Superimposed structure in the southern periphery of Abu Gharadig Basin, Egypt: Implication to petroleum system

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Abstract: South West Abu-Sennan (SWS) area near the southern periphery of the Abu-Gharadig petroliferous basin in the Egyptian Northern Western Desert is an important hydrocarbon field characterized by being a multi-reservoir with a complex structural architecture. Therefore, in this study, we illustrated the regional structural role that facilitated having Jurassic mature source rocks (Masajid and Khatatba formations) through surgical seismic interpretation and observed the controlling petroleum system of the study area using a set of 20 seismic lines and 4 wells data. The study resulted in having the SWS oil field controlled by a strike-slip movement that occurred during the Upper Cretaceous time accompanying the African Plate movement against the Eurasian Plate superimposing an ENE–WSW strike-slip fault zone in the region and a strong pattern of NW–SE-oriented faults due to numerous phases of extension. The associated structures include horsts, normal fault propagation folds, and strike-slip-related anticlines. The strike-slip tectonics played a major role in forming entrapment for the Jurassic expelled hydrocarbons. The seismic horizons flattening exercise performed on AR/G member and Khoman Formation demonstrated that the main reason for not having hydrocarbon accumulations in the Jurassic levels in the study area is that the trap configuration was ready to accumulate hydrocarbon but after the hydrocarbon generation and migration time. The study concluded that the hydrocarbons migrated along the faults which cut deeply to the source rocks and entrapped in the possible cretaceous reservoirs during the late cretaceous time. The conducted workflow in this study can be utilized to better explore and develop cretaceous reservoirs in the study and neighbouring areas.

Key words: South West Abu-Sennan (SWS) area, structural geology, seismic interpretation, horizon flattening, petroleum system

1. Introduction

It is important to perform a detailed structural analysis based on subsurface geological information since the current energy industry seeks to im-

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prove subsurface exploration through accurate assessment and competent production (*Wu and Xu, 2004; Yan-Lin et al., 2011; Radwan, 2022; Noureldin et al., 2023*).

Numerous rift basins can be recognized across North Africa (*Guiraud et al., 2005; Bosworth et al., 2008; Moustafa, 2008*), such as the intra-cratonic Abu Gharadig Basin in the Egyptian Western Desert that is trended in the E–W direction. The Abu Gharadig Basin spreads from the Qattara depression to the west and the Kattaniya horst to the east. The Abu Gharadig Basin is confined by two basements elevated to the North as the Sharib–Sheiba platform and to the South as the Sitra platform, respectively (*Abd El-Aal and Moustafa, 1988; EGPC, 1992*).

This study illustrated the regional structural pattern that affected the SWS oil field which is confined by latitudes of 29° 32′ to 29° 35′ North and longitudes of 28° 30′ to 28° 35′ East (Fig. 1) in the southern periphery of the Abu Gharadig Basin and investigated the structural architecture of the study area by flattening the picked seismic horizon and surgical seismic interpretation. It also investigated how structural events implemented the working petroleum system in the study area.

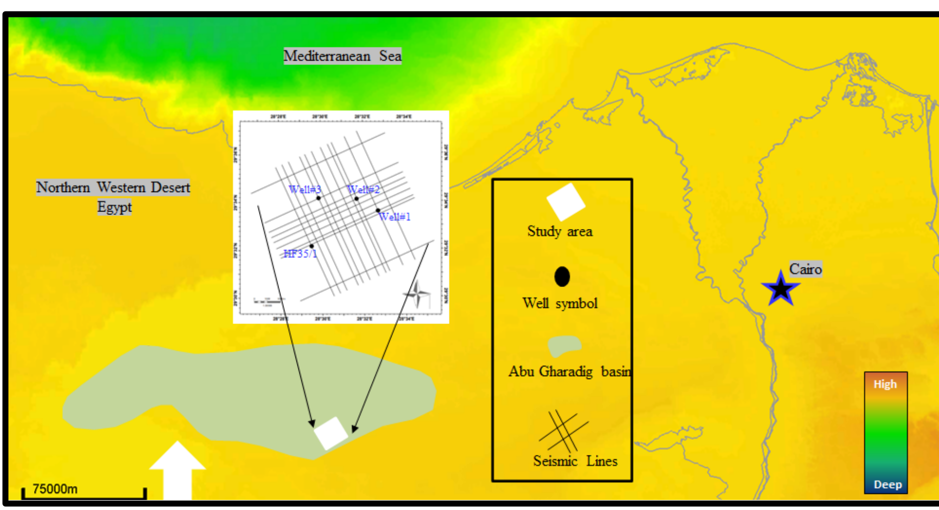

Fig. 1. Regional bathymetry map for North Egypt (*GEBCO, 2023*), overlayed by the SWS oil field located on the southern periphery of the Abu Gharadig Basin. White base map of the used 2D seismic lines and wells in the present study magnified.

2. Geologic settings

Egyptian Northern Western Desert comprises numerous employed petroleum systems (*Meshref, 1990*) where rich organic matter source rocks can be found in the extended rift basins (*Katz, 1995*). The stratigraphical column of the Egyptian Northern Western Desert highlighting the petroleum system elements (PSE) is represented in Fig. 2.

The Abu Gharadig Basin is subjugated to ENE–WSW faults together with a strong pattern of NW–SE-oriented faults signifying that regional strike-slip movement affected the basin and numerous phases of rifting (*Abd El-Aal and Moustafa, 1988*). The Abu Gharadig Basin holds a thick Late Jurassic-early Cretaceous sedimentary succession that was influenced by two essential sinistral and dextral shear tectonic events related to the opening of the Atlantic Ocean as (i) left lateral movement of Africa against Eurasia during the Late Jurassic to the Early Cretaceous and hence Africa moved eastward relative to Eurasia, (ii) right lateral movement during the Late Cretaceous to Paleocene time during the opening of the North Atlantic Ocean, leading Africa to move westward against Eurasia (*Longacre et al., 2007; Bosworth et al., 2008*) (Fig. 3).

The elliptical Abu Gharadig Basin is a trended E–W Mesozoic rift basin. It touched its maturation phase during the Cretaceous time. However, its tilting commenced in the Santonian age and continued through the early Tertiary as a result of NW–SE compressive force. This compressive stress formed right lateral motion for the pre-existing normal faults which were generated former in the basin; Figure 3 shows Egypt's Western Desert location and the regional geologic setting (*Longacre et al., 2007; Bosworth et al., 2008*).

3. Material and methods

Twenty seismic lines covering the study area characterized by zero phase with frequency ranging from 10 to 45 Hz in addition to 4 wells (Well-1, Well-2, Well-3, and HF-35/1) data including well-head surface positions, well picks, and velocity control were used and integrated into the present study (Fig. 4). The electrical logs and seismic data must get prepared and checked for the sake of accurate workflow steps and outputs (*Noureldin et*

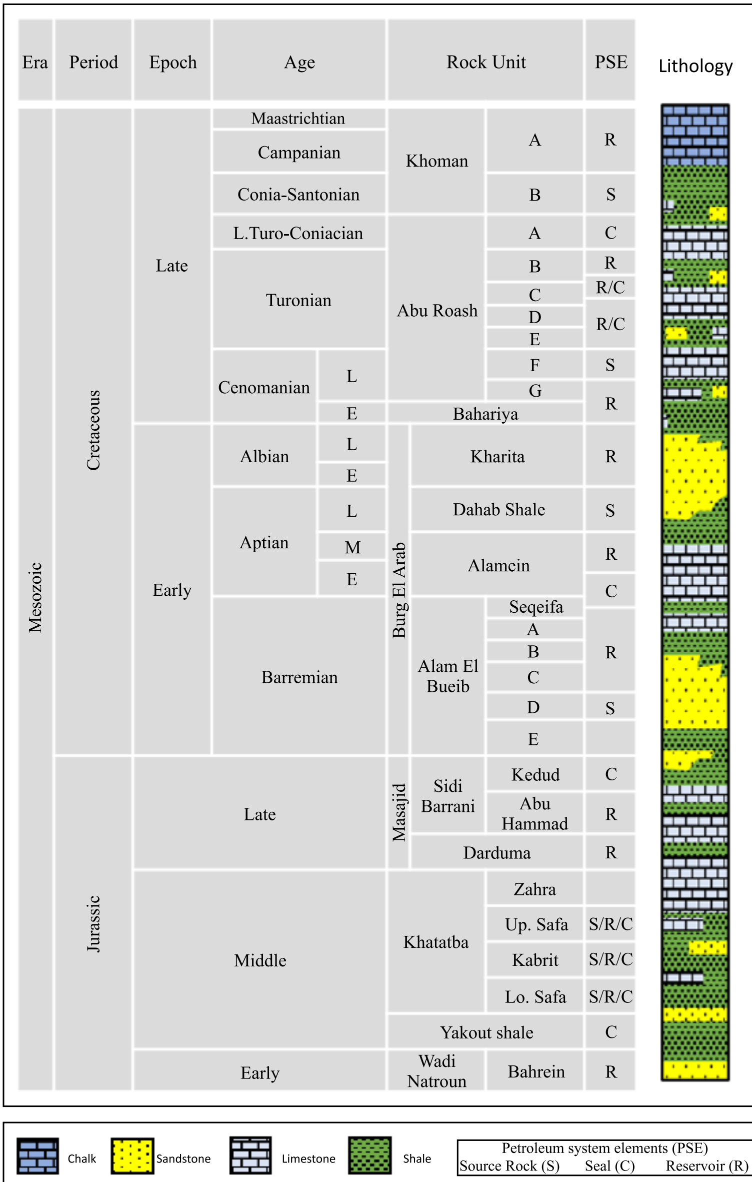

Fig. 2. Lithostratigraphic log based on the available well data for the Cretaceous sedimentary succession of Abu Gharadig petroliferous basin.

al., 2023).

Figure 5 depicts the procedures used in this study, the practical work performed in this study initiated with data gathering and preparations, followed by seismic data interpretation along with implications to the controlling petroleum system and structural analysis.

Seismic data interpretation initiated by employing the time domain seismic data along with the well data to create the wavelet then producing the synthetic seismogram that showed excellent agreement with the stacked seismic traces (Fig. 6). Seismic and well data are mostly used to connect formations and member tops with two-way time reflectivity data (*Ali et al., 2022*), and horizon tracking is then carried out (*Noureldin et al., 2023*).

Almost 37 subsurface fault elements were picked across the study area and 3 seismic reflectors/horizons (Khoman Formation, Abu Roash/G mem-

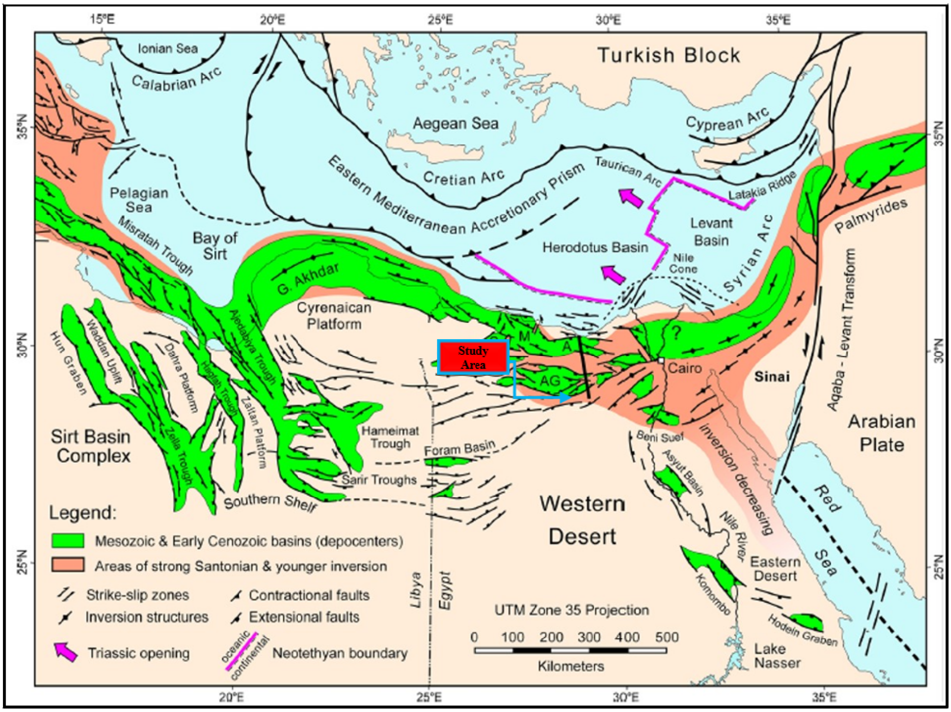

Fig. 3. Egypt's Western Desert and the regional geologic setting, (AG: Abu Gharadig Basin) (*Longacre et al., 2007; Bosworth et al., 2008*).

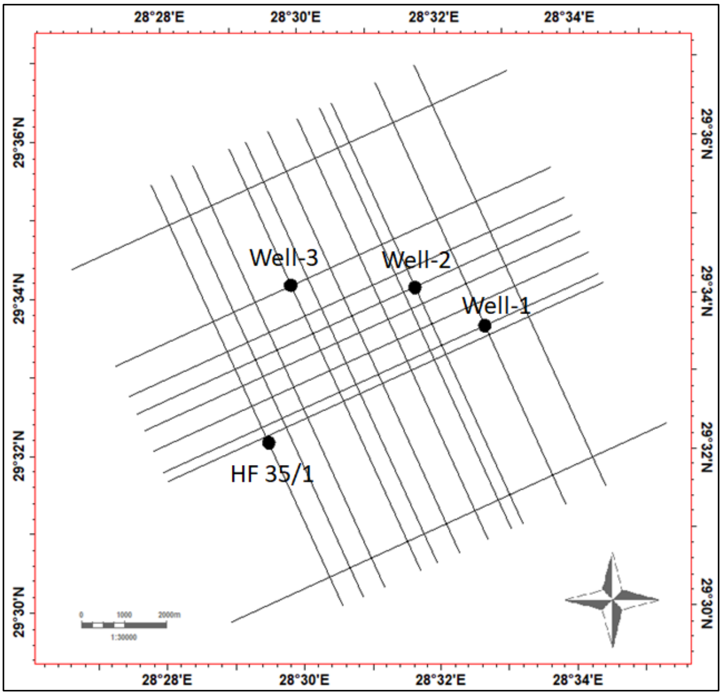

Fig. 4. Base map for the wells locations of Well-1, Well-2, Well-3, and HF-35/1, covered by the used 2D seismic lines in time domain.

ber, and Alamein Formation were traced in the time domain and then converted to depth using the main formula of velocity (*Newton, 1687*). Figure 7 is showing the main interpreted events in the study area.

$$\text{velocity} = \text{depth}/\text{one-way time}\,, \qquad (1)$$

where depth in meters and one-way time is msec of the traveling wave.

Ibrahim and Abdel Aziz (1995) conducted geochemical analysis for the cutting samples from the HF35/1 well (Table 1), to assess the Jurassic

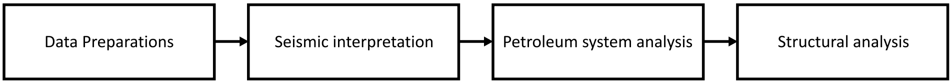

Fig. 5. The workflow defines the practical steps followed in the structural analysis.

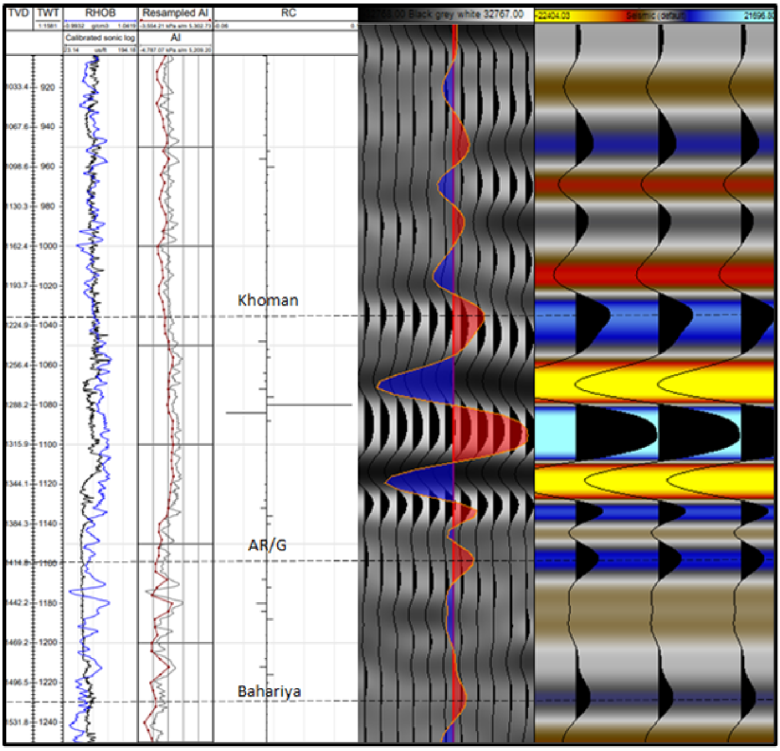

Fig. 6. Synthetic seismograms were generated through Well-2.

Table 1. Geochemical data from the HF-35/1 well in the South West Abu Sennan for Khatatba and Masajid formations, vitrinite reflectance, and TOC values (*Ibrahim and Abdel Aziz, 1995*).

Formation	Cutting Sample #	Drilling Depth (m)	TOC	T_{max} (°C)	R0 (%)
Masajid	3	3523	0.5	458	1.08
Khatatba	2	3612	1.6	462	1.16
Khatatba	15	3763	1.4	464	1.19
Khatatba	24	3867	2	464	1.19

source rocks (Khatatba and Masajid), Khatatba pyrolysis study exhibited that the well HF35/1 shale samples are situated between type-2 and type-3 borders.

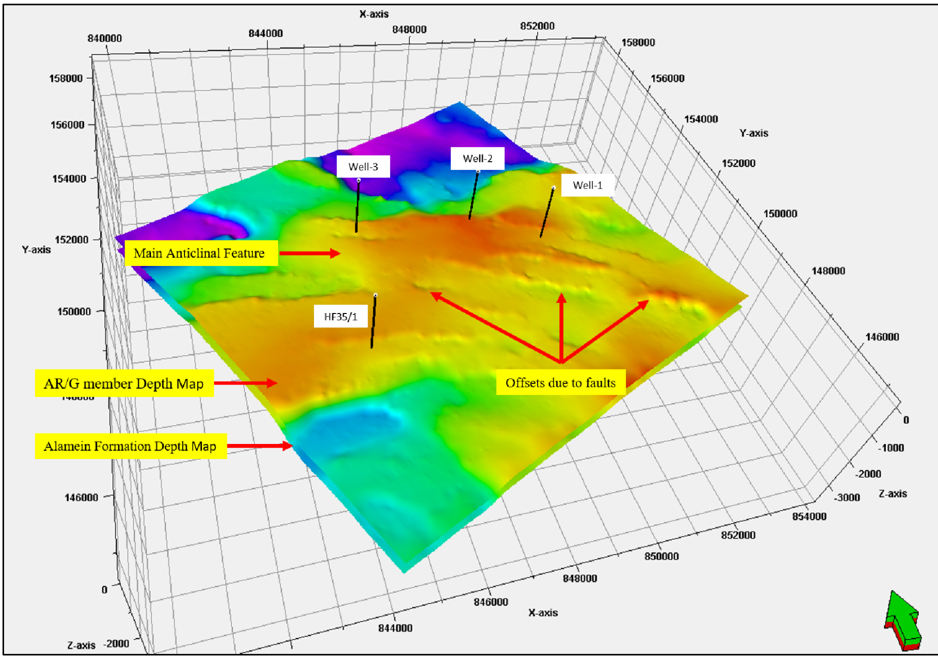

Fig. 7. 3D view showing the main interpreted events in the study area.

4. Results and discussions

4.1. Seismic interpretation

Seismic data interpretation has been one of the most effective tools for hydrocarbon prospecting since the 1920s, reflections are the direct outcome of variations in acoustic impedance through underground rocks that come into contact with various physical qualities (*Ukaigwe, 2000; Karbalaali et al., 2013; Eze et al., 2019; Noureldin et al., 2023*).

Subsurface mapping in the study area resulted in having a faulted anticlinal form that spreads all over the study area (Figs. 6, 8, 9, 10), the seismic reflectors representing the top of the Khoman and Alamein Formations were traced (Fig. 8) on the seismic sections due to its comparatively high amplitude character. However, Abu Roash-G is a significantly discontinuous reflector due to its segmentation by many normal faults that reflect

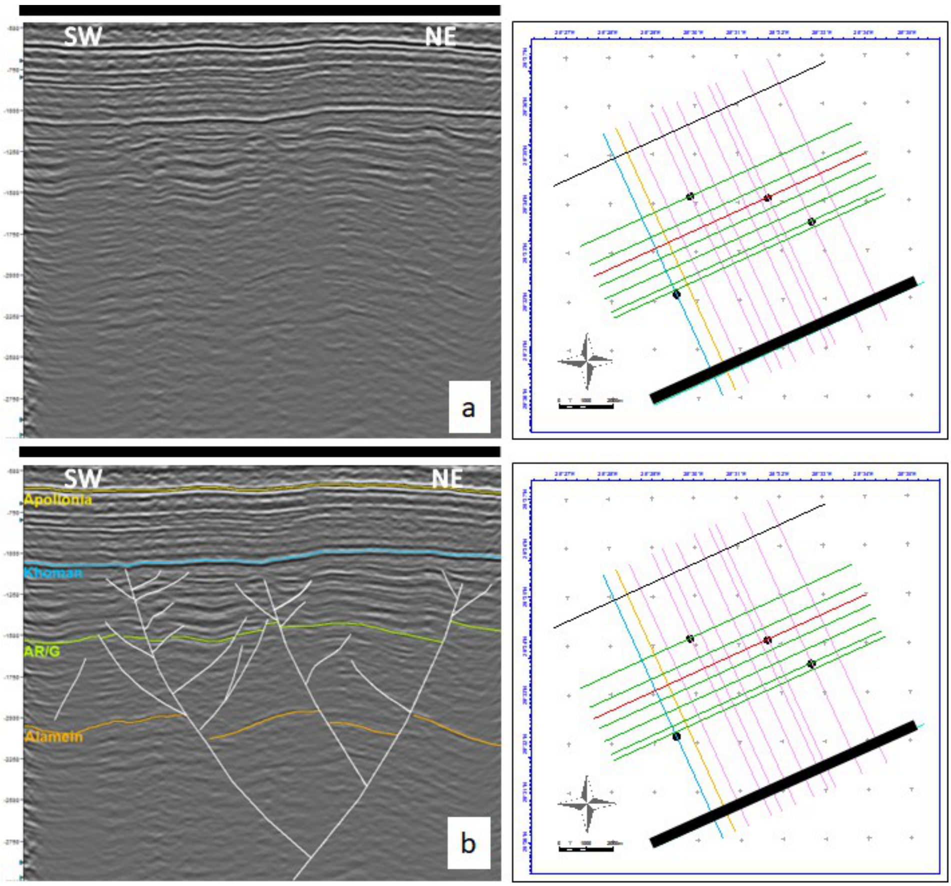

Fig. 8. Example from the ENE–WSW time domain seismic Xline#30 before (a) blank and after interpretation (b) showing the faulted anticlinal form.

tectonics that touch the Middle part of the Cretaceous sequence in the study area.

The AR/G member has depth values of $1400 \sim 1700$ m as shown in Figure 9. The predominant structures that are observed from the depth structure contour map are NW-oriented normal faults and NE-oriented faulted plunging to double plunging folds. The largest fold structure occurs within the central part of the mapped area of the top AR/G member (Figs. 6, 9), where a NE-oriented anticlinal structure has a structural relief. The anti-

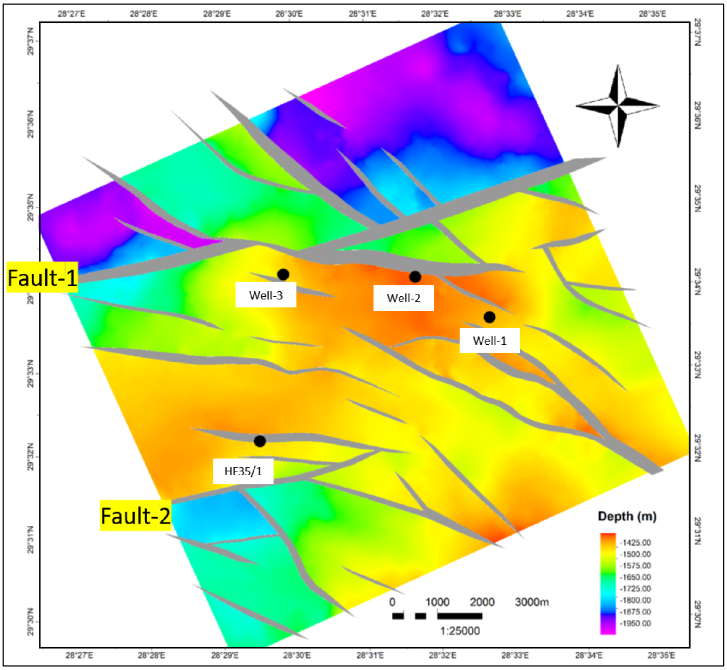

Fig. 9. Top AR/G depth structural contour map.

clinal structure is breached by the ENE-oriented strike-slip faults Fault-1 and Fault-2. On the structural map, the generally ENE-oriented strike-slip Fault-1 is shown to be segmented into two main right-stepped fault segments forming a linkage in between. This linkage consists of NW-oriented normal faults throwing basin-ward. The maturation of organic matter and the generation of hydrocarbons occurred at Jurassic level depths.

Figure 10 is showing anticlinal structure bounded by the two major ENE-oriented structural elements neglecting the minor structural elements in the seismic section. Seismic flattening to the top Abu Roash-G (Fig. 10a) indicates sediments deposition during the Early Cretaceous rifting phase and subsidence against accompanied Faults-1 & -2. The Campanian–Maastrichtian (Khoman Formation) flattening exercise showed a syn-compression tectonostratigraphic sequence represented by growth folding for Jurassic plays after the Late Cretaceous structural events due to the applied tectonism (Fig. 10b).

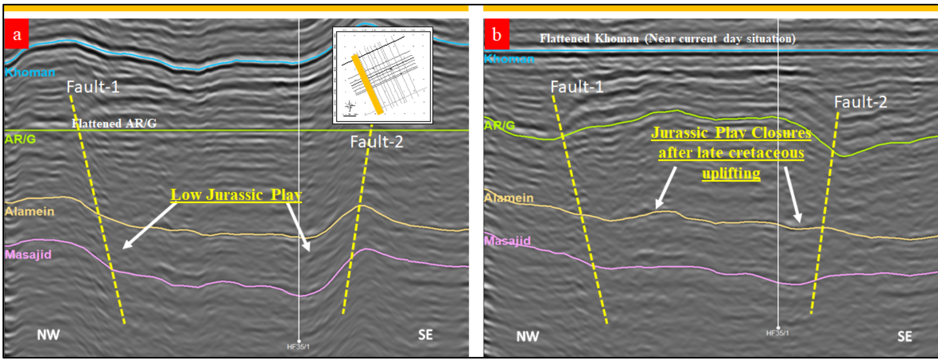

Fig. 10. Scheme model, examples from time domain NW–SE oriented seismic Inline#102 showing only the behavior of buried seismic events by applying successive horizon flattening (a and b) on Mid and late-Cretaceous and the related inverted visible structural elements (modified after *Noureldin, 2017*).

4.2. Petroleum system

Early Cretaceous rifting (*Noureldin, et al., 2023*) led to a rise in heat flow, increasing the maturation of the Jurassic source rocks and generating hydrocarbons. According to the source rock analysis of HF 35-1 well (*Ibrahim and Abdel Aziz, 1995*), the Jurassic source rock is in a maturation state to expel hydrocarbon to the surrounding Cretaceous/Jurassic traps. According to the structural observations (Figs. 6, 8, 9, 10) and the burial history (Fig. 11), the Abu Roash/F member is immature in the study area due to its presence in a relatively structurally high area (lower heat flow).

The event chart (Fig. 12) is showing that the main reason for not having hydrocarbons in the Jurassic levels of the well HF35/1 is that the trap configuration was ready to accumulate hydrocarbon but after the hydrocarbon generation and migration time.

The Abu Gharadig basin contains excellent reservoirs related to Cretaceous times. Different types of potential petroleum traps have been identified by analyzing the study area's structural and tectonic framework. These traps are related to Early and Late Cretaceous normal and strike-slip faults. The field is dominated by a three-way dip closure, which is dissected by normal faults and segments of the Santonian and Campanian–Maastrichtian strike-slip fault. The Cenomanian Bahariya shale, Abu Roash/G shale and

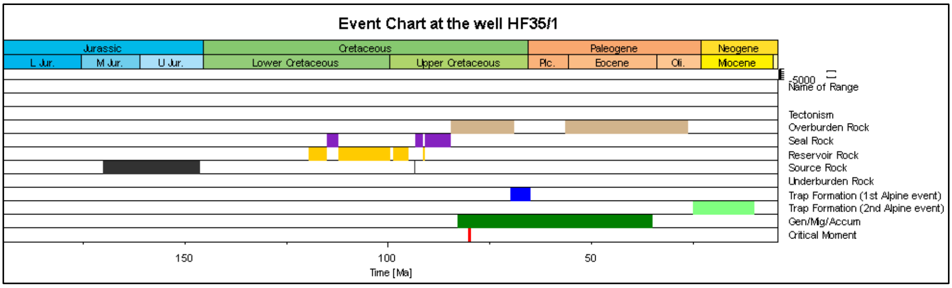

Fig. 11. Simulated burial and heating history for the well HF35/1 as a function of time and space (*Noureldin et al., 2023*).

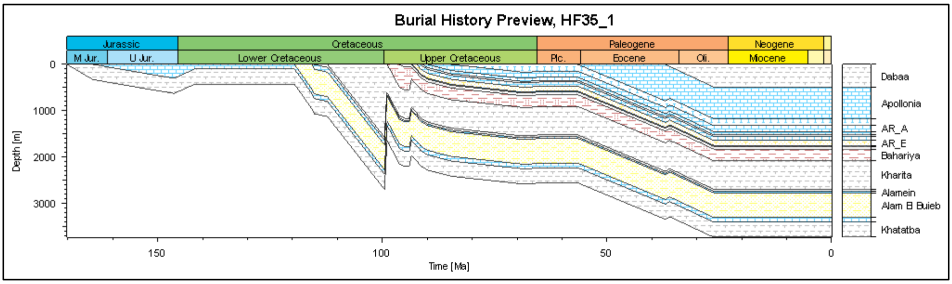

Fig. 12. Event chart shows the petroleum system elements at the well HF35/1 (*Noureldin, et al., 2023*).

carbonates, and the Abu Roash/F carbonates are considered to form the important top seals in the study area. According to the timing of deformation, the NW–SE horst structures that form the main entrapment were formed in the Early Cretaceous tectonic-stratigraphic sequence (Figs. 6, 8, 9, 10).

5. Conclusions

- SWS in the Southern periphery of the Abu Gharadig basin is influenced by the Early Cretaceous rifting that was followed by strike-slip tectonics during the late Cretaceous times.
- The Early Cretaceous rifting facilitated the maturation of the deeper source rocks (Lower Cretaceous shales of the Kharita Formation) due to high heat flow during rifting.

- Hydrocarbon migrated along the faults which cut deeply to the source rocks and entrapped in the possible cretaceous reservoirs during the late cretaceous time.
- The seismic horizons flattening exercise helped in the conducted structural analysis and demonstrated that the main reason for not having hydrocarbons in the Jurassic levels in the study area is that the trap configuration was ready to accumulate hydrocarbon but after the hydrocarbon generation and migration time.
- Abu Roash/F member in structurally high areas like the Abu Gharadig's periphery wasn't able to facilitate the maturation of the organic materials due to the shallow burial.

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