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Original Article

Seismic structural analysis in Horus Field, Western Desert, Egypt

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ABSTRACT

Horus field is located in the northern part of the Western Desert. Cretaceous age is the main production succession in the Horus field. The main objective of the work is to study the seismic pattern of the structural inversion and to detect the structural trend during the Cretaceous and Jurassic ages in Horus field and to assimilate the investigation results for the discovery of the hydrocarbon entrapments in the study area. Thirty 2D (PSTM) seismic lines with five wells are used, to describe the structural configuration and inversion in the study area. 2D seismic lines have been reviewed and the best quality lines have been accessed and worked on. The data calibration to the well tops is the first step, then mapping the main surfaces. The mapping from the 2D seismic lines revealed that, the main fault trend is the NW-SE and the interpreted seismic sections display half graben, which is effected by several faults. These faults were affected by differential inversion movements in two stages during the Late Cretaceous time. The inversion related structures are the main hydrocarbon traps in the study area. Precise modeling for the Jurassic and Cretaceous faults is highly recommended, to reduce the uncertainty of the new hydrocarbon exploration in Horus field.

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1. Introduction

The Horus field is cited in the northeastern part of the Western Desert, 7 km northeast of Alamein field, between Latitudes (30o 36' 00" and 30 o 41' 59.98" N) and Longitudes (28 o 47' 59.97"and 28 o 53' 59.99" E) (Fig. 1). The field was discovered at 1982 by Murphy Egypt and the joint venture "Alamein Petroleum Company" was established under the law #29/1979 in 1985. In 1990, Murphy renounce to Kriti Oil & Gas and the last drilling activity was in 2008. 20 wells were drilled in the Horus Development Lease, started with Horus 1, and followed by the remaining wells. This area evidenced to be one of the leading hydrocarbon producers in the Alamin Basin. The field produces about 1,100 BOPD with average water cut of 35 %. In petroleum potential, numerous wells have been reached the Upper (Abu Roash G dolomite unite and Bahariya formation) and the Lower Cretaceous (Alam El Bueib formation) targets. Several attempts were made to penetrate the deeper reservoir in the study area, but it didn't work except for the H.N2x well, which was produced from Alam El Bueib Formation. The Alam El Bueib Formation, Bahariya Formation and Abu Roash G Dolomite units are oil-bearing and have an extensive lateral extent in the province. So, these formations are considered the most remarkable among the Lower Cretaceous deposits. The Horus Oil Field is located alongside the Alamein/Razzak Ridge, which consists of the leading hydrocarbon reservoirs, with several closed structures in the Alamein Basin, (Vegas Oil and Gas S.A. Company, 2010).

Most of the drilled wells in the study area are located on three-way dip closures, concentrated at the central part of the area and outspreading to the WNW direction, having variable fault thrown. Horus wells penetrated a stratigraphic section ranging from Marmarica Limestone on the surface to Alam El-Bueib Formation in the bottom; following the normal stratigraphic sequence of the north Western Desert (Fig. 2). Apollonia formation unconformity surface. The section complete absence in the Horus Field, due to erosion/or non-deposition (GPC, 2021).

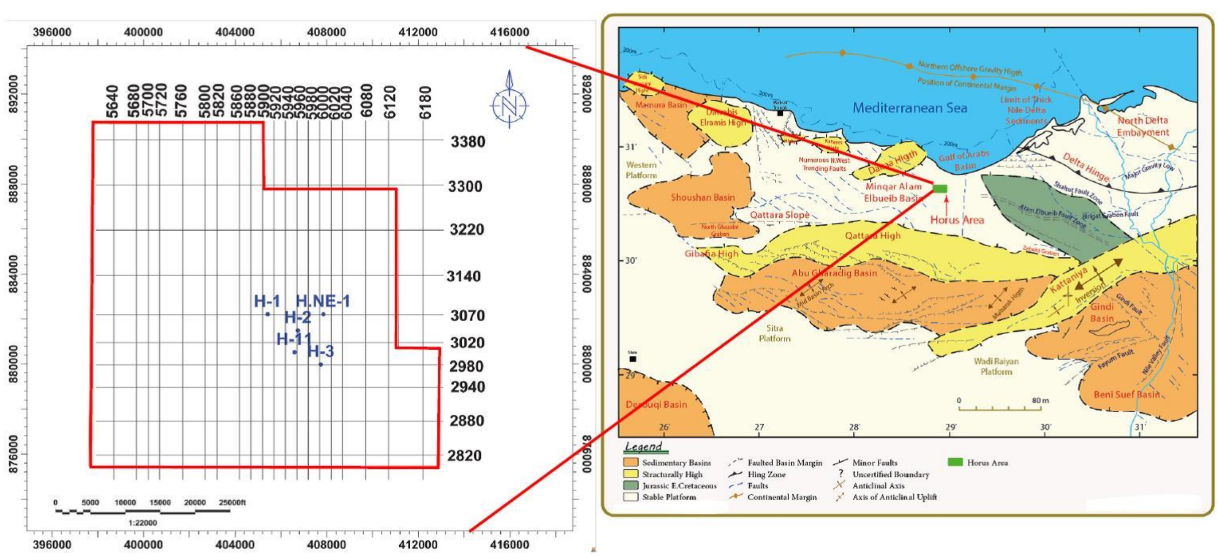

Fig. 1: Location map of the Horus Field, Western Desert, Egypt (modified after Bayoumi, 1996).

2. Geologic Setting

2.1. Structural elements

A Mesozoic petroleum system in the Western Desert is recognized to be active (Hegazy, 1992; Dolson et al, 2000; and Younes, 2003). Source rocks and reservoirs in both the Jurassic tilted fault blocks and Cretaceous inverted anticlines, were deposited in the framework of the Neo-Tethyan margins. These inverted anticlines were created from the inversion during the Senonian compressional event, that inverted standing extensional grabens (Ayyad and Darwish, 1996). Most of the folds have a NE– SW trend and formed during compressional movements at the late Cretaceous-Early Tertiary tectonic event. Also, there are folds created from normal or horizontally displaced faults, with parallel, oblique, or perpendicular axes to the fault trend reliant to the extent of the component of the strike-slip movement (Said, 1990). Horus Oil Field is drilled on the up-thrown side of a normally faulted ENE-WSW anticline, that is intersected by the Late Cretaceous NW-SE normal faults with right-lateral movement component. The field structure is completely terminated on the middle of the concession of the field by WNW-ESE en-echelon normal faults (Zawra, 2015), the tectono-stratigraphic column of the Western Desert of Egypt (Fig. 3) Horus Field is considered to be one of the Western Desert fields, which effected by the Late Cretaceous-Early Tertiary inversion. The field is typically forced fold, that undergone an extensional regime, to develop a half graben and transpressional stresses creating the inversion. The depocenter, along the main bounding fault to the NW, has been inverted, to form the crest of the fold with a steep limb over the re-activated fault. The criterion of the inversion in Horus Field exhibit in the asymmetric fold with steep climb to the NW direction, as shown on the field's map and seismic line (Fig. 5) Beside that, the thickening of the AEB Formation during rifting system aid to form anticlinal form on the Alamein Dolomite level and the other shallow targets, such as Dahab, Bahariya and Abu Roash formations, which are the important producing reservoirs in the area. The thickening of AEB Formation is bounded by the NW-SE normal fault (tensional force) extended from the Pre-Jurassic age, signifying the reverse force (compressional Force) along the plane of this fault and showing the rejuvenation of this fault during the inversion time (Zawra, 2015).

2.2 Stratigraphic column

- *Jurassic section*

The thickness of Jurassic sediments increases and become more common adjacent to the upper part of the section. The Jurassic in the Western Desert is classified into different formations, from bottom to top: Bahrein, Wadi Natrun, Khatatba and Masajid formations.

The Bahrein Formation un-conformably covers the Paleozoic (Barren sediments) or the basement. The formation is composed of red color clastics and consists of coarse quartzose sandstone, with thin pebble interbeds, siltstones and shale, rarely carbonaceous or pyritic and few anhydrite beds, which may point to a super-tidal to lagoonal environment (Said, 1990). The Wadi Natrun Formation is covered by the Khatatba Formation, where the contact between them is easily drawn on paleontological evidence and depending also on the lithologic stuffing of Wadi Natrun Formation, which include more limestone beds at its top part than the lower part of the overlying Khatatba Formation. It has a partial spreading only in the eastern part of the area and sideways its northern border, including Horus concession (Said, 1990).

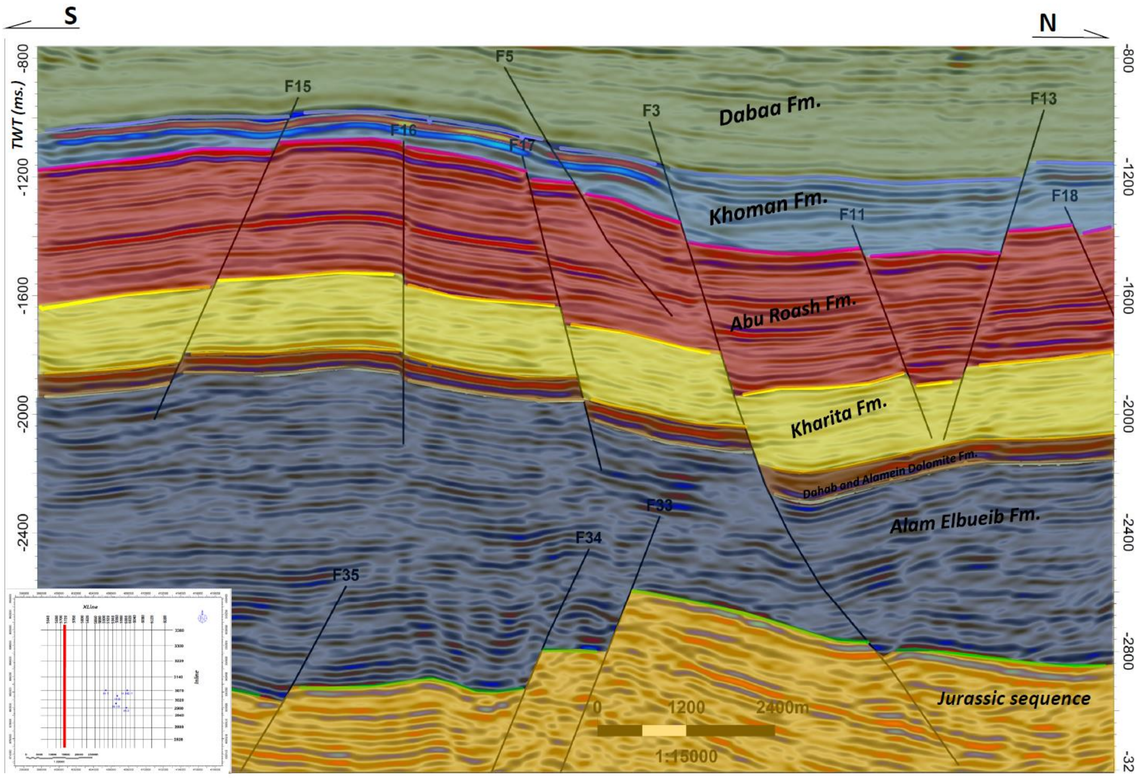

Fig. 2: S-N Seismic line 5720, through Horus area, showing the main fault trend in Cretaceous (rifting and compressional force) NW-SE trend and Jurassic rifting of ENE-WSW trend.

The marine Middle Jurassic clastic Khatatba Formation is mainly made up of sandstone and shale, with rare limestone interbeds. The shale is grey to brownish grey in color. The limestone layers are microcrystalline, argillaceous and in places carbonaceous, with thin coal seams at changed heights of the section. The formation lies conformably over the Wadi Natrun Formation towards the northeastern and eastern parts of the area, and over the Bahrein Formation at the remaining parts of the area (Said, 1990).

The Middle to Late Jurassic Masajid Formation is typically a massive limestone sequence (Said, 1990). The Masajid Formation is characterized by seismic strong Peak, compared to the overlying Alam El Bueib Formation faint seismic event (Because of the presence of thick clastics of the Alam El Bueib Formation (Fig.2). The Masajid Formation is composed of carbonate mainly limestone and show high acoustic impedance, relative to the superimposing Lower Cretaceous Alam El Bueib Formation, which has low acoustic impedance.

- *Lower Cretaceous*

Lower Cretaceous in Horus area is represented by Alam EL Bueib Formation (Neocomian-Barremian Lower Aptian age) up to Kharita Formation (Albian age), where the Aptian age is represented by Alam El Bueib Formation up to Dahab Formation while the Albian age is represented by Dahab Formation up to the Kharita Formation (Said, 1990).

- *Alam El Bueib Formation*

That is composed of sandstone and shale, with little streaks of limestone (General Petroleum Company, 2021). Alam El Bueib Formation is located between two strong Peaks, related to high acoustic impedance is underly the marked Alamein Dolomite Formation and overly the Masajid Formation. This formation consists of sandstone with repeated shale interbeds in its lower part and rare limestone beds in its upper part. The thickness of the limestone beds increases towards the northwestern part of the Western Desert, away from Horus Field, showing shallow marine environment over a shallow shelf (Said, 1990). Alam El Bueib Formation in Horus Field is divided into six mean rock units started from AEB 1 unit (Alam El Bueib unit 1) continuously down to AEB 6 unit (Alam El Bueib unit 6). The AEB 3unit (Alam El Bueib unit 3) is divided into six sub, units, started with AEB 3A continuously down to AEB 3G. However, Alam El Bueib Formation is one of the important formations in the Western Desert, as a reservoir rock in many of its units such as AEB 1, AEB 3A, AEB 3B, AEB 2D, AEB 3E, AEB-3G and the Basal AEB unit (AEB 6). All these rock units are formations, which characterize the reservoir rock in Horus area.

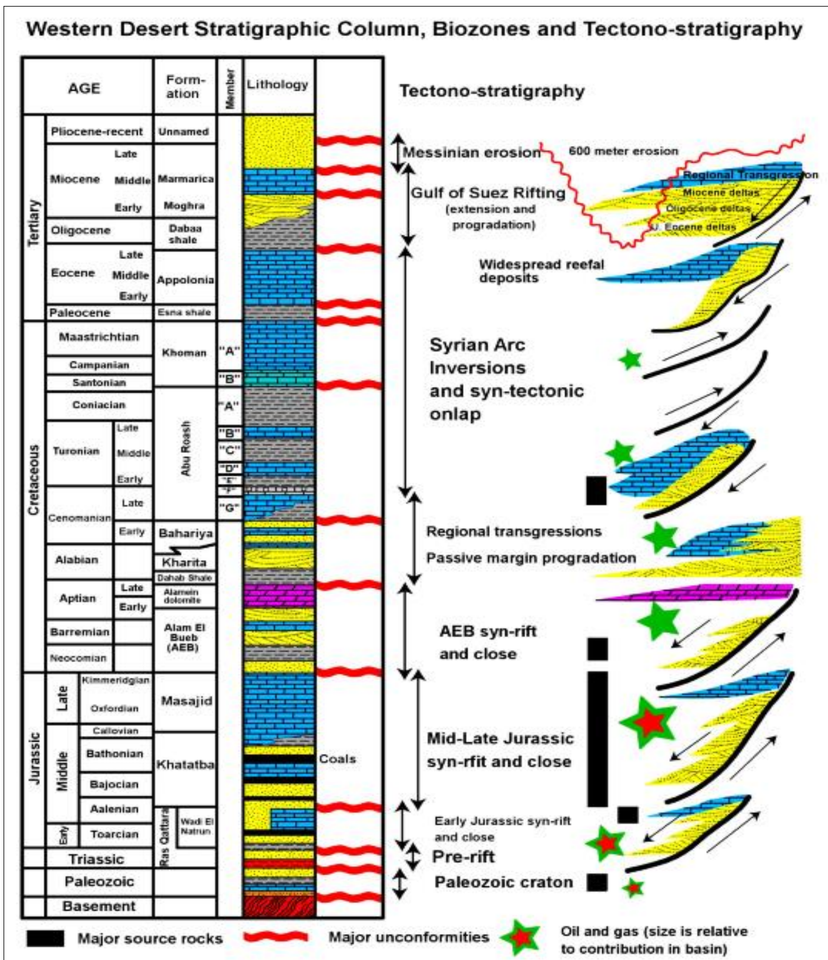

Fig. 3: Tectono-stratigraphic table of the Western Desert, modified after Wescott et al. (2011).

- *Kharita Formation*

Kharita Formation extends over most of the northern Western Desert (Fig.2). It is Upper Aptian-Albian in most areas. The section contains fine to coarse sandstone, with shale interbeds, and some carbonates. the formation thickness is about 1300 ft., as reported in many wells.

- *Abu Roash Formation*

The Abu Roash Formation is subdivided into seven litho-stratigraphic members, well-known from base to top as “G”, “F”, “E”, “D”, “C”, “B” and “A” Members, respectively (Aadland and Hassan, 1972; Schlumberger, 1984). The limestone and shale sequences of the Abu Roash “B”, “D” and “F” members distinguishing the marine transgression periods, while the clastic deposits of Abu Roash members “C”, “E” and “G” representing regressive phases (Norton, 1967). The top Abu Roash represents the event occurred between two boundaries, the high impedance of Khoman Formation and the low acoustic impedance of Abu Roash Formation (Fig. 2).

- *Khoman Formation*

Khoman Formation consists of chalky limestone. The limestone contained chert and several minerals, such as pyrite and glauconite. In Horus area, the Khoman Formation is sub-divided into two members “A “, and “B “Members. The lower member B" is composed of shale and argillaceous limestone and the upper "A" Member is of chalky limestone. The Khoman Formation overlies Abu Roash Formation with a marked unconformity. This formation reflects very strong peak and located between two faint reflectors Dabaa shale (low acoustic impedance) and Abu Roash Formation (low acoustic impedance). The thickness of Khoman Formation in Horus area is more than 700 ft. from the drilled wells, where the depocenter of the rock unit is located in the northern side of Abu Gharadig Basin. The Khoman Formation gradually thins from its depocenter, towards the southern limit of the Abu Gharadig Basin. The Khoman Formation age is Coniacian - Santonian to Mastrichtian. It has an open marine to outer shelf facies (Abd El Halim, 1992). This paper is dedicated to recognize the seismic structural configuration of Horus field and the evaluation of the inversion structure related to the oil and gas entrapments and proposing a realistic structural model of Horus area.

3. Data and Methods

A thirty 2-D seismic lines of post-stack time migration (PSTM) are used in the automated seismic interpretation. Five wells and stratigraphic boundary for tying with the seismic reflectors (H-1, H-2, H-3, H-11 and H.NE-1) wells. Five horizons (Masajid, Alam El Bueib, Kharita, Abu Roash, and Khoman formations) are mapped structurally in this study. Mapping of these horizons facilitated the reducing of the structural uncertainties and creating a realistic structural model. Creating structural maps, in addition to constructing the west-east and south-north seismic sections, showing the relation between the tectonic movements and structural trends during the Jurassic and Cretaceous ages, and related to the inversion structure.

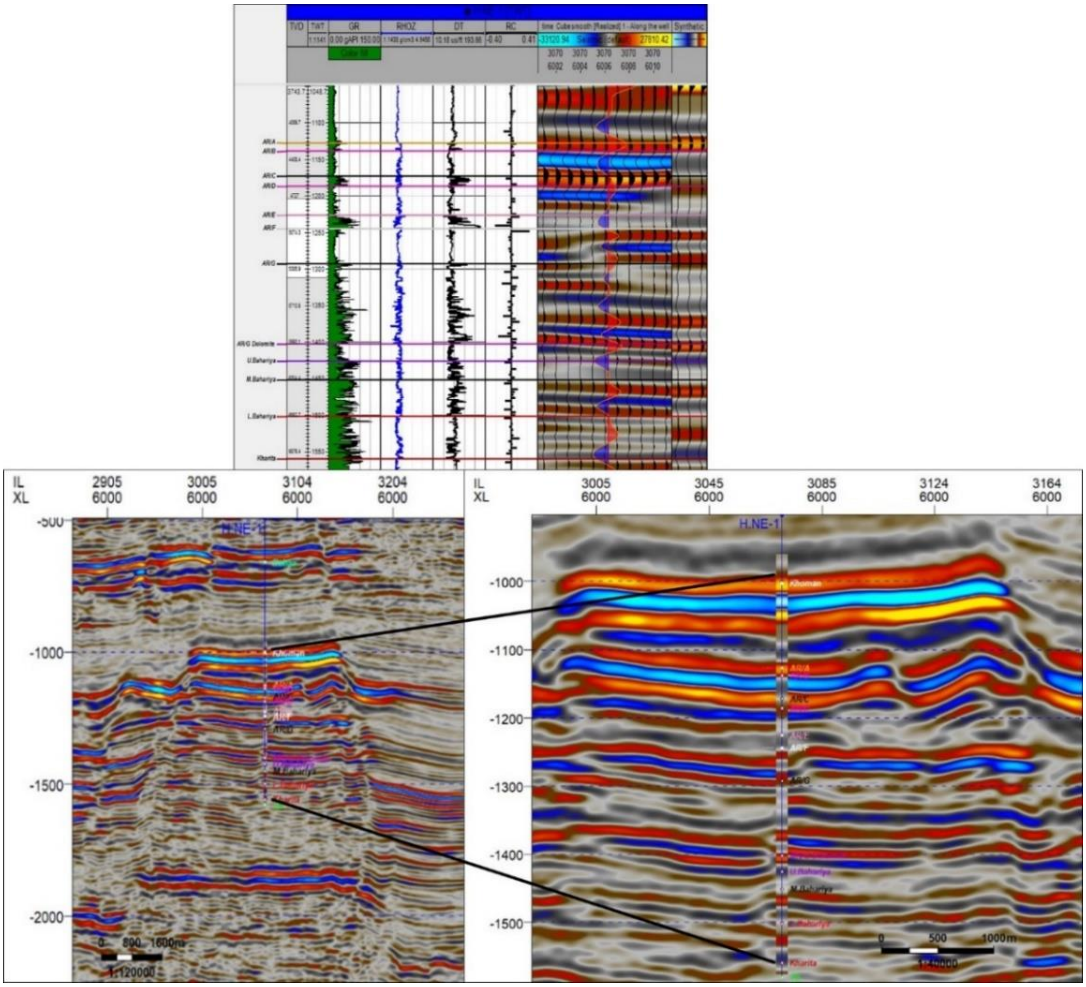

Fig. 4: Synthetic trace construction methods for H.NE-1 well. (A) Acoustic impedance is calculated by multiplying the values of density and velocity, in which the reflection coefficients are computed and convolved with an appropriate seismic wavelet, to obtain the synthetic trace.

4. Results and Discussion

Synthetic seismogram It is necessary to create a synthetic seismogram or a trace to accomplish the tie-to the well parameters. The input data in the synthetic seismogram consists of: sonic log (BHC), pore hole compensated, Density log and Vertical seismic profile (VSP) to produce a seismic reflectivity trace, that convolved with a selected seismic wavelet, to create a synthetic trace (Veeken, 2007). In this study, the seismic well tie was showed only on H.NE-1 well, as seen in (Fig.4)

4.1 Seismic interpretation

By integrating all the existing seismic and geologic data available in the study area, a seismic structural interpretation was implemented. The link will be between the seismic data and formation tops, that were defined from the selected drilled wells.

The five interpreted horizons were Khoman, Abu Roash, Kharita, Alam El Bueib and Masajid formations, from top to base (Fig. 9 & 10). The Masajid Formation is not present in the wells of the study area, due to the drilling is bottomed in the Lower Cretaceous (Alam El Bueib Formation). The interpreted Masajid Formation depends on a strong peak, due to its lithology, which consists of limestone (High acoustic impedance) underling Alam El Bueib Formation (Low acoustic impedance), that mainly consists of clastics (sand and shale). The Horus Field has very complex structures.

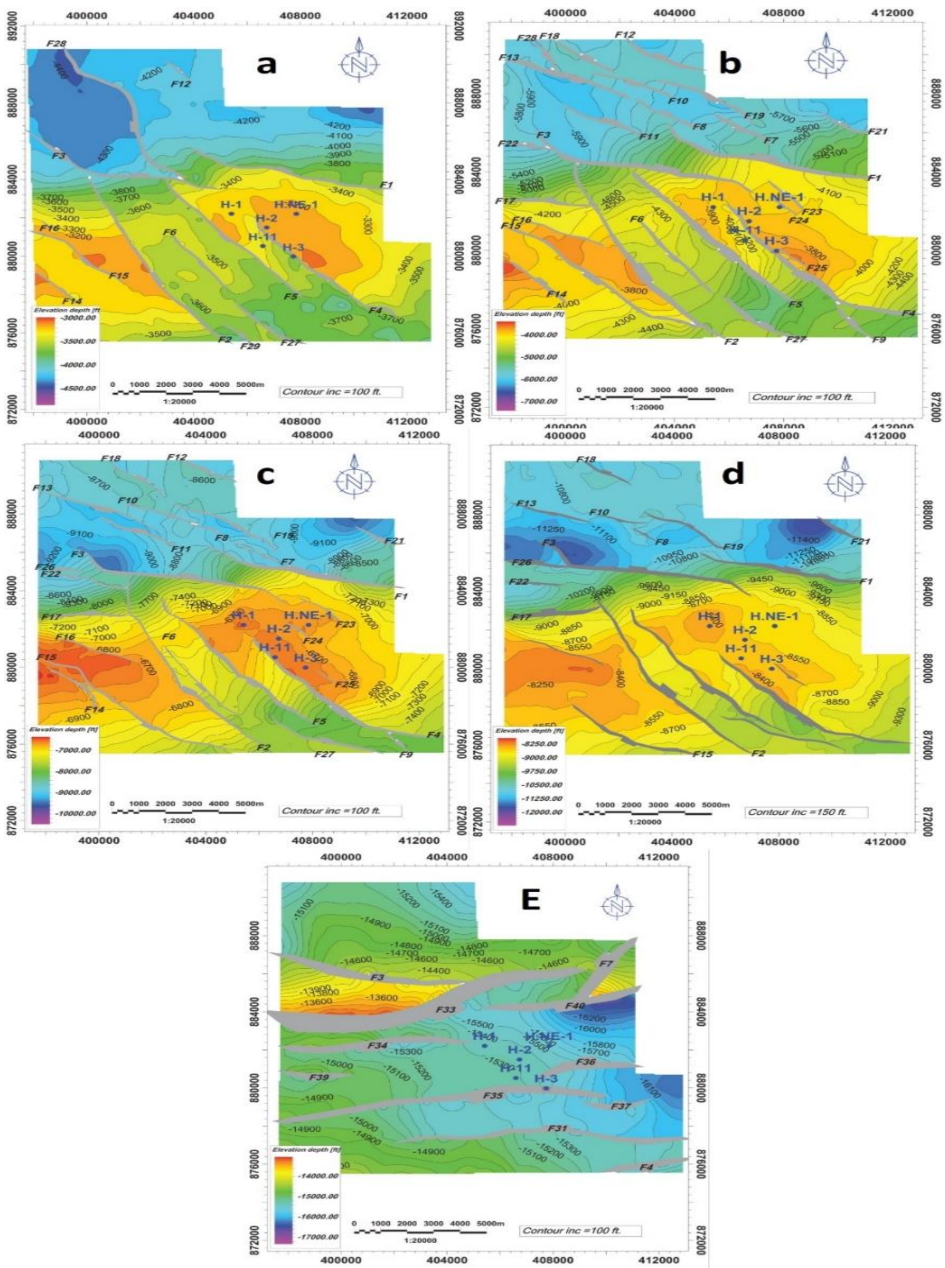

Fig. 5: Depth Map of (a) top Cretaceous (Khoman), (b) top Abu Roash Formation, (c) top Kharita Formation, (d) Top Alam El-Bueib Formation, (E) Top Masajid Formation, these is Show the main fault trends in the study area from Jurassic to Late cretaceous and the basin inversion through the Cretaceous age.

However, the area affected by several faults. Those faults must be interpreted, to detect the geologic history and interpretation of the sequences, finally in order to identify the prospective parts containing hydrocarbons. The effects are very clear, where the locations of the faults may be highly evident. The interpreted faults are normal, forming grabens and half grabens. The interpreted faults have two main orientations: 1) WNW–ESE, and 2) NW–SE. These faults were active in the Jurassic, Early and Late Cretaceous times. The seismic interpretation of both the NE-SW inverted faults (Fig.5E) and the Cretaceous NW-SE faults (Figs.5a, b, c and d) on top Khoman, Top Abu Roash, Top Kharita Top Alam El Bueib and near top Masajid formations. According to the seismic interpretation, we can detect the main structural trends. The leading structural trend in the Jurassic, based on the interpretation of the 2D lines, have ENE-WSW direction (Fig.5). While their trends in the Lower and Upper Cretaceous NW-SE and WNW-ESE, respectively (Fig.5). The Masajid surface is intersected by a major ENE-WSW normal fault called (F33) (Fig.5). Which has a SE dipping direction, creating a large half-graben structure in the southern part of the field (Fig.5).

4.2 Isopach maps

Integrating of the previously interpreted seismic profiles and the composite logs of the drilled wells, four isopach maps were created for the Khoman, Abu Roash, Kharita and Alam El Bueib formations. The isopach map is used to illustrate the changes in the formation thickness and its trends.

- *The isopach map of the Khoman Fm***.** (Fig. 6a) have a sedimentation thickness (>1900 ft.). The thickness growing toward the northern and southeastern parts of the study area and decreasing toward the central and southwestern parts of the study area. The thickness of the Khoman Formation is thinning toward the main horst block of Horus area, as related to the inverted anticline, but the deposition continued above the down thrown side of the horst block.

- *Isopach map of the Abu Roash Formation* in the present study shows, that the thickness enlarged toward the western, northeastern, and southeastern parts, recording the maximum value 2550 ft. and decreases towards the central part, with a minimum thickness of 1350 ft. the thickness of Abu Roash Fm. Decreases toward the central part, due to the main horst block of Horus field Also, thickness increases toward the western, northeastern, and southeastern directions, due to the location of the main basin at these directions (Fig. 6b).

- *The isopach map, made for the interval from top Kharita Formation to top Dahab Formation (Fig. 6c)*, shows variable thicknesses ranging from 800 ft. to 1700 ft. The extreme thickness of Kharita Formation is encountered at its northwestern part. Meanwhile, it exhibits its minimum thickness at the central and southwestern parts of the study area. This map displays basinal area in the study area that was created during the deposition of the Cretaceous Period. This map reflect that, most wells have not complete thickness, because the drilling were not continue after the Lower Bahariya.

- *The isopach map of the interval from top Alam El Bueib Formation to top Masajid Formation (Fig. 6d)***,** shows variable thickness as ranging between 1200 ft and 9000 ft. The maximum thickness of Alam El Bueib Fm. is located at the central and southwestern parts of the field.

Meanwhile, it exhibits its minimum thickness at the northwestern, northeastern and southeastern parts of the study area. This map shows basinal area at the central and southwestern parts of the field, that was created during the deposition of the Cretaceous Period. This map shows that, the thickness increases toward the opposite directions of its increase in the other maps, due to the area is cited by the Alamein inverted basins in which its area is affected by the compressional force during the Late Cretaceous, which characterized by inversion structure.

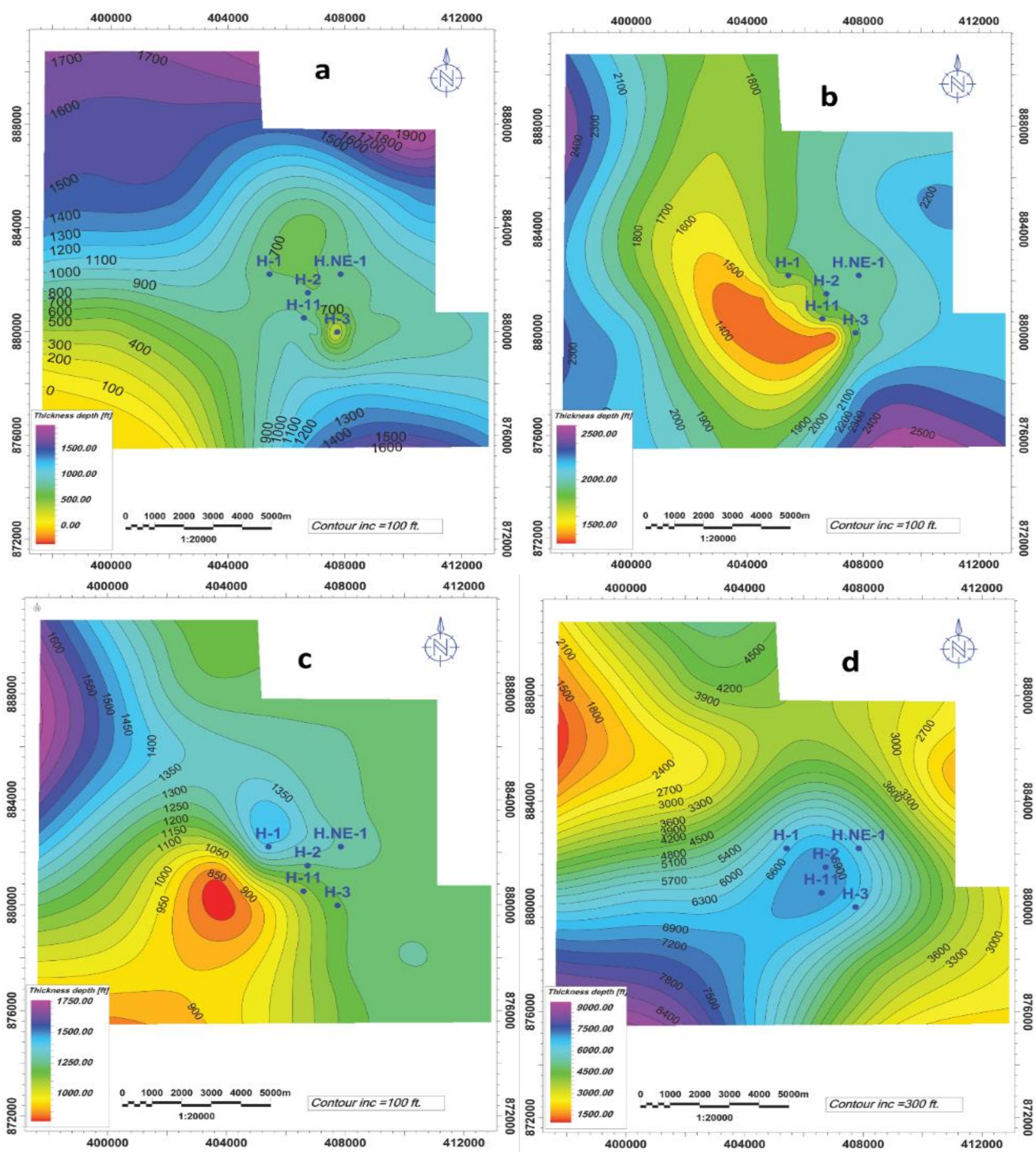

Fig. 6: Isopach contour maps of (a) Khoman (B) Abu Roash, (c) Kharita, and (d) Alam El Bueib formations, showing the basin inversion in the study area.

4.3 Seismic Cross Sections

Seismic interpretations of a set of S-N seismic sections (Fig. 7) (parallel to the Cretaceous faults) and W-E lines (perpendicular to the Jurassic faults) are presented in (Fig. 8). From seismic sections we can show that, the sediments at the hanging wall are thicker than the sediments at the foot wall in the major fault F-33 at the Jurassic section (Fig. 7), the thickness of Cretaceous age at the hanging wall of this fault is thinner than at the foot wall, which gives clear indication that, the Horus oil field is located in an inverted basin (Fig.7). This Fault die out at the upper part of Alam El Bueib Formation. The faults (F3, F5, F4, F2, F11 and F16) affected the Lower Cretaceous and rejuvenated at the Upper Cretaceous as related to the Syrian arc system of compressional force (Fig.7&8). The F-3 major fault affected the study area. This fault occurred during the Jurassic age rifting tectonic movement, then rejuvenated during the Lower Cretaceous (rifting) and Upper Cretaceous compressional force tectonic movement, as shown in (Fig. 7b & 7c). The structures between the Upper Cretaceous and the Lower Cretaceous is different, due to the faults that rejuvenated during the late cretaceous age. The Khoman Formation is thickened at the hanging-walls of the normal faults, which have NW-SE-trends, as shown in (Fig. 7 & 8) indicating that, these faults continued during the Oligocene time. The seismic lines (Fig. 7 & 8) show the Jurassic deposits, affected by a major ENE-trending normal fault, with the hanging-wall, that is thickened more by the fault F33 and the sediments thinned more at the footwall by this fault. As a result of the increasing in thickness of the Lower Cretaceous covering the Jurassic rocks, the area continued normal deposition during the Late Cretaceous age, due to increasing in the thickness of the Jurassic rocks, this helped to migrate hydrocarbons to the Cretaceous rock upwardly the low pressure conditions. The lines (Fig.9) was flattened on the top Khoman and Abu Roash formation. Detecting the sediments on the top Khoman and Abu Roash formations, which indicated that, the thickness increases toward the northern direction, unlike the Jurassic deposits that increases southward. The lines (Fig. 9) was flattened at the top Khoman Formation, and Abu Roash Formation, which indicates the presence of two compressional pulses or more.

4.4. Geologic cross-sections

The geologic cross sections are constructed, by using the available wells data, to approve the structural trends of Horus field. Creating these cross sections, by using the interpreted faults, with the structure contour maps. The formation tops and fault cuts from composite logs correlation and detecting the missing in the formations were used to construct the horizons between wells in the considered area. In this study, two sections are constructed in the dip direction, confirming the structural trends in the Jurassic and Cretaceous times of the field.

The first cross-section was created between H-3 and H.NE-1 wells (Fig. 10). The section in the S-N direction, which is the main dip direction perpendicular to the Jurassic faults of the area. All wells in the field penetrated the Abu Roash and Bahariya formations. The second cross-section was constructed through H-1 well (Fig. 11). This section has an S-N direction, which is the main dip direction of the area. The well H-1 penetrated Abu Roash and Bahariya rock units, reach Alam El Bueib formations. It was drilled at the main horst block of the study area on three-way dip closure and produced from the AR/G Dolomite, Upper Bahariya, Middle Bahariya and Lower Bahariya rock units.

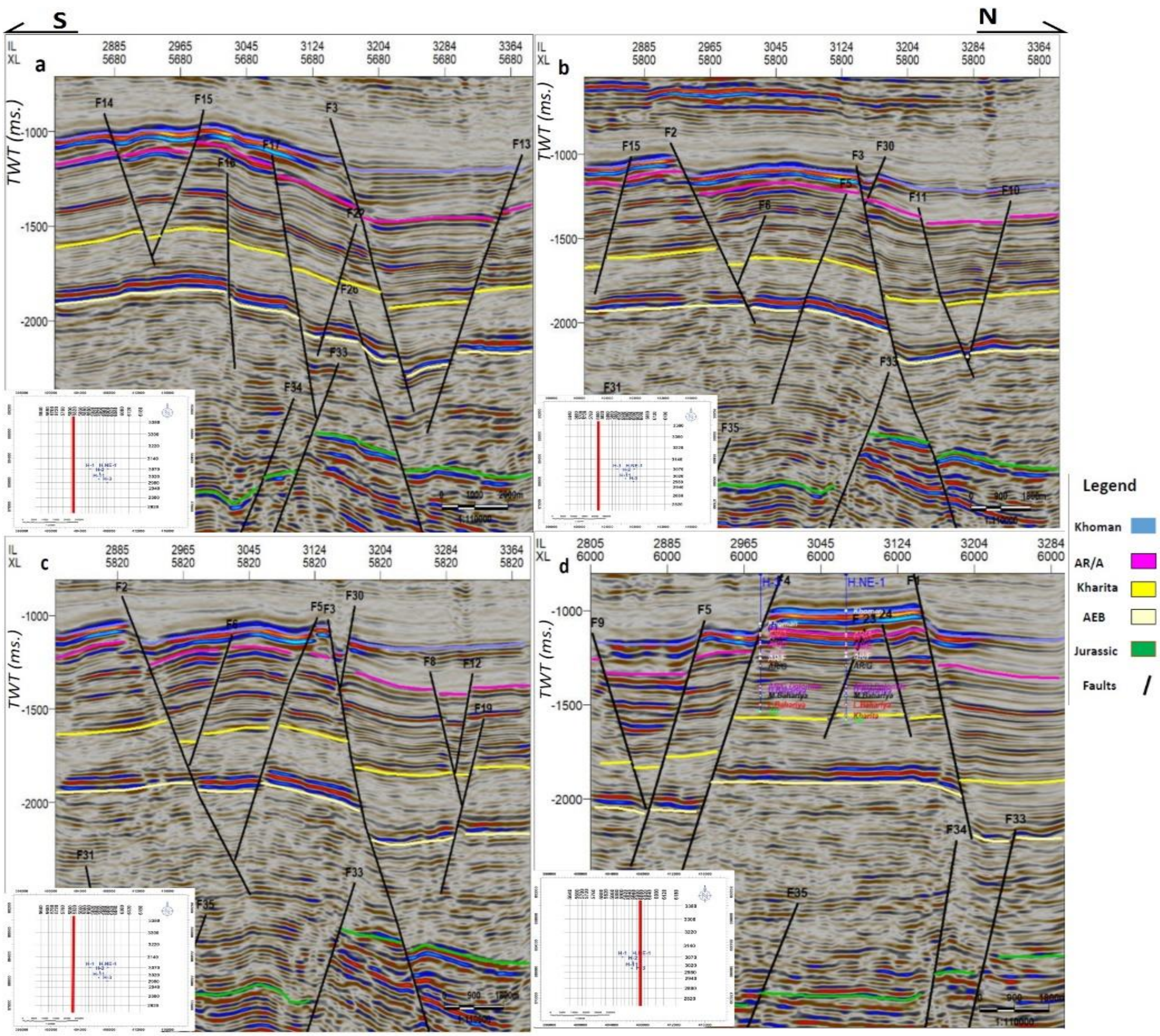

Figure 7. South-north seismic lines are perpendicular to the segment strikes in the Jurassic half grabens.

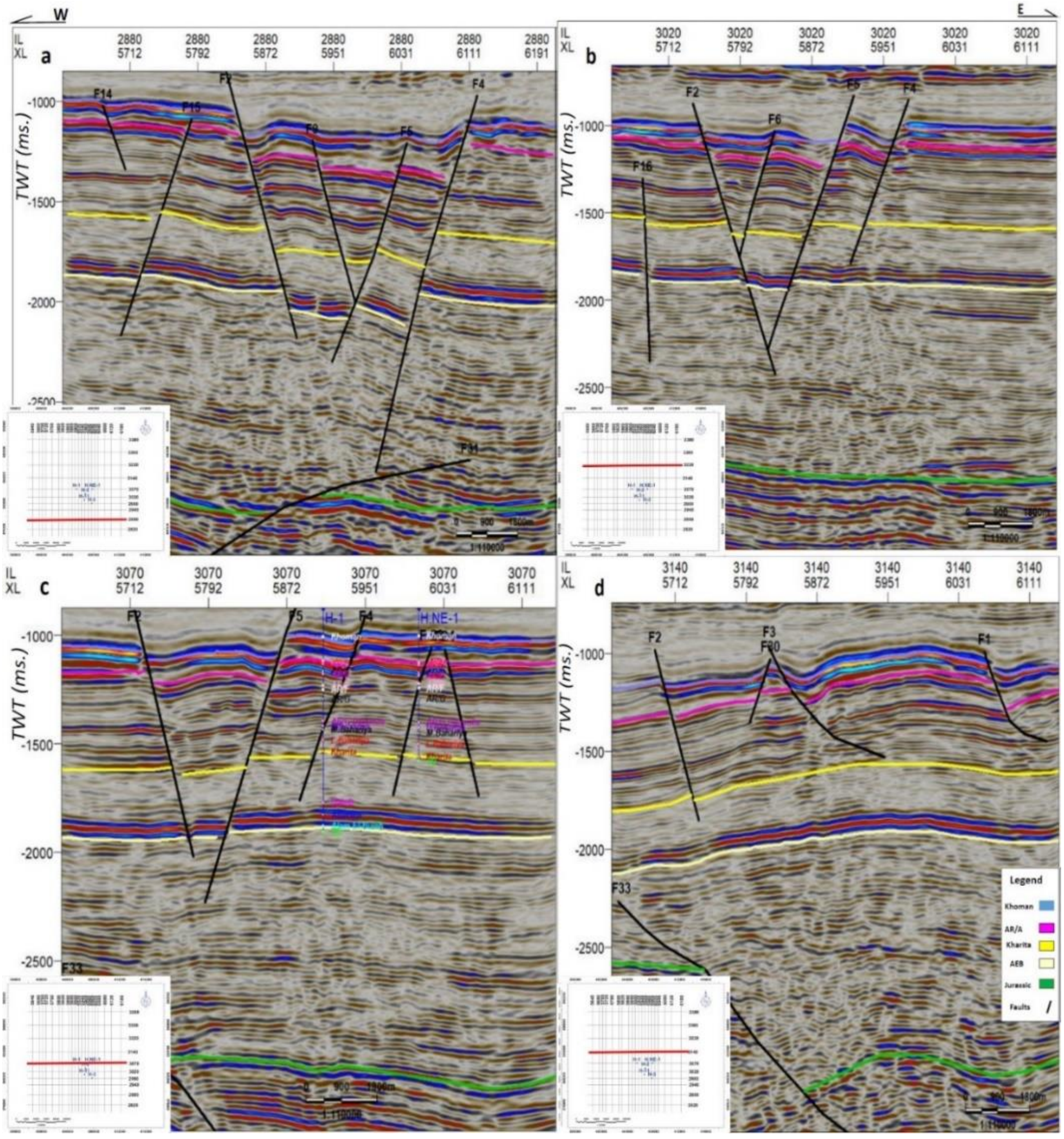

Figure 8. West-East seismic lines are parallel to segment strikes in the Jurassic half graben.

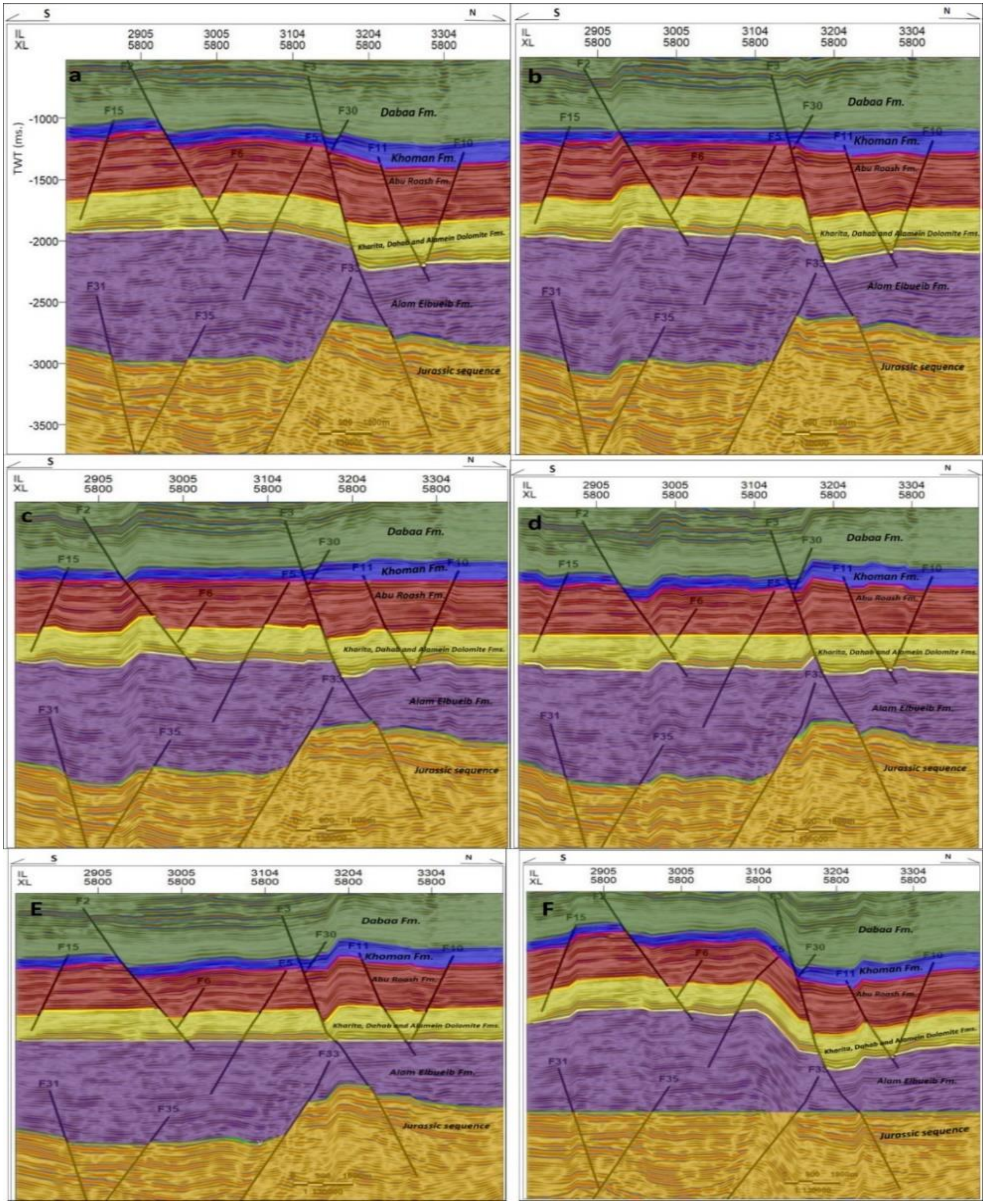

Fig. 9: South-North seismic line through Horus closures (a) Original Cross section (b) Cross section flattened on the top of Khoman Formation. (c) Cross section flattened on the top of Abu Roash Formation. (d) Cross section flattened on the top of Kharita Formation. (E) Cross

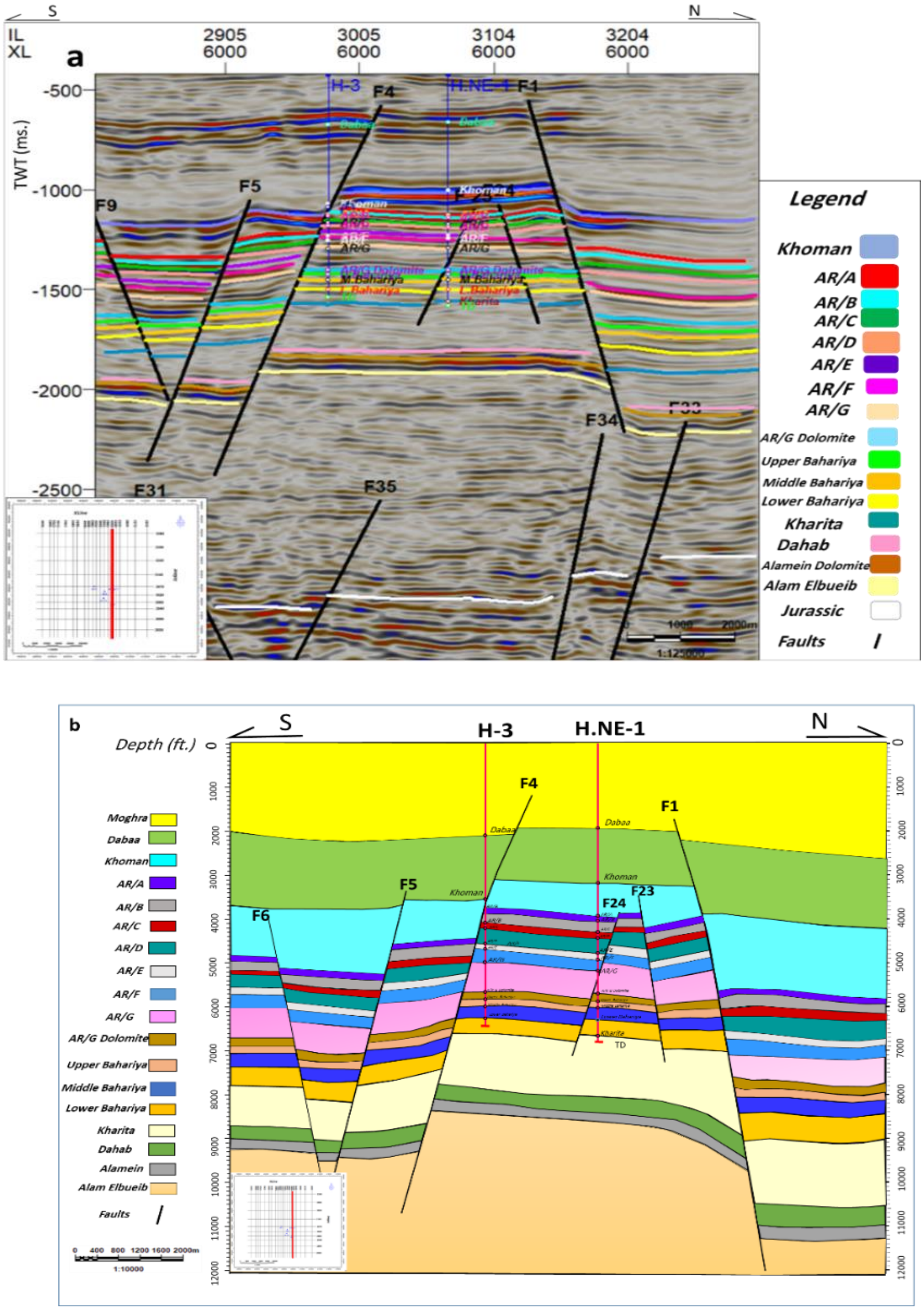

Fig. 10: a) N-S Seismic line 6000, passing through H-3 and H.NE-1 wells and (b) Geoseismic cross section through H-3 and H.NE-1 wells, Horus area, north Western Desert, Egypt.

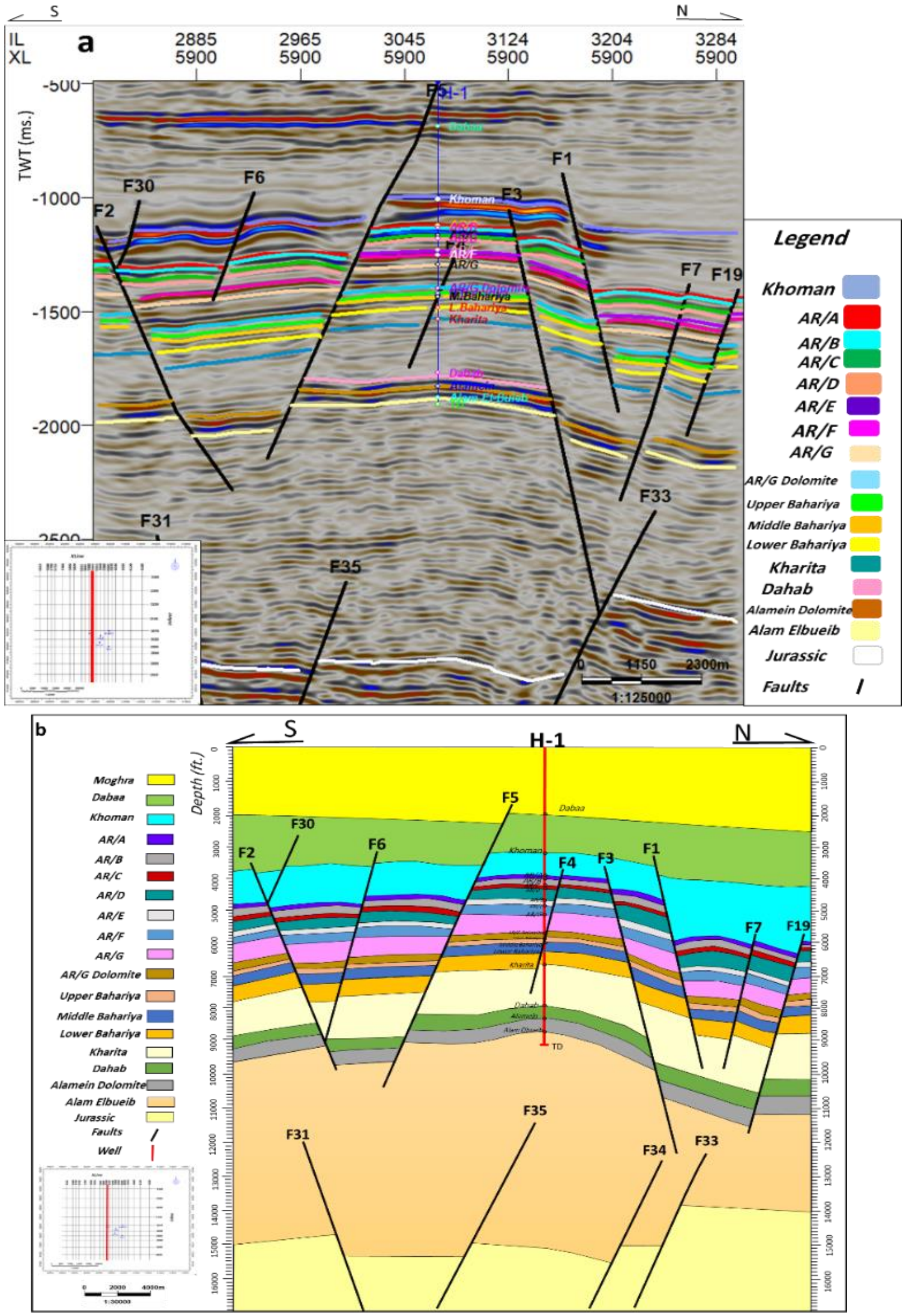

Fig. 11: a) N-S Seismic line 5900 passing through H-1 well and b) Geoseismic cross section through H-1 well, Horus area, north Western Desert, Egypt.

5. Conclusions

Seismic interpretation helps to detect the structural trends and traps in the study area. After interpretation of 2D seismic lines, it has been reached that, the structural trends in the study area during the Late Cretaceous are NW-SE and ENE-WSW, and related to the inverted tectonics. The Lower Cretaceous has NW-SE structural trend, related to the rifting during this age and the Jurassic trend is ENE-WSW, related to the rifting during the Jurassic age. After accomplishing the interpretation of thirty 2D seismic lines and establishing the depth structure maps, the results and the actual data of the drilled wells have been integrated, through the seismic interpretation of these lines, promising new exploration opportunities discovered southwest of the study area. Horus oil field is drilled on the up-thrown side of a normally faulted ENE-WSW anticline that is intersected by the Late Cretaceous NW-SE normal faults with right-lateral strike component. The field structure is completely terminated at the middle part of the concession by WEW-ESE normal faults.

Declaration of Competing Interest
The authors declare that they have no conflict of interest.

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