# Structural Restoration of the Jurassic Section at Kra Al-Maru and Riksah Structures, West Kuwait*

**Aimen Amer[1], Hanan Salem[2], Talal Al Adwani[2], Meshal Al Wadi[2], Abdulaziz Sajer[2], and Bhaskar Chakrabarti[2]**

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[1]PTS, Schlumberger, Ahmadi, Kuwait (amer@slb.com)
[2]Prospect Evaluation, Kuwait Oil Company, Ahmadi, Kuwait

## Abstract

Jurassic reservoirs in Kra Al-Maru and Riksah areas, consists of two reservoir units from base up as a heterogeneously interbedded limestone, dolomite and anhydrite succeeded by an upper homogeneous succession composed mainly of tight limestones, carbonaceous shales and kerogen. Both the units are capped by a thick cyclic salt and anhydrite sequences. The rock succession has a simple stratigraphic configuration; however, the tectonic events that this area has undergone are complex. In an attempt to capture major tectonic variables associated within the study area during the Jurassic, structural restoration by backstripping and Finite Element Method has been used. The reason behind doing such analysis is to understand the kinematics and the drivers behind negative inversion along the major dextral strike-slip fault system. Two representative cross-sections have been utilized for the restoration. One cross-section along WNW-ESE and the other along NE-SW has been used. The cross-sections are perpendicular and parallel to the major strike-slip faults, so that the variations in fault kinematics are adequately captured. The structural restoration analysis reveals that during the Lower-Jurassic the study area is subjected to extension, followed by two stages of compression and a stage of strike-slip movement in the Upper-Jurassic. During Neocomian, earlier deposited salts are compacted, consequently leading to lateral salt movement and thrusting. It is therefore inferred that local tectonics has its own fingerprint in the area, which is superimposed by regional plate-wide tectonic stresses. The analysis is proven vital for prospect evaluation. The study shows that Riksah structure has been subjected to series of uplift and subsidence events leading maximum strain and stress concentration in the area. Such concentrations would result in congenial natural fracture system and help upgrading the prospectivity of Jurassic units in the area and adjoining exploratory areas as well.

## Introduction

Kra Al-Maru and Riksah structures are well-defined four-way closures that vary in area and structural alignment. Kra Al-Maru follows a NW-SE trend and is composed of more than one anticline structure making it an anticlinorium structure. The structure is intersected by numerous fault systems that exhibit no visible throw on seismic, except two NE-SW trending faults that have been interpreted as a principal displacement. Riksah structure on the other hand, follows an ENE-WSW trend and the anticlinal structure bifurcates to the northeast. This structure is also intersected by a number of faults, but mainly NE-SW trending faults (Figure 1).

The main stratigraphic units targeted by this study are the Jurassic formations. In Kuwait, these units are known as Marrat, Dharuma, Sargelu, Najmah, Gotnia and Hith formations. The main reservoirs are Marrat, Sargelu and Najmah formations, whereas the seal is represented by Gotnia and Hith formations. The source rock is found within the Najmah Formation and is locally referred to as Najmah kerogen due to the high kerogen content (Figure 2). From the finite element modeling point of view it is very critical to know the rock behavior to deformation through burial, compaction and tectonic compression. This will allow us better calculate stress concentrations and principal strains at the top and base of each formation interface. The results obtained using this technique has been quality checked and calibrate with well and 3D seismic ant track volumes.

## 2D-3D Structural Restoration

In order to understand the kinematics of this area, structural restoration and balancing has been utilized based on the finite element method. The restoration technique is used to quantitatively estimate the depth that the formations of interest would be in the absence of sediment and water loading. This depth provides a measure of the unknown tectonic driving forces that are responsible for basin formation (tectonic subsidence or uplift). The finite element method is a numerical procedure, which provides solutions to problems that would otherwise be difficult to obtain. Usually the problem addressed is too complicated to be solved by classical or analytical methods.

The WNW-ESE (a-a') 20 restored cross-section shows the unique tectonic development of the area combined with variations in the depositional patterns that mainly reflect accommodation space. It is suggested that the major tectonic deformation that occurred between the Triassic and Cretaceous times within this area occurred between the Oxfordian and Tithonian stages (Figure 3).

The analysis also indicated that during the Aptian Albian stages tectonic reactivation has occurred to the main strike-slip fault system. This late reactivation has resulted partially in Gotnia halokinesis and 1.8 kilometers salt creep to the southwest. This distance has been calculated based on an observed shift in the anticlinal crests position once comparing Najmah and Gotnia structural tops. Based on these observations a second cross section was performed to understand the implications of salt movement to the southwest direction. This observation raised a valid argument, which is, if we have salt movement within Gotnia Formation we would expect to have associated faulting within the competent anhydrite layers. These are expected to be small-scale features and are not normal interpreted due to their regional irrelevance and small scale. However finding such faults would confirm our observations and add more credibility to our overall assessment.

Based on a number of geomechanical burial models (reference), we expect to observe such faults over the lower units of Gotnia Formation. This understanding narrowed our search window and a regional hunt started to find such faults within this formation. It has been found that the NE-SW seismic section shows a very clear thrust fault that is found over the lower section of Gotnia Formation. The offset on this fault is 1.8 km, which is equal to the offset between the two structural crests (Najmah and Gotnia). This distance is believed to represent the creep distance of the salt movement (Figure 4). In an adjacent field, we have found that the well logs correlation of various intervals shows a relatively thicker unusual section. After close examination, we have found that this thicker section is a result of a repeat section due to a thrust fault system crossing Well W4 (Figure 5).

The NE-SW (b-b') cross section has been taken parallel to the main principal displacement zone (Figure 6). The main objectives of restoring this section, was to confirm the tectonics and structural reactivation timings in addition to gaining more understanding on the Gotnia halokinesis. The section illustrated that during the Aptian Albian stages salt movement occurred. This movement resulted in the faulting of the lower more competent layers of Gotnia Formation and salt mobilization over the crestal region of the Oxfordian and Tithonian structural axis. This lead to more accommodation space at the crestal region of the structure that lead to more sedimentation load expediting the halokinesis effect.

Based on the 20 structural restoration and geomechanical strain computations, it is suggested that the Riksah structure has exceeded the yield threshold. This means that the rocks are more stressed then those rocks present over Kra Al-Maru field. From our current understanding the yield point threshold could mean the rocks could be harder (because of porosity reduction) or fractured. Using a leaner elastic approach, we cannot differentiate between both. However, by analyzing the Kra Al-Maru wells, it can be suggested that the rocks have a higher potential to be fractured, because the model shows that on the Kra Al-Maru limbs of anticline are more stressed and from the well data we know it is more fractured (Figure 7). This observation is also experienced over the 3D restoration that has been performed independently over this area. Such outputs can be utilized in further fracture modeling and can help in assisting fracture distributions (Figure 8).

## Conclusions and Discussions

Structural restoration over the Kra Al-Maru and Riksah areas reveals that during the Lower Jurassic the study area was subjected to extension. This extension provided the accommodation space needed for sediment accumulation and the generation of a normal faulting system. This extensional phase was followed by the Oxfordian and Tithonian transpressional tectonics that resulted in the formation of compressional structures and the early development of strike-slip faulting. During the second tectonic event (Aptian-Albian), the area was subjected to compressional tectonics. This resulted in the reactivation of the old normal fault (this is believed to extend to the basement), resulting in negative inversion. This reactivation coincided with the main Gotnia halokinesis over the crestal regions of Kra Al-Maru structure allowing a 1.8km salt creep. After the Albian it is suggested that halokinesis stopped because of the consolidation and dehydration of gypsum layers that later became low in porosity and hardened into anhydrites. The presence of four anhydrite cycles within the Gotnia salts is believed to prevent seismic scale recognizable consequent movements. Further analysis of the burial history of these structures it is observed that during the period between the Oxfordian to Albian, the area was subjected to rapid subsidence (Figure 9). This observation confirms the tectonic evolution scenario proposed in this study.

Utilizing the finite element simulator, we have calculated the cumulative principal strains over the 20 and 3D restored formations. The main objective of performing such step was to attempt to predict high fracture density zones to locate new wells. This technique is still under development and extra care is needed if any of its results are to be used. In this case, we have used drilled wells to calibrate our strain map and we have correlated the strains to fracture intensities obtained from wells. Two independent restorations utilizing 20 and 3D methods showed the same results, giving a high confident level of our results.

The workflow developed over this study proved to be useful in new prospect evaluation. The study shows that Riksah structure has been subjected to a series of uplift and subsidence events leading maximum strain and stress concentration in the area. Such concentrations would result in congenial natural fracture system and help upgrading the prospectivity of Jurassic units in the area and adjoining exploratory areas as well.


## Acknowledgements

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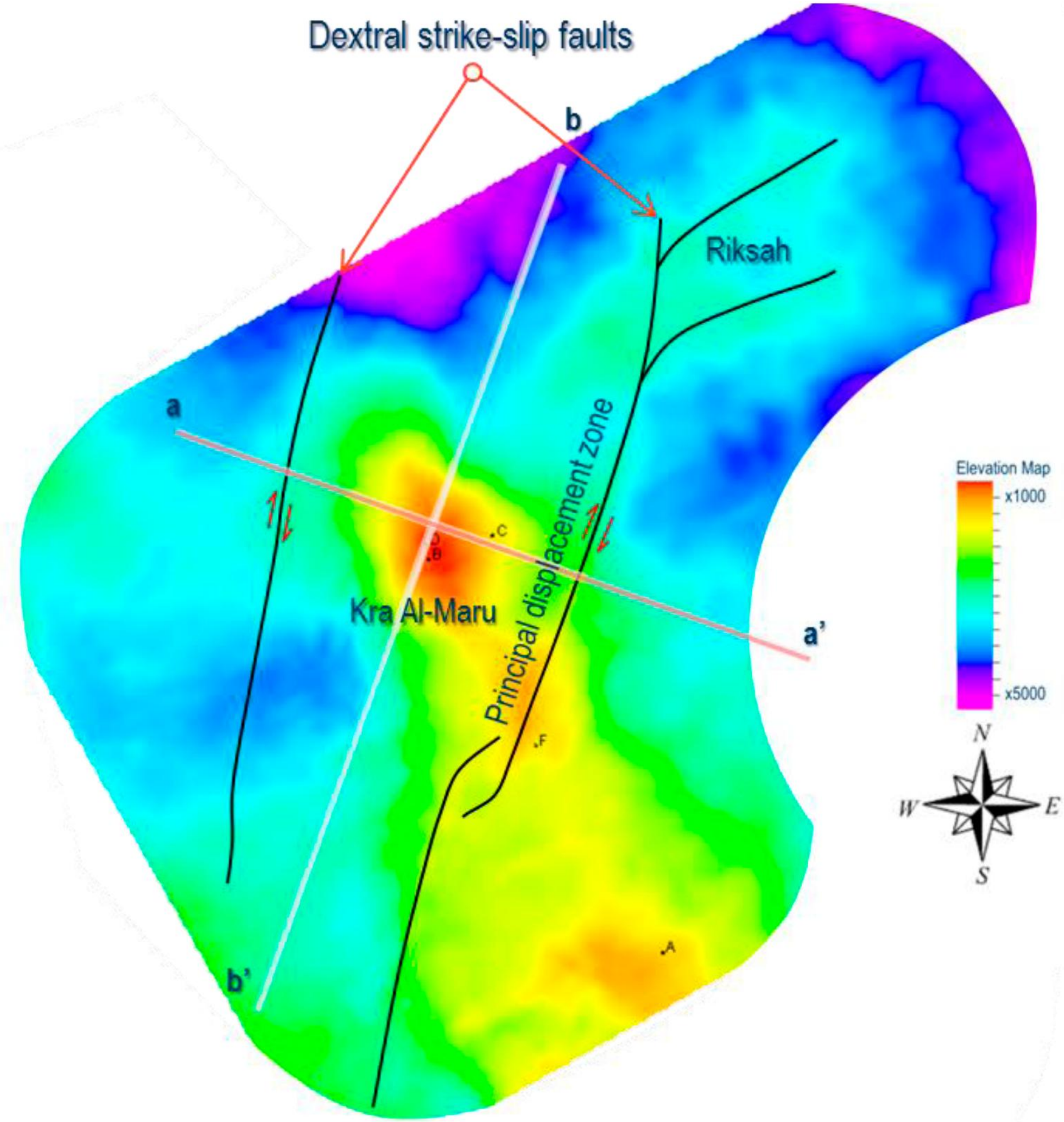


Figure 1. Showing the location of Kra Al-Maru and Riksah structures.

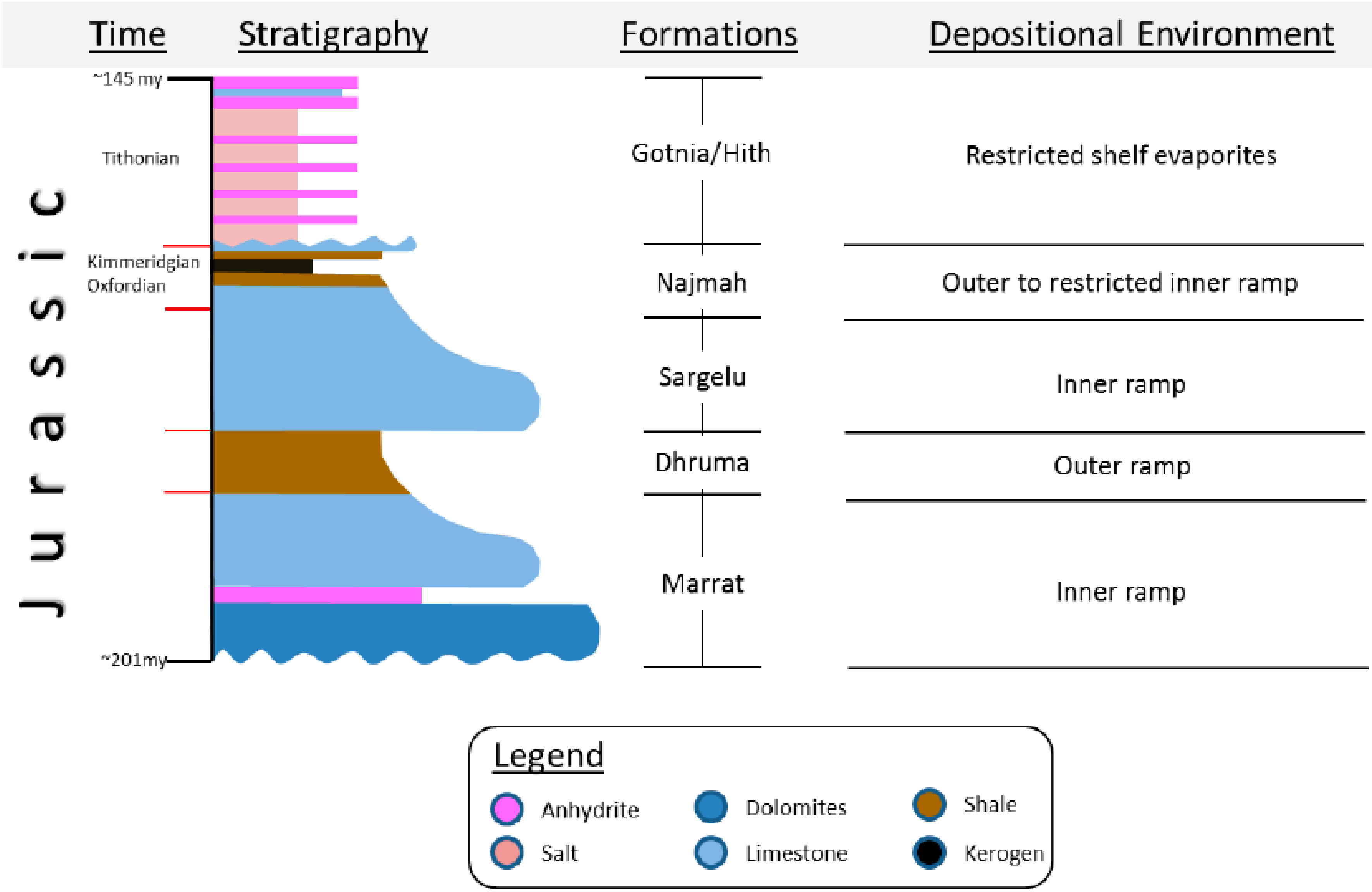


Figure 2. Showing a simplified stratigraphic section of the study area.

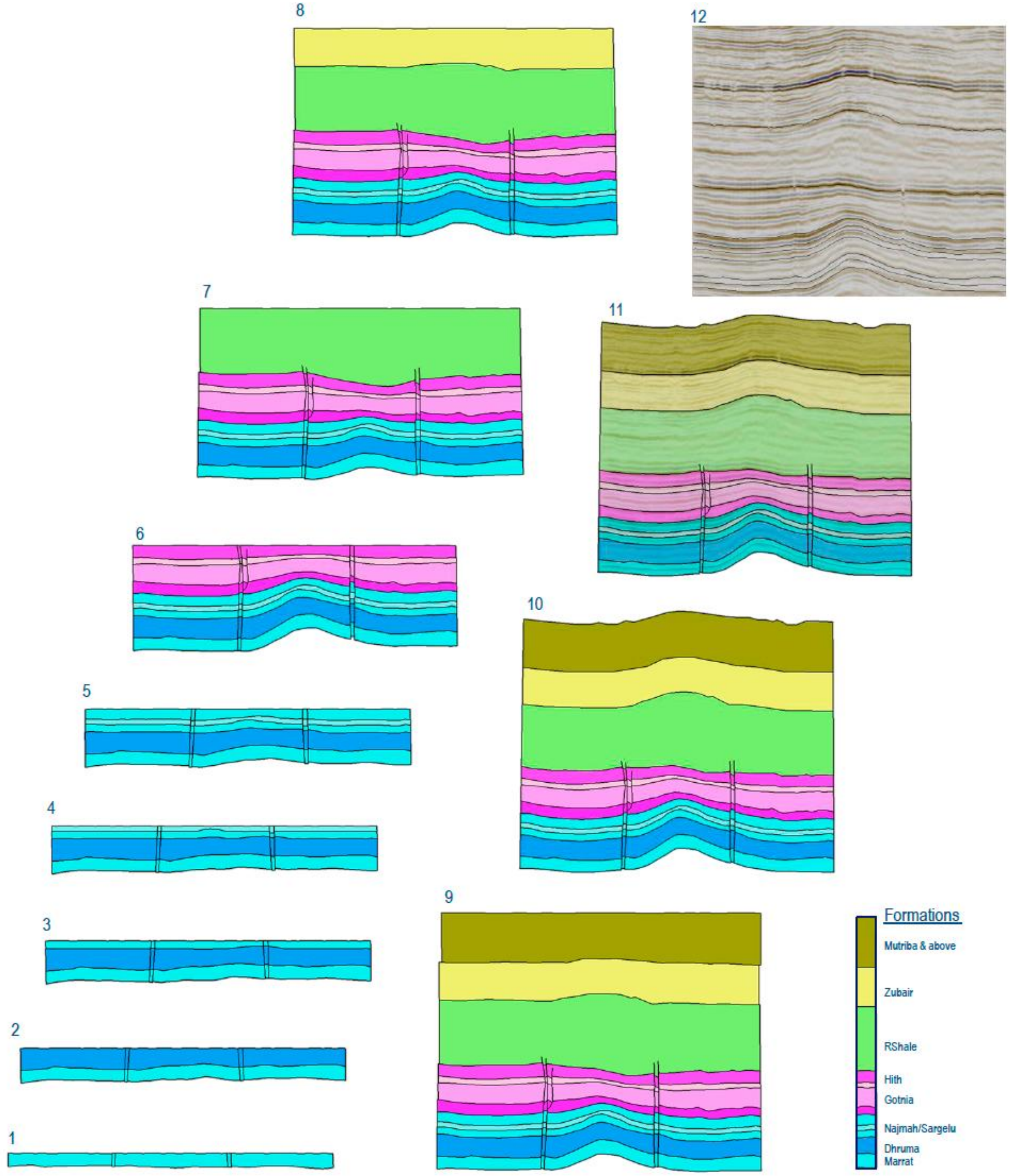


Figure 3. WNW-ESE (a-a') structural retorted cross section along the two main faults crossing the study area. The objectives of this section was to time the tectonic inversion and activation timing and also evaluate the mechanism behind salt movement in Gotnia/Hith intervals

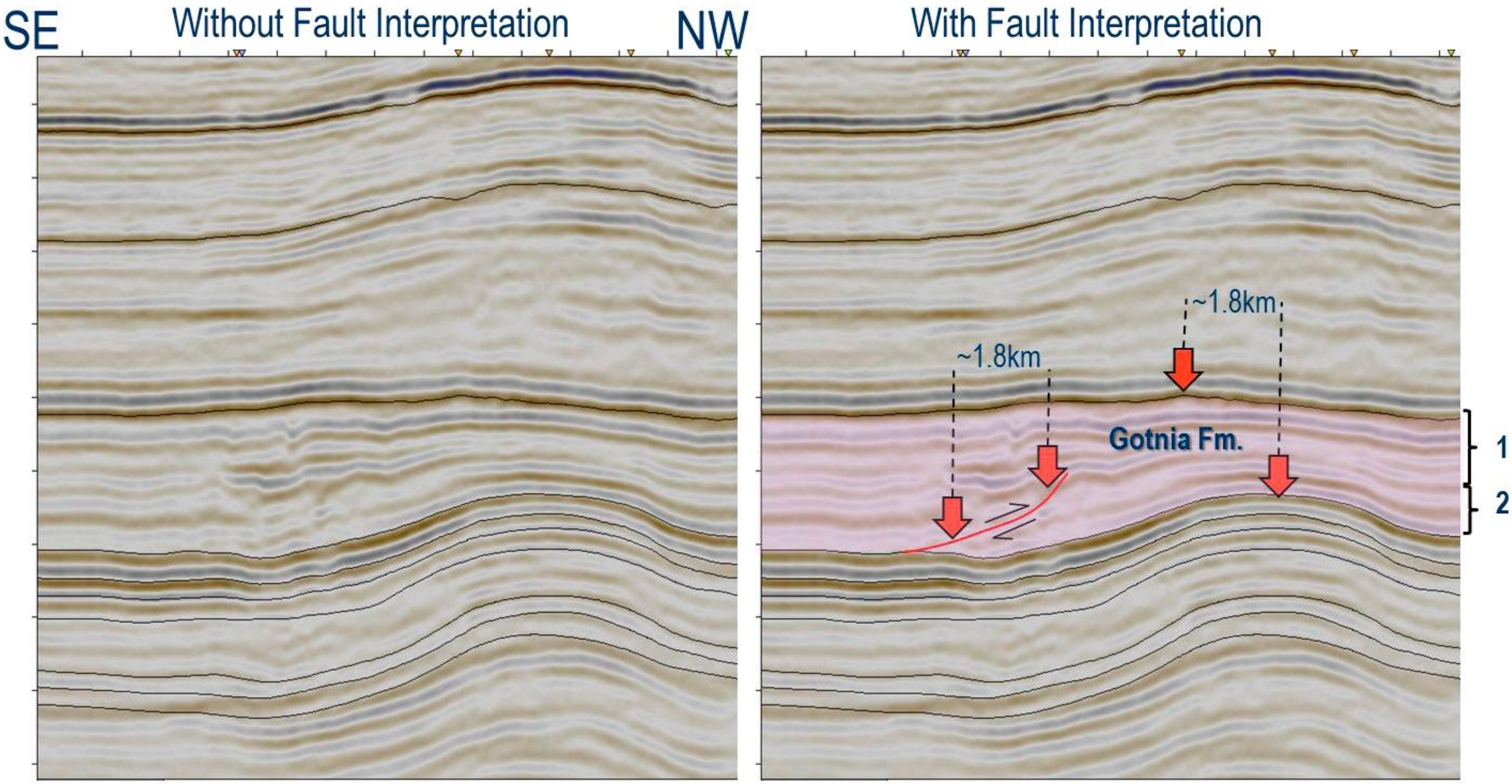


Figure 4. Showing the amount of shortening is equal to the amount of salt movement. l- The upper less compacted layers accommodated the creep stresses. 2- The lower more compacted and lithified layers accommodated the stresses by thrusting.

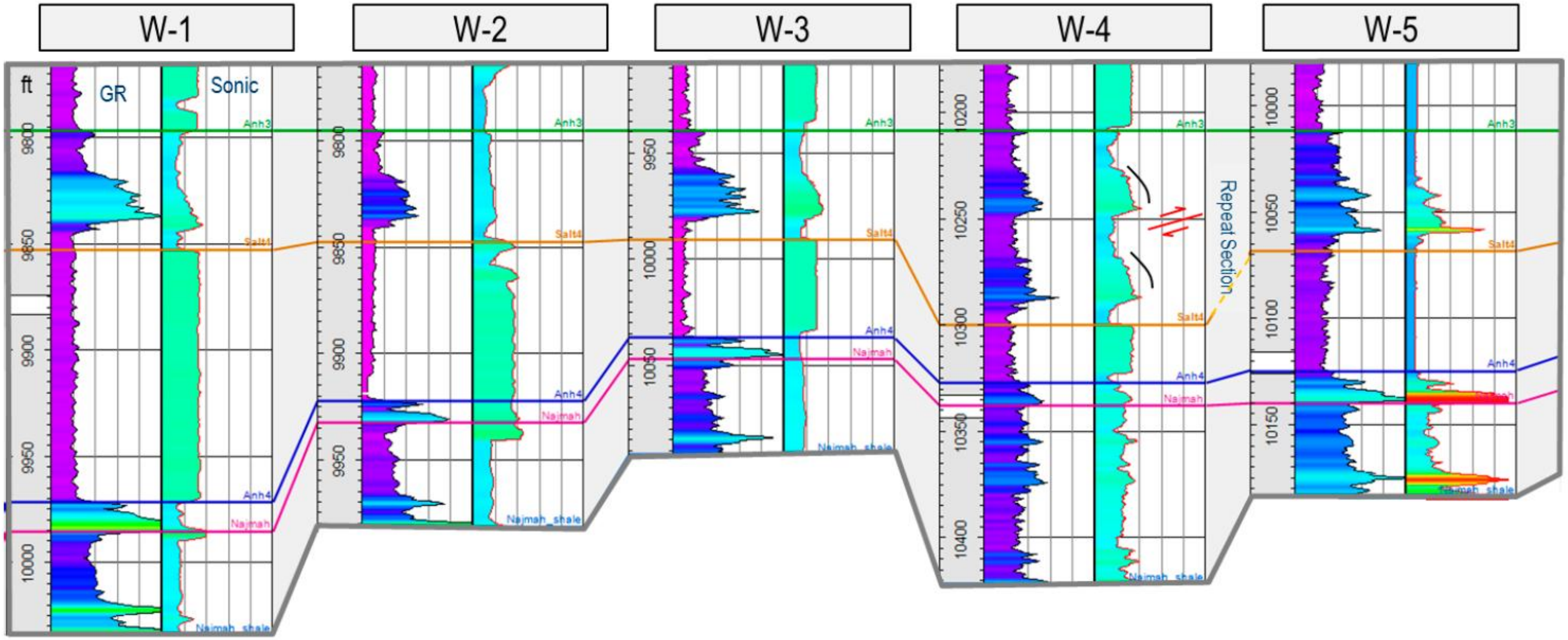


Figure 5. Showing five wells correlation over the lower section of Gotnia Formation. All wells have the same anhydrite-3 thickness accept well W-4. This thickness is attributed to a repeat section resulting from a thrust fault.

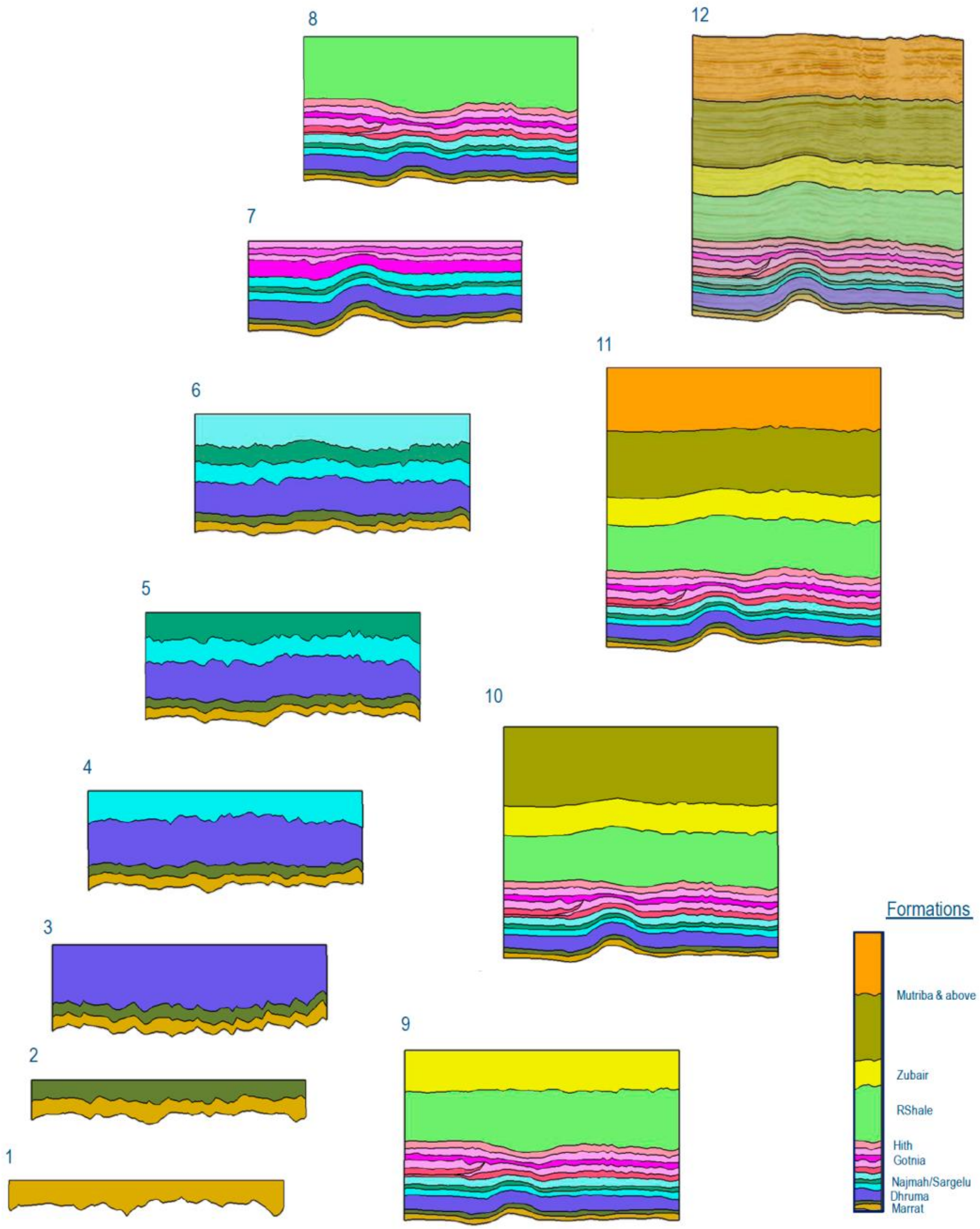


Figure 6. NE-NW structural restored cross section parallel to the two main faults in the study area. The objectives of this section were to time the tectonic reactivation and evaluate the mechanism behind salt movement in the Gotnia Formation.

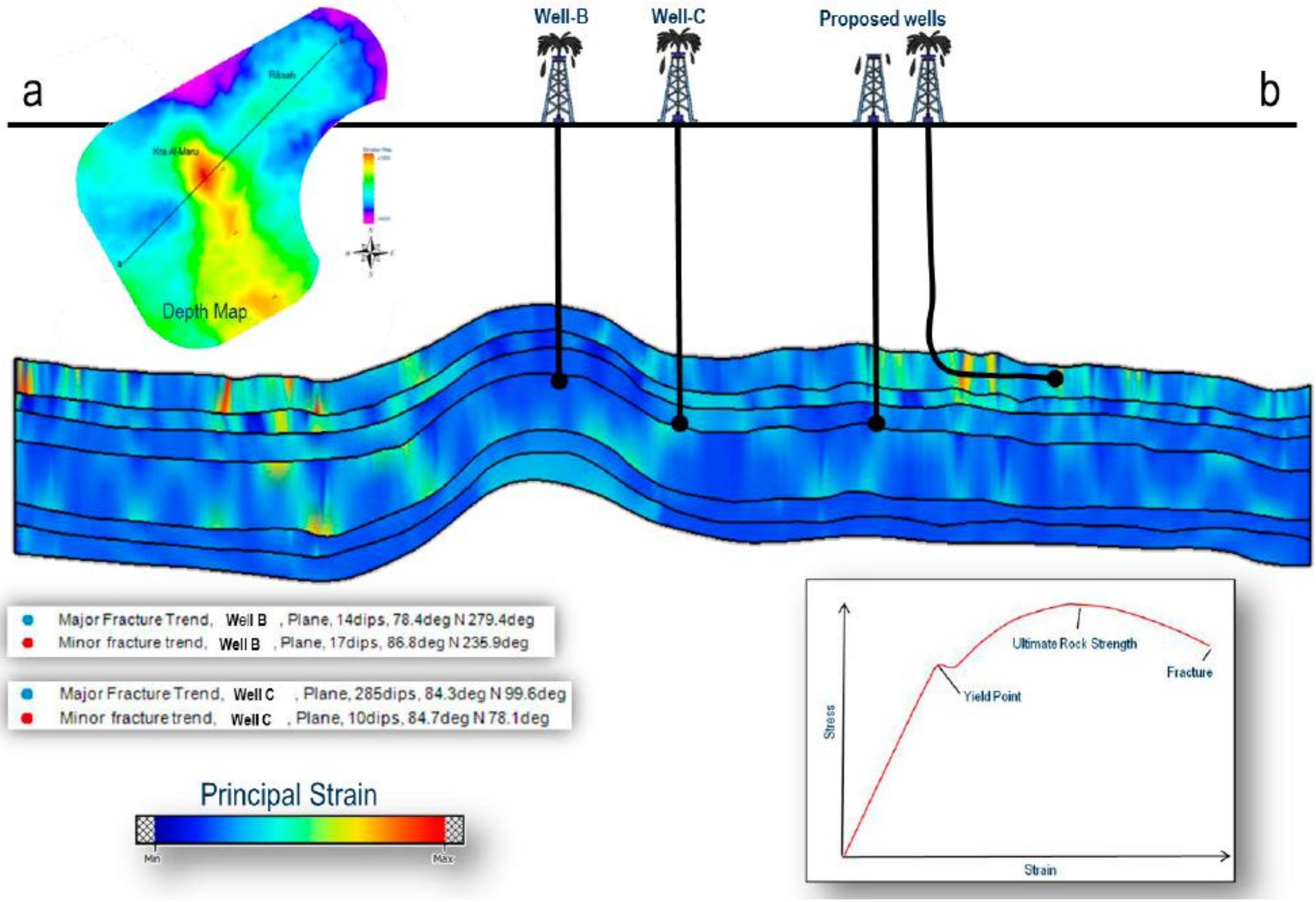


Figure 7. NE-SW restored cross section showing Najmah Formation at the cross section top. Well C is drilled over a high strain area and has more fractures then Well B. Riksah structure has a higher strain level. Two proposed wells are simulated over the high stressed area and it shows that the horizontal well is a better option for developing this structure.

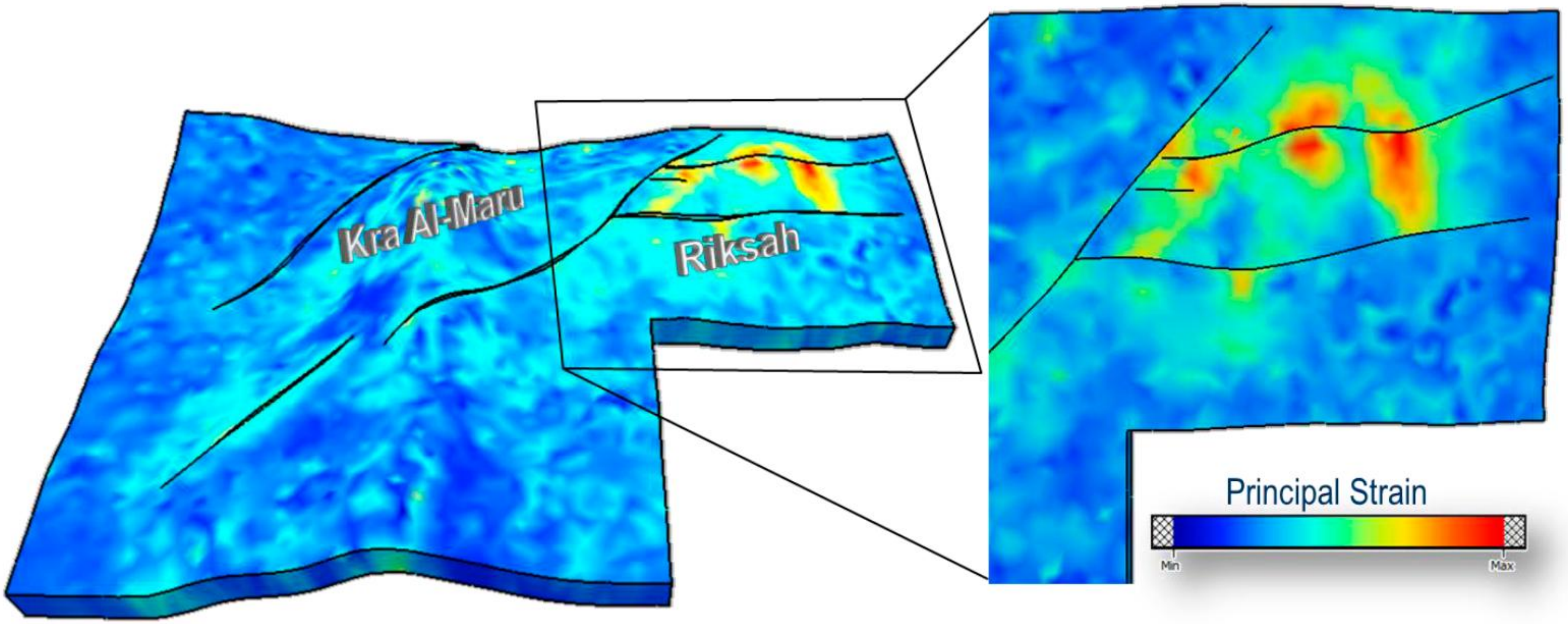


Figure 8. Riksah structure shows more principal strain concentration, indicating that the structure could be more fractured. These results are extracted from independent 2D and 3D structural restored models.

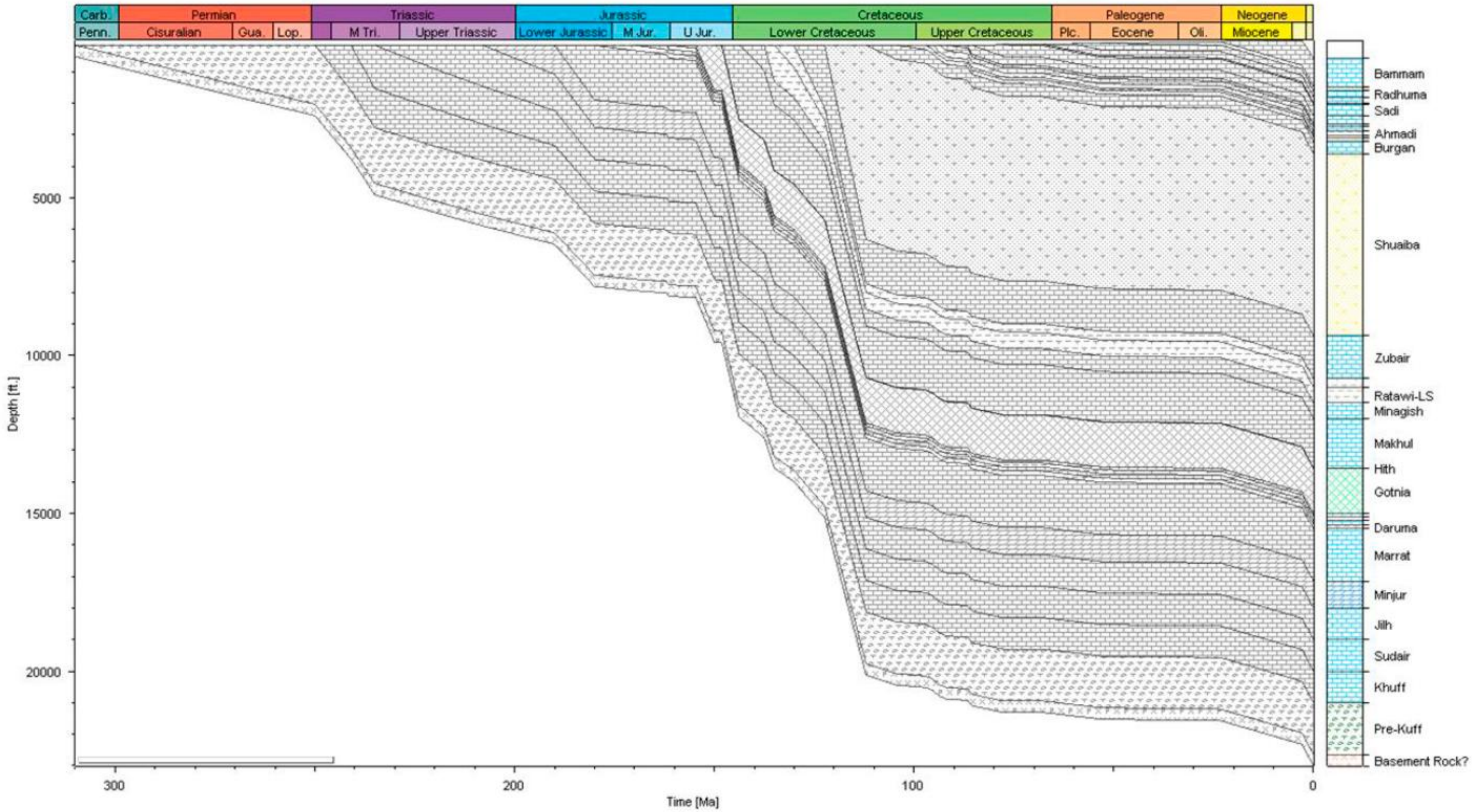


Figure 9. Burial history of the studied area showing a rapid subsidence rate between the Oxfordian to Albian periods.