure 8). The Miocene series who show an important thinning at the approach of the ridge indicates that the halokinetic movements are largely related to Mio-Pliocene compressive movements. Thus, this salt structure presents another argument of no-synchronous triggering halokinetic movements in the study zone.

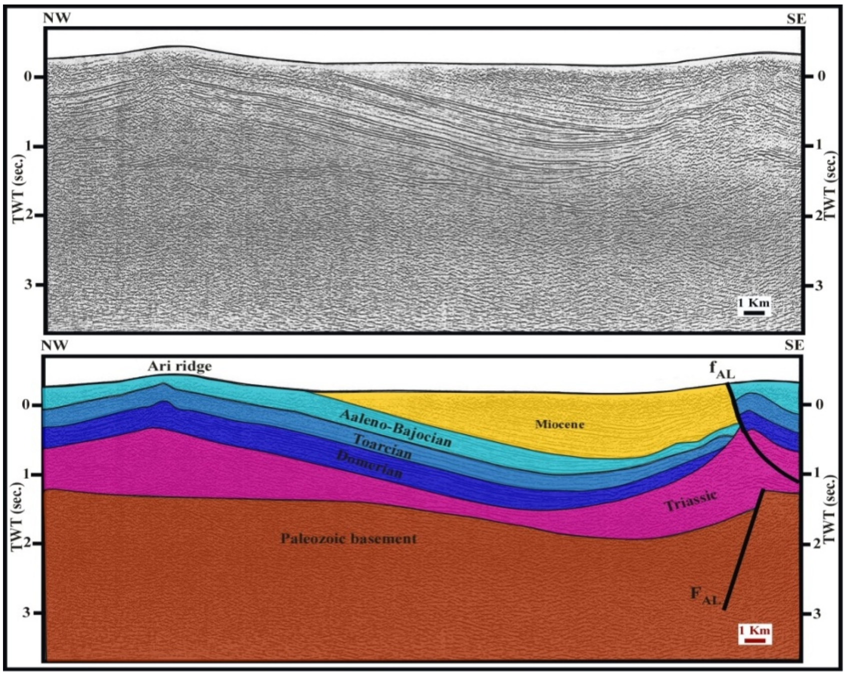

Figure 8: Seismic profile R_4 illustrating the salt structure of Ari (see location in Figure 4)

5. Discussion and Interpretation

The development of halokinetic structures are generally related to the geometry and structural evolution of the substratum [15]. In the Prerifan ridges area, the salt structures which are located at the top of the normal faults testify that the halokinetic movements were under direct control of the extension. Thus, the variations of seismic facies and thickness of post-Triassic series, the progressive unconformities with Toplap terminations, and locally the agglomeration figures with Onlap terminations are well recorded at the approach of the Salt structures. Therefore, a genetic link should exist between extension and halokinesis.

The detailed analysis of the seismic profiles provides information on the timing of the triggering of halokinetic movements and on the development of diapirism in the Prerifan ridges area. The syn-sedimentary normal faults during the Mesozoic period resulted in a remarkably variable rate of sedimentation. The resulting differential overload activated a creep of the salt. The seismic study also showed that the triggering of salt movement is not synchronous in all the salt structures identified in the zone.

In some ridges, the initial forms anterior to compression, linked only to creep of salt, have had obvious influence on the geometry of the folds during the inversion of the tectonic regime. This influence already confirmed by studies based on experimental models carried out in other regions [16]. The salt structures have a major effect on the current shape and size of structures of Prerifan ridges. This explains the form and size of Ari ridge compared to the others ridges in the area. In this study, we suggest that most of the salt diapirs are pre-orogenic, and possibly had a prominent role in determining the location of folds during the Alpin orogeny.

The Boukenfoud ridge and the Mesrana ridge form good examples of salt structures controlled by the crustal extension (Figure 7). The interactions between halokinesis and sedimentation of post-salt series provide information on the history and evolution of diapirism in this two ridges. We present a scenario explaining the current architecture of the two structures of Boukenfoud and Mesrana (Figure 9).

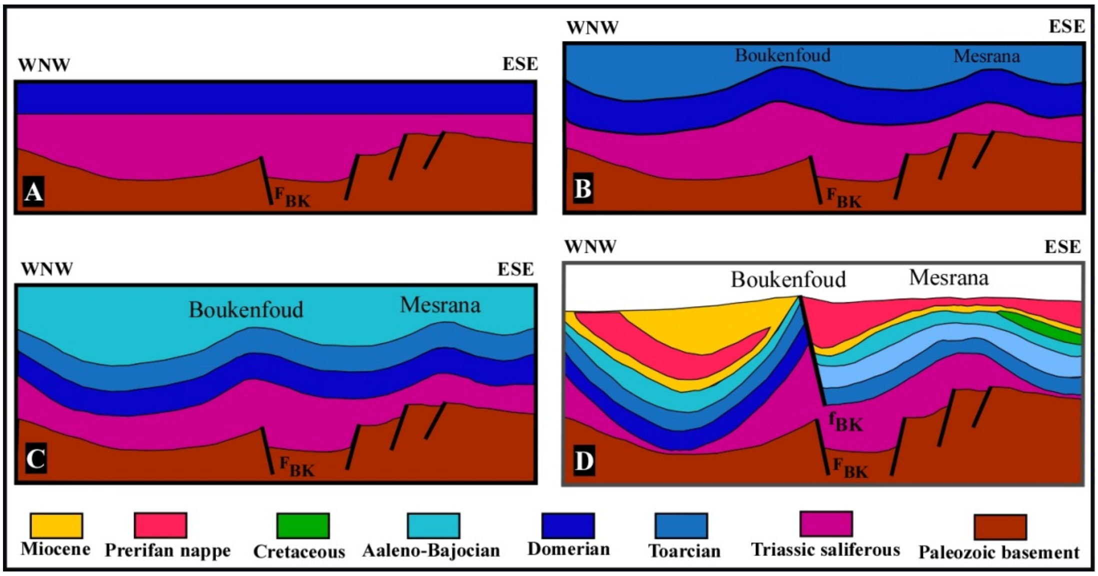

Figure 9: Model explaining the evolution of two salt structures of Boukenfoud and Mesrana

A/ plane stage (Figure 9-A): the Triassic salt and the Domerian form horizontal layers. The isopach character of the Domerian sequence indicates that the salt movements were triggered after the deposition of the Domerian serie in these two ridges.

B/ The initial bulging stage (Figure 9-B): The stage of initial bulging and the formation of a cushion is indicated by the appearance of the first thinning above the isopach supra-salt layers [17]. The reflectors belonging to the Toarcian with Onlap terminations (Figure 7) indicate the halokinetic movements were triggered at the Domerian. The resumption of the extension causes the creep of the salt towards the high blocks [18,19, 20]. The salt leaks the collapsed compartment towards the high compartment in a direction parallel to normal faults. Two bulges are individualized and gradually take on a cushion form.

C/ salt pillow stage and formation of rim syncline (Figure 9-C): The deposition of the Mesozoic series was controlled both by extensive movements and halokinetic movements. The creep of salt created around the two early crest depressions where the sediments of the Toarcian and the Aaleno-Bajocian accumulated. Consequently, under the double action of the growth of the rim syncline and the vertical movement of the salt, the flanks of the two crests straighten and form two salt pillows at the Toarcian.

D/ The piercing stage (Figure 9-D): The post-salt sequences show no evidence piercing prior to the inversion of the tectonic regime. The salt piercing is reached in the ridge of the Boukenfoud at the Mio-Pliocene compressive phase. The inversion of the F_{Bk} fault allowed the salt to inject through the strike-strip fault (f_{BK}) located at the top of normal fault F_{Bk}. In contrast, the Mesrana ridge did not reach the piercing stage.

Conclusion

The Moroccan salt basins related to the Triassic syn-rift salt basin appear not to be studied a lot. Some studies were mainly interested in the salt basins of the Atlantic margin of Morocco [21, 22, 23]. Matias [22] suggest that these salt basins project to the north. The Prerifan ridges zone, who is part of these northern extension suggested by Matias [22], is characterized by the superposition of the Triassic-Liassic extension, the salt tectonics and the Mio-Pliocene compression. Our study shows the presence of halokinetic structures that played an important role in evolution of Prerifan ridges. The initial salt structures had a prominent role in determining the location of folds during the Alpin orogeny and had a major effect on the current shape and size of structures of Prerifan ridges. The salt tectonics in the study area was controlled by the atlantic rifting and the alpine orogeny. These tectonic controls are responsible for diachronism of salt movements.

If we compare the halokinetic movements in Prerifan ridges with those shown along the Atlantic margin of Morocco, we notice that in Prerifan ridges, all the structures are autochthonous, whereas in Atlantic margin basins, the salt movements were more active and several allochthonous salt structures are present [23].

Acknowledgments- The authors wish to thank the ONHYM (ex ONAREP), Rabat, for providing seismic and well data used in this study.

References

1. J.C. Vidal, J. C. Faufères, *Comptes Rendus Académie sciences, Paris.* 281 (1975) 1951.
2. J.C. Faugères, *Bordeaux 1 University.* (1978) 480.
3. M. Zizi, *Rice University, Houston.* (1996) 280.
4. M. El-Mourabet, *Mohamed V University, Rabat.* (1996) 191.
5. J. Kenafi, E. Toto, M. Dakki, L. Asebriy, *Africa Geoscience Review.* 3 (2001) 337.
6. J. Kenafi, *Ibn Tofail University, Kénitra.* (2002) 188.
7. F. Daguin, *Notes et Mém. du Serv. Géol. Maroc.* 1 (1927) 413.
8. M. Durand-Delga, L. Hottinger, J. Marcais, M. Mattauer, Y. Milliard, G. Suter, *Mém. Soc. Géol. France.* 1 (1962) 399.
9. G. Suter, *Serv. Géol. Du Maroc, Notes et Mém.* (1980-b) 245.
10. P.E. Biron, B. Courtinat, *Geobios.* 15 (1982) 231.
11. J. Taugourdeau-Lanz, *Notes Serv. Géol. Maroc.* 275 (1988) 135.
12. H.M. Salvan, *Rev. Géogr. Phys. Géol. Dyn., Paris.* 25 (1984) 187.
13. J.C. Lorenz, *In: V.H. Jacobshagen (Ed.), Springer-Verlag.* 15 (1988) 139.
14. Chambre Syndicale de la Recherche et de la Production du Pétrole et de Gaz Naturel, (C.S.R.P.P.G.N.), *ED, TECHNIP, Paris.* (1989) 258.
15. H. Koyi, K. Peterson, *Marine and petroleum Geology.* 10 (1993) 82.
16. J.P. Callot, T. Vincent, J. Letouzey, E. Albouy, S. Jahani, S. Sherkati, *Geological Society, London, Special Publication.* 363 (2012) 545.
17. F. Trusheim, *Amer. Ass. Pet. Gel. Bulletin.* 44 (1960) 1519.
18. B.C. Vendeville, P.R. Cobbold, P. Davy, J.P. Bruno, P. Choukroune, in M.P. Coward, J.F. Dewey, P.L. Hancock, *eds., Geological Society of London Special Publication.* 28 (1987) 95.
19. B.C. Vendeville, M.P.A. Jackson, *Marine and Petroleum Geology.* 9 (1992) 331.
20. T. Nalpas, J.P. Brun, *Tectonophysics.* 228 (1993) 349.
21. K. Mehdi, R. Griboulard, C. Bobier, *C. R. Geoscience.* 6 (2004) 587.
22. H. Matias, P. Kress, P. Terrinha, W. Mohriak, P. T. L. Menezes, *American Association of Petroleum Geologists Bulletin.* 95 (2011) 1667.
23. G. Tari, H. Jabour, *Geological Society, London, Special Publications.* 369 (2013) 337.

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