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Assessing the inversion structure during Late Jurassic-Early Cretaceous period depending on interpretation of seismic reflection methods: A case study from Horus oil field, North Western Desert of Egypt

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***ABSTRACT*: The primary objective of this study is to assess the inversion structure and specific structural components utilizing high-quality 2D seismic lines obtained from the Horus oil field. This field is situated in the southern section of the Alamein Basin, positioned above the hanging-wall of a normal fault from the Jurassic-Early Cretaceous period. This fault extends in an ENE-WSW direction and bounds half graben trough in the northern margin of Horus oil field. Cretaceous period appears NE-asymmetrical anticline overlying Jurassic rifting. The movements of the tectonic belts resulted in a regional extensional regime during the Jurassic and Early Cretaceous periods. Subsequently, stress movements during the Late Cretaceous to Oligocene period led to the inversion of the Alamein Basin. Numerous NW-SE oriented normal faults, varying in length and throw, dissect the Cretaceous horizons. These faults partition the anticline into multiple blocks. The inversion of this basin is ascribed to the Syrian-Arc event, which prevailed over North Africa at the Late Cretaceous period.**

KEYWORDS:* *Alamein Basin; Horus oil field; Inversion Structure; Seismic interpretation.

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I. INTRODUCTION

This study will discuss inversion structure of Horus oil field and evaluation of tectonic movements during two different time periods. **(Glennie and Boegner, 1981)** define the structural inversion as conversion of basin area into a structural high and the converse while **(Bally, 1982)** define inversion structure as basins or half-graben systems are varying degrees turned inside out by compressional forces. Inversion can classified into two categories, first type is positive structural inversion that refers to change in polarity of structural relief from low basin to high uplift structure **(Harding, 1985)** and second type is negative inversion which used to describe of compressional fault segments that were subsequently reactivated in extension time **(Powell and Williams, 1989)**.

The Alamein Basin, situated in the northern Western Desert of Egypt, ranks among the largest basins and serves as a primary hydrocarbon reservoir. Positioned northward of the Abu Gharadig Basin, separated by the Shareb-Sheiba ridge and lies to the southeast of the Matruh Basin. Alamein basin contains several oil producing fields like Horus, Razzak, Yidma and Alamein oil fields.

The study primarily focus on the Horus oil field, located approximately 25 km south of Alamein city and adjacent to the northern coast of the Mediterranean Sea. This field positioned between the Burg El-Arab oil field to the east and the Alamein-Yidma oil field to the west **(Fig.1A)** and is situated within the latitudes of 30°34ʹ00ʺN and 30°41ʹ00ʺN, and longitudes 28°45ʹ00ʺE and 28°53ʹ00ʺE **(Fig. 1B)**.

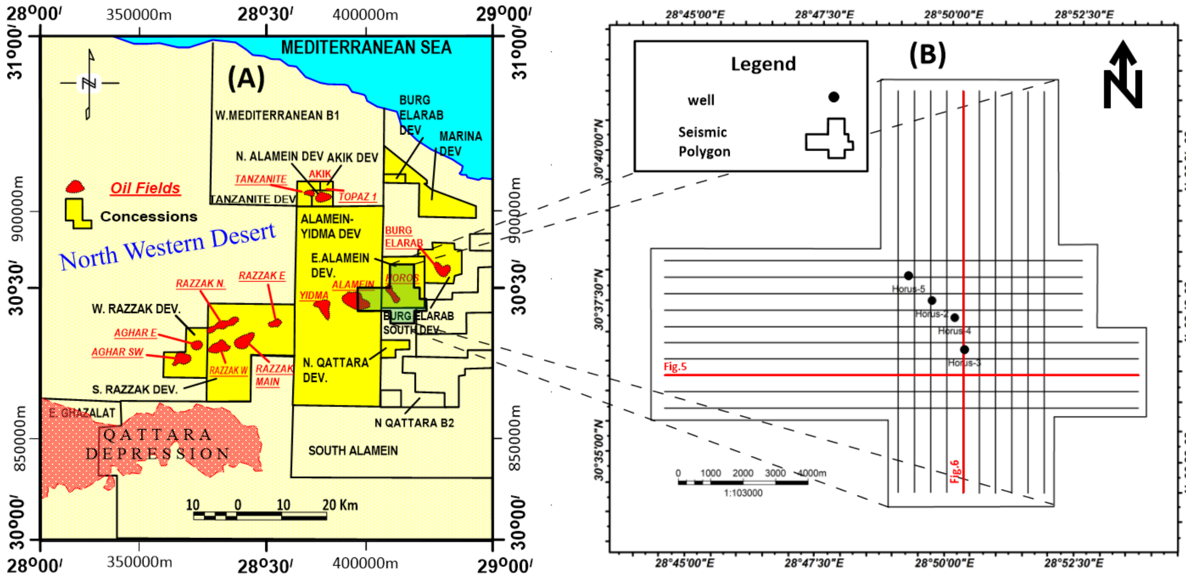

Figure 1. Location map **(A)** main concessions and oil fields of Alamein Basin, **(B)** seismic lines and wells of Horus oil field.

This paper focuses on assessing positive inversion phenomena observed in the Horus oil field, stemming from both compressional and tensional movements (inversion mechanisms). Furthermore, the study aims to elucidate the interplay between tectonic forces and inversion structures. Beyond this, the paper underscores the impact of structural styles in influencing the entrapment of hydrocarbons.

II. GEOLOGICAL SETTING

Petroleum exploration in the Western Desert of Egypt has concentrated on its northern region. The occurrence of petroleum is intricately connected to the tectonic and stratigraphic history of the northern Western Desert, giving rise to numerous reservoirs governed by diverse structural traps.

Tectonically, **El-Malky (1974)** pointed that the geological history of the northern Western Desert has been shaped by several cycles, including: A) Early Paleozoic cycle, B) Late Paleozoic cycle, C) Late or post-Jurassic cycle, D) Late Cretaceous-Early Eocene cycle that led to the development of the NE-SW Syrian arcing system **(Fig. 2)**, E) Mid to Late Tertiary cycle, and F) Post-Miocene cycle. **Guiraud (1998)** considering rifting phase commenced during the Late Jurassic to Early Cretaceous period. **Meshref (1982)** deduced the collision of Africa with Asia during Late Eocene to Early Oligocene period, which resulted in compressive force.

Structurally, in the Jurassic and Early Cretaceous periods, the northern Western Desert underwent a rifting phase that resulted in the formation of substantial faults. These faults played a key role in controlling the deposition of thick sediment layers by creating half-grabens. Subsequently, the rifting tectonic activity concluded in the Late Cretaceous with the onset of the Syrian Arc inversion phase **(MacGregor and Moody, 1998)**. This phase led to the inversion of previously deposited rift sub-basins, transforming them into asymmetric anticlines.

The sedimentation of the entire stratigraphic column in the northeastern corner of Africa was predominantly influenced by two main factors: the Arabo-Nubian Shield and the Tethyan Sea **(Ayyad and Darwish, 1996)**.

Figure (3) illustrates the Lithostratigraphic succession within the Horus field, showcasing distinct lithology units and the diverse thicknesses of formations. The Horus wells traverse through strata ranging from the Miocene age Moghra Formation to the Early Cretaceous Lower Baharyia Formation.

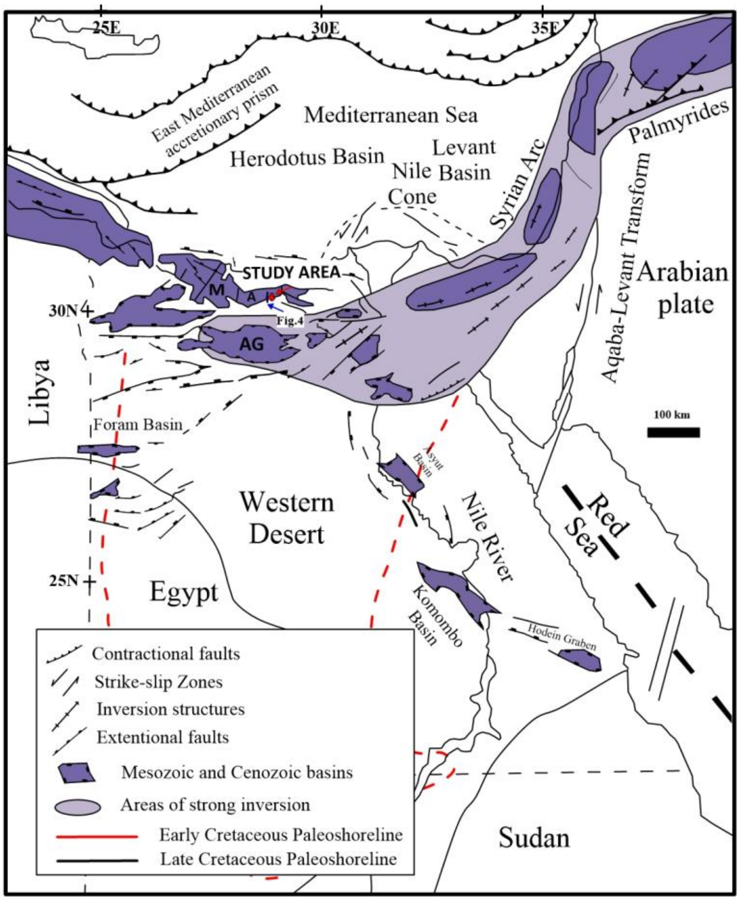

Figure 2. Tectonic setting of the northeast Africa and eastern Mediterranean. This map is compiled from **Guiraud et al. (2005)** and **Bosworth et al. (2008**). A = Alamein Basin; AG = Abu Gharadig; M = Matruh Basin.

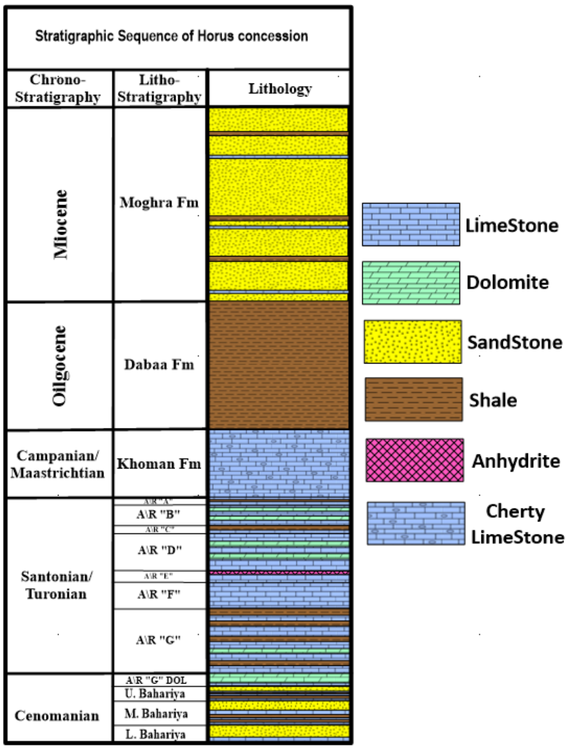

Figure 3. Schematic stratigraphic column of Horus area **(after GPC, 2021)**.

III. MATERIALS AND METHODS

The dataset utilized in this study consist of four wells and twenty 2D migrated seismic time sections extracted from a 3D cube. These seismic sections consist of ten (N-S) in-lines and ten (E-W) crosslines **(Fig.1B)**.

Depending on check shot, tying process of time migrated seismic lines with drilled wells is successful. Tops of Cretaceous-Tertiary are picked manually along all seismic lines. Drawing from prior researchs, our investigation reveals that the Zain-1X well, situated in the Yidma-Alamein Development **(Fig.4)**, achieved a total depth of 17,000 feet (approximately 5200 meters). This marks the deepest well ever drilled in the Alamein basin and the second deepest in the Western Desert of Egypt. By the aid of Zain-1X well, the paper effectively identifies the Jurassic summit in the Horus oil field. After picking various horizons, closing loops around drilled wells and fault to create time structure map.

Based on check shot of each well, the interval velocity maps of each top are built. The interval velocity maps are combined together to construct velocity model. The process of depth conversion can be effortlessly accomplished by utilizing a velocity model. This allows for the generation of depth maps for each horizon, as well as displaying of fault locations and their extensions on the maps.

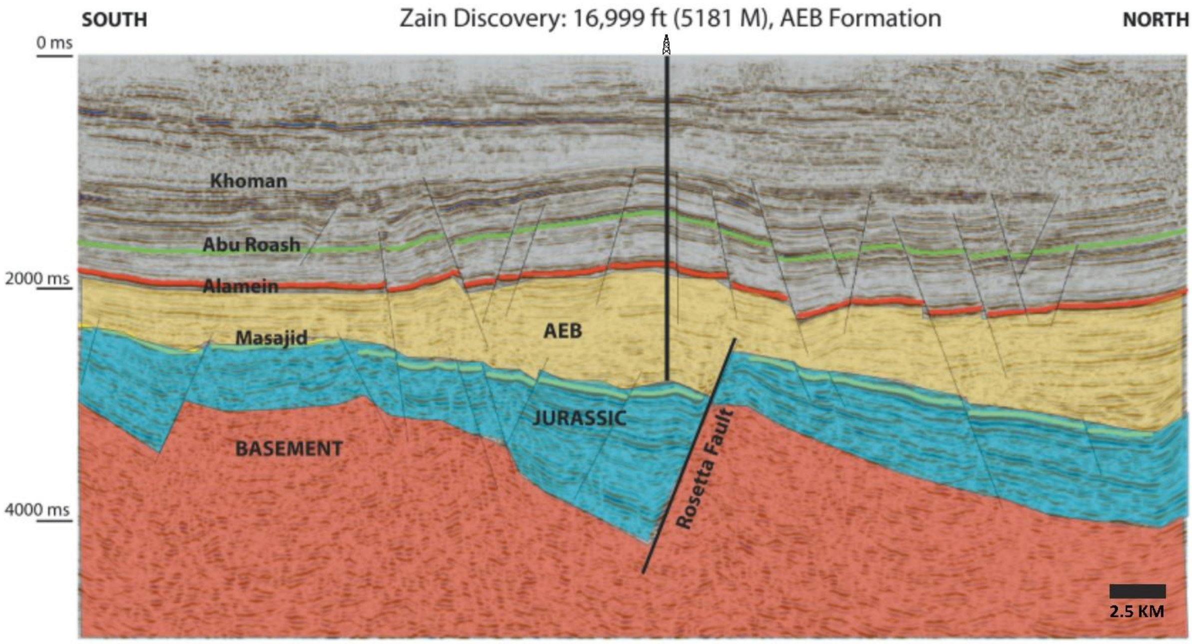

Figure 4. South-north seismic section showing the Zain discovery well testing an AEB inversion structure above an undrilled Jurassic syn-rift **(after Dolson et al., 2014).**

IV. RESULTS AND DISCUSSION

A- Horizons and fault picking

The interpretation commenced with the correlation of seismic lines and drilled wells to identify the Dabaa formation and various Cretaceous horizons besides top of Jurassic. The raw data **(Fig. 5A)** and interpreted section **(Fig. 5B)** extends from west to east, and illustrates the geometry of six Formation and member tops and identifies the outlines of various structural elements. The seismic line exhibits three major faults (**F1**, **F2**, **F3**) extends from early Cretaceous to Tertiary period. Khoman Formation, along with its Abu Roash (A) and Abu Roash (G) dolomite members, as well as the Alamein Formation, are characterized by a substantial number of faults with varying lengths and throws. Structural elements exhibits en-echelon form between faults (**F3**, **F2**). Faults (**F1**, **F2**) and (**F8**, **F9**) forming graben shape between them. Top of Jurassic had been cut off with one fault only in this trend.

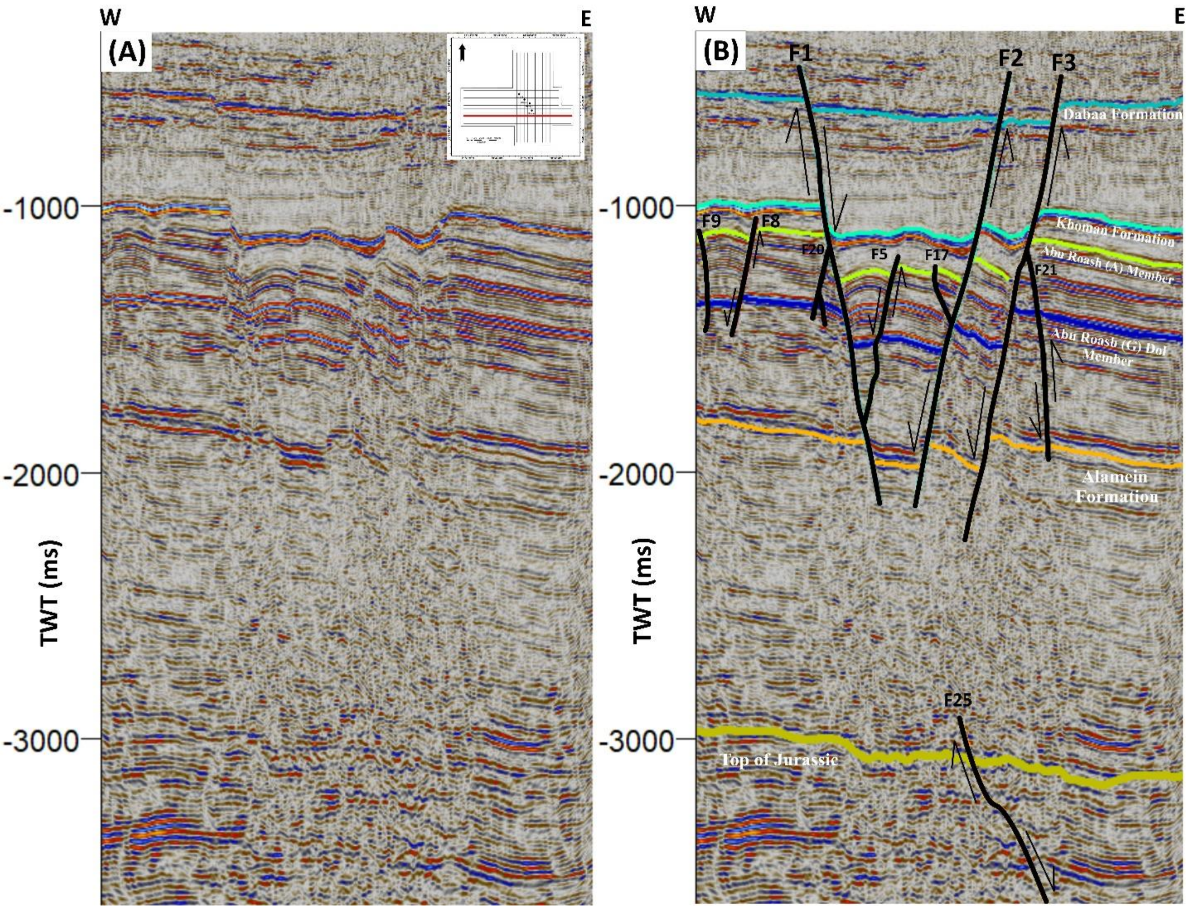

Figure 5. (A) Raw data and **(B)** Interpreted seismic section oriented in west-east direction showing picked horizons and structural features of Horus field.

Figure (6A) displays raw seismic line while **(Fig. 6B)** exhibits interpretation of same seismic line that extends from south to north passing throw Horus-3 well. The seismic section is distinguished with asymmetrical anticlinal horst, dipping flanks towards the north and south. This big horst create between faults (**F3**, **F4**). The interpreted section shows numerous faults dissect horizons of Cretaceous period diverse in length and throws. Three major faults (**F2**, **F3**, **F4**) prolong from Dabaa Formation (Oligocene) to Alamein Formation (Aptian). We can notice also in Oligocene and Cretaceous stage that: **1)** increase thickness of Dabaa Formation in northern and southern parts according to grow of major fault throw (**F2**, **F4**). **2)** The Cretaceous horizons exhibit good thickness due to the uplifting of domes in the central part of the field and substantial vertical displacement of faults in both the northern and southern regions. **3)** The structural patterns are characterized by a noticeable shift in throw with depth, suggesting that the area has subjected to multiple phases of subsidence over time. **4)** Khoman Formation is identified as the uppermost layer of the Cretaceous, conflicting with the overlying top of the Dabba Formation due to a greater occurrence of faults that differ in distribution, length, and displacement. Additionally, the onset of stress-related effects becomes more apparent. **5)** Abu Roash (A), Abu Roash (G) dolomite members and Alamein Formation approximately shows the same number of faults and fold form of Khoman Formation with degree more than of Dabaa Formation.

Based on earlier research conducted in the Alamein Basin, particularly at the Zain oil field, the paper closely identifies the top of the Jurassic as a crucial marker for inversion events. Top of Jurassic cut off by number of faults forming half-graben. This faults extends and died out at Early Cretaceous. As a result of extension, a half-graben develops, bounded on one side by the master fault and on the other by a zone of dipping beds, causing the total structure to be asymmetric **(Groshong Jr, 1989)**. Extensional faults are characterized with segmentation, and sediments frequently enter into the hanging-wall accommodation space where fault segments interact, either at transfer faults, accommodation zones, or relay ramps **(Gawthorpe and Hurst, 1993)**.

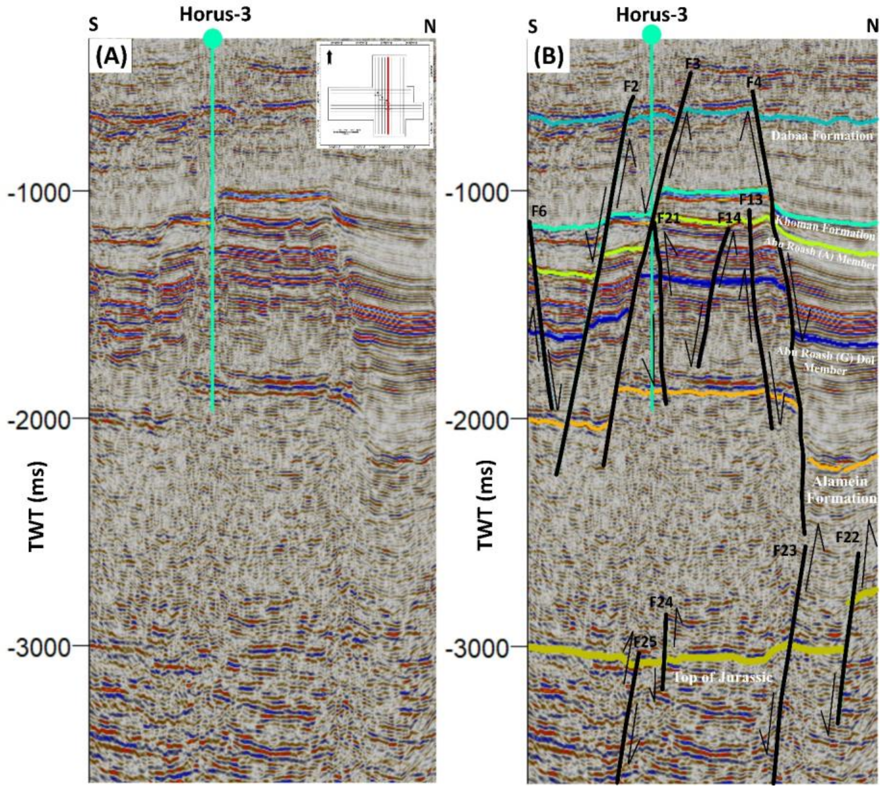

Figure 6. (A) Raw data and **(B)** Interpreted seismic section oriented in south-north direction showing picked horizons and structural features of Horus field.

B- Depth-structure maps

Depth conversion process was done to convert time structure maps into depth structure maps by aid of velocity model. Six structure depth maps are displayed on tops from Oligocene followed with Cretaceous and terminated in top of Jurassic. **Figure (7A)** shows depth structure map of Dabaa Formation which appears subsidence in central, northern and southern parts bounded by northwest faults. The map exhibits absence of minor faults and strong presence of major faults forming obvious graben shape between faults (**F1** and **F2)**. The next top is Khoman Formation **(Fig.7B)** that manifest high level of deformation according to presence large number of north westerly minor and major faults dissects anticline into set of segments. The map display NE-trending asymmetrical anticline (Syrian arc trend). Abu Roash (A) depth structure map **(Fig.7C)** and Abu Roash (G) dolomite depth structure map **(Fig.7D)** show approximately the same pattern of Khoman depth map with difference in number of faults and increase in depth of each horizon. Abu Roash (A) and (G) dolomite depth maps appears alot of NW-trending faults cut off NE-trending anticline. **Figure (8A)** represents depth structure map of Alamein Formation which are characterized with decrease number of faults comparison with above layers. Major fault (**F4**) bounded subsidence area in the northern part. The dominance trend of faults at Teritary-Cretaceous period is NW-SE. Depth structure map of top Jurassic **(Fig.8B)** manifest reverse structure style relative to the overlying layers. This map illustrates the initial occurrence of northeast-trending faults and the transformation of a prominent Cretaceous anticline, depicted in depth maps, into a half-graben structure during the Jurassic period. This map exhibits fewer faults compared to those found in Cretaceous tops.

V. CONCLUSION

The Horus oil field is a part of the Alamein basin, positioned above the hanging wall of several northeast-trending Jurassic-Early Cretaceous faults. The faults from the Jurassic period are categorized as extensional faults, resulting from significant tension between two main tectonic plates. The top of the Jurassic exhibits a dissected with a relatively low number of extensional faults, forming a half-graben structure that plays a key role in controlling the deposition of thick sediment.

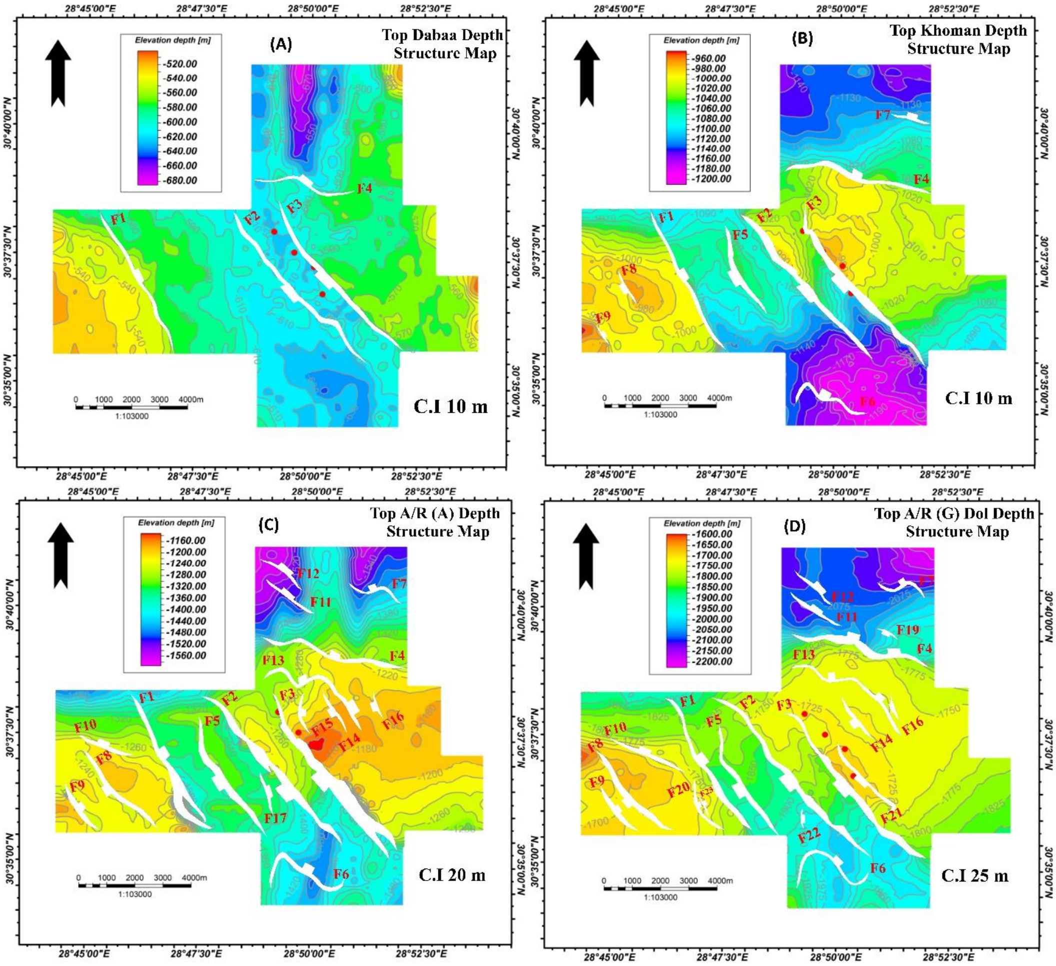

Figure 7. Structure depth maps of top **(A)** Dabaa Formation, **(B)** Khoman Formation, **(C)** Abu Roash (A) member and **(D)** Abu Roash (G) Dolomite member.

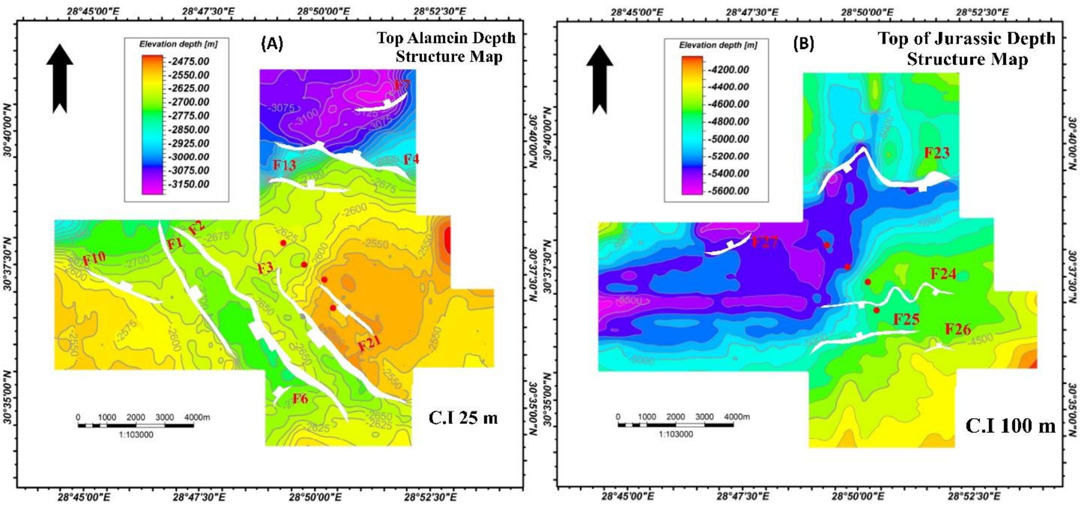

Figure 8. Structure depth maps of top **(A)** Alamein Formation and **(B)** Jurassic period.

The tops of the overlying Cretaceous exhibit an NE-SW-trending inversion asymmetrical anticline situated above a Jurassic half-graben. This anticline is segmented by a substantial quantity of NW-SE trending faults. The number of faults with significant displacements in the horizons ranging from the Khoman formation to the Alamein formation seems to be on the rise. This is particularly notable when comparing them with the upper and lower layers, suggesting a heightened level of compression activity during the Cretaceous period. The

Tertiary period is characterized by the Dabaa Formation, which is dissected by major faults featuring weak throws. The Tertiary age appears relatively stable when considering both the number and throws of faults, especially when contrasted with the compression observed during the Cretaceous period and the tension experienced in the Jurassic period.

The manifestation of a positive inversion structure becomes evident during the Jurassic period due to tensional forces, leading to the formation of half-graben and subsequently influenced by compression forces during the Cretaceous period, resulting in the creation of anticline.

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