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Development of depressions (Sag ponds) South of Heet, West of Iraq

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ABSTRACT

Four depressions (sag ponds) are developed along a line trending northwest – southeast, Abu Jir, Al-Mudowar, Al-Jabha and Awasil that locate south of Heet city. Seismic reflection sections appear Abu Jir Fault Zone extended beneath the four sag ponds. Abu Jir Fault Zone is formed due to the rifting of northeast passive margin of Arabian Plate and suffered by right-lateral strike-slip movement. Negative Flower Structure is figured in seismic sections that mean extension in upper part of the sections developed. Abu Jir Fault Zone consists of some major faults that rarely perfectly straight but rather curved back and forth to some degree forming the sag ponds. Hydrogen sulfide-bearing groundwater rises from the deeper hydrogeological units to the shallower ones. It passes through the fault planes and fractures, due to the faulting, of the stratigraphic sequence. Limestone, soluble rocks, is the main component of the sequence. This process is played other role to develop the sag ponds and produce many water springs along the fault zone.

Introduction

The aim of this research is to know how Abu Jir, Al-Mudowar, Al-Jabha and Awasil Sag ponds are developed. The sag ponds are located along a line, northwest – southeast trending, south of Heet city about 140 km west of Baghdad. Some researchers mentioned to the depressions, but no detail study is curried out to know how the depression developed. The current study is achieved by using seismic reflection sections, the best method to give detail information of subsurface geological structures, especially if coupled with the development of advanced remote sensing and computing technologies. Three digital seismic reflection sections, SEG-Y format, oriented northeast – southwest direction and approximately perpendicular to the main subsurface structure, Abu-Jir Fault Zone, are selected. They are Abu-Jir survey-38 (AR-38), Abu-Jir survey-40 (AR-40) and Abu-Jir survey-50 (AR-50) **(Fig. 1)**.

Scene of Landsat-8 LDCM (Landsat Data Continuity Mission) image 169-37 at 5-6-2015 is used. Spatial resolution of Landsat-8 LDCM is 30 m for all bands except panchromatic (band 8). The later has special resolution of 15 m, and thermal bands (10 and 11) of 100 m. Layer stack are applied by ERDAS IMAGING version 2014 software for all bands with spatial resolution of 30 m (bands 1, 2, 3, 4, 5, 6, 7 and 9) to produce multispectral band. Merging bands between panchromatic band and multispectral band are done to increase the spatial resolution of the later band from 30 m to 15 m. Some enhancement processes are applied such as high pass filter and color composite. High resolution enhanced satellite imagery allows the linear features, such as Abu-Jir Fault Zone, to appear clearly. ArcGIS version 10.3 is used to export the final maps. Data of oil wells spreading in study area are used too (**Fig. 1**).

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The geological setting

The area is almost flat terrain. Strata are approximate horizontal which have gentle dip northeastward. Significant surface structures are absent, but Abu-Jir Fault Zone is the main subsurface structure west of Tigris River (**Fig. 2**). It is clear in view of satellite image. Sometimes it appears on the surface especially in area west of Al-Razazza Lake and very clear by digital images between Al-Najif and Heet cities (**Fig. 2**). Many researchers use Abu-Jir Fault Zone as the boundary between stable and unstable shelves of Iraqi territory, but they differ in extend it beyond Heet city (**Fig. 2**). The fault is delineated after Heet vicinity northward along Al-Thirthar valley to meet Makhul-Hamrin range and turns westward through Sinjar area where dies there [1]. Abu- Jir Fault Zone is never continuous northward, but it turns in Heet vicinity westward to meet Anah Graben and construct Anah-Abu Jir Fault System [2]. Also Abu-Jir Fault Zone is used as a boundary between inner and outer platforms of Iraqi territory (**Fig. 2**) [3].

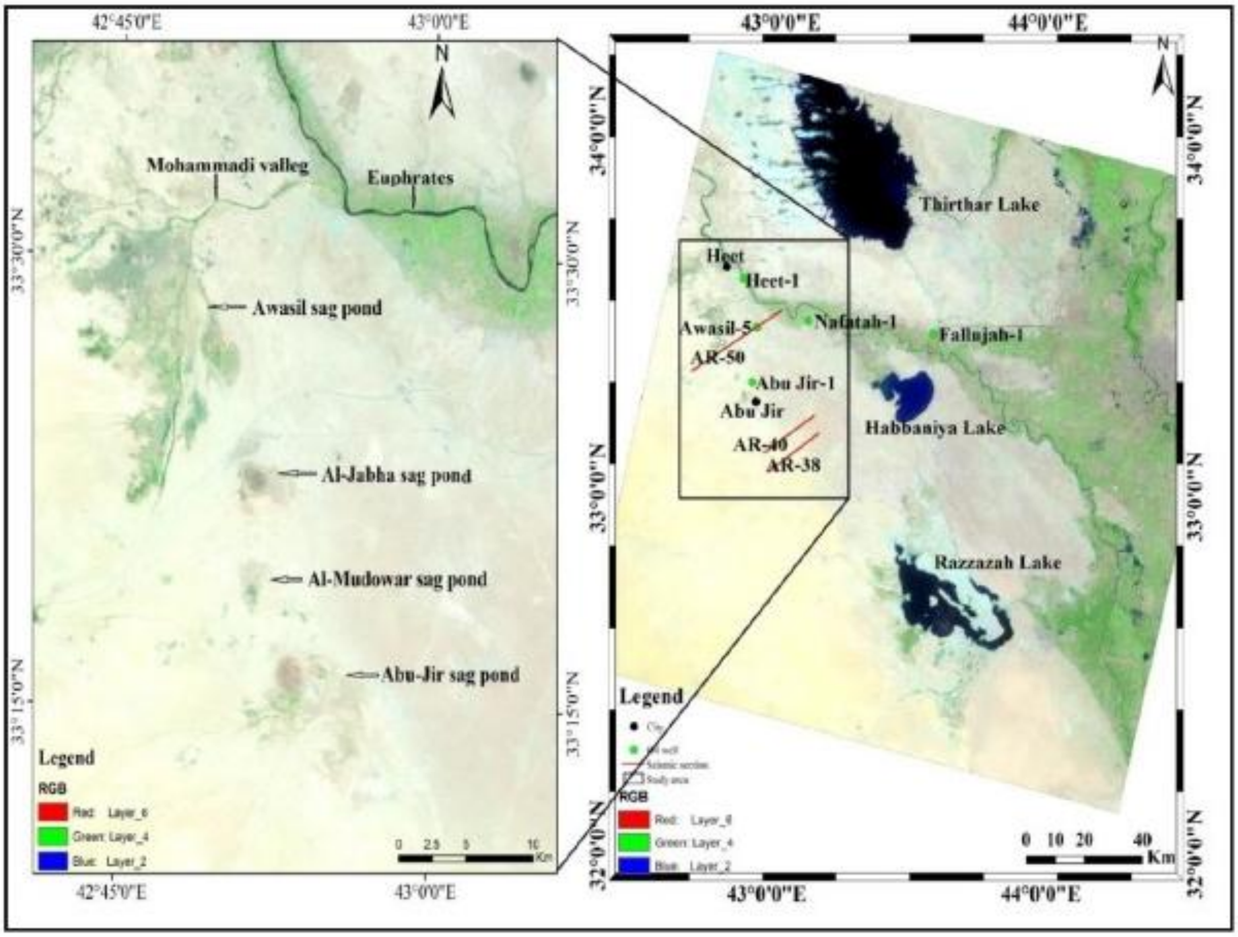

Fig (1): Location map of study area.

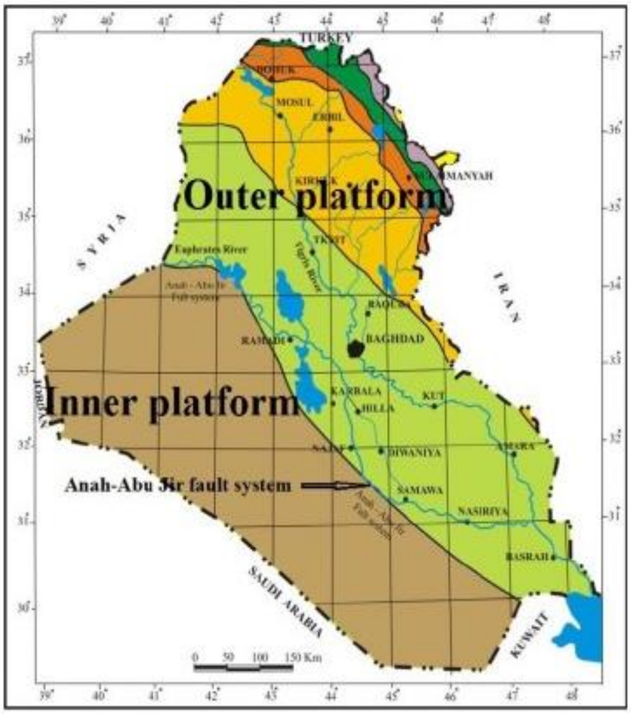

Fig (2): The boundary between stable and unstable shelves or Inner and Outer platforms of Iraqi territory (after [2 & 3])

Geomorphology, the area is flat and the slop is gentle toward northeast. There are four important depressions or sag ponds Abu-Jir, Al-Mudowar, Al-Jabha and Awasil that extend NW-SE. Digital image reveals many valleys run northeast due to the slope of the region. The main valley is Mohammadi valley. All valleys drain into Euphrates except some drain into Abu-Jir sag pond.

Stratigraphy, the age of the exposed rocks in study area is ranging from early Miocene to Holocene. Generally, the oldest rocks are referred to Euphrates Formation (early Miocene) that exposes west of Heet vicinity within Iraqi Western Desert [4] (**Fig. 3**). It consists of three units lower, middle and upper. It comprises of soft, fossiliferous bluish green marl, interbedded with thin beds of shelly recrystallized limestone or shelly oolitic limestone [5]. Nevertheless, the upper unit (Unit C) is formed to be another formation, which is named as Nfayil Formation (middle Miocene) [6]. The bedding in the limestone of unit C along and west of the Euphrates is often controlled especially along Abu-Jir Fault. This controlled bedding may have formed soon after sedimentation due to fluid movement, (e.g. gas escape) or mud thixotropic due to earthquakes along Abu Jir fault zone [7]. Fatha Formation, especially lower member, (middle Miocene) is cropped out west of Euphrates in Heet vicinity, whereas upper member is exposed east of

Euphrates. The distinctive feature of Fatha Formation is the presence of the evaporate facies, which is represented mainly by thick bed of gypsum- anhydrite. This occurs as a part of a cyclic nature with common rhythm being marl-claystone, limestone and evaporates [8]. Injana Formation (late Miocene) is exposed east of Euphrates within Al-Jazira area. It consists predominantly of red, brown and grey claystone, siltstone and sandstone [9]. Quaternary sediments include wide spread gypcrete layer (Holocene) and flood plain deposits in both banks of Euphrates east of Heet (**Fig. 3**).

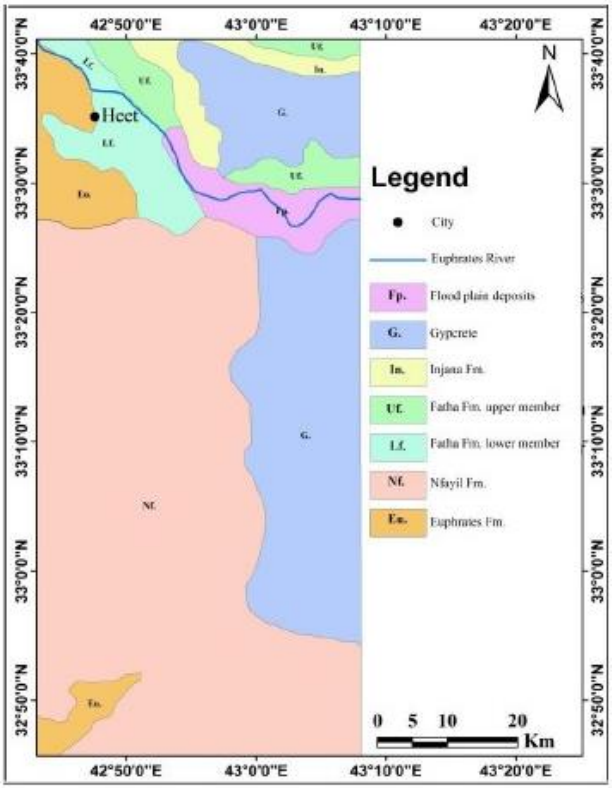

Fig (3): Geological map of the study area (modified from [4]).

Seismic reflection section AR-38

Five reflectors are picked in this seismic section and their formation ages are determined based on synthetic seismograms and log properties of some oil wells spread in the area. The reflectors represent tops the following formations (**Fig. 4**).

1. Dammam Formation (middle - late Eocene).
2. Mauddud Formation (Albian).
3. Shuaiba Formation (Aptian)
4. Gotnia Formation (Callovian to early Tithonian).
5. Alan Formation (late Liassic)

In general, the reflectors are parallel to sub-parallel to each other, and dipping slightly toward northeast. Basin stratigraphy develops before; during and after extensional fault movement may be described as pre-, syn- and post-rift sequence [10]. Formations from Shuaiba to Dammam in this seismic reflection section are syn-rift as indicated by the presence of faulting and thickening. Sequence with uniform thickness inside and outside of some extensional structures below Shuaiba Formation represents pre-rift. Neither thickening nor faulting above Dammam Formation is occurred, therefore it is post-rift.

Abu-Jir Fault appears in this section as a zone. The width of the zone is approximately 8 km between shot points 1116 and 1222 measured on Dammam reflector (**Fig. 4**). It consists of five main planar faults F1, F2, F3, F4 and F5. F1 crosses all sequence of Paleogene, Mesozoic, Paleozoic and may be reaching to basement. The depth of basement in this area is between 5 -7 km [7]. The main fault F1 has high angle apparent dip toward northeast. It involves steep angle fault flower (**Fig. 4**). It contains some steeply dipping normal faults that divergent upward. The fault flower composes two sets of minor faults dipping toward each other. The minor synthetic faults are dipping in a same direction of main fault, whereas the minor antithetic fault dipping opposite to the main fault.

Flower structures can be occurred within seismic section in either strike-slip displacement or as dip-slip inversion.

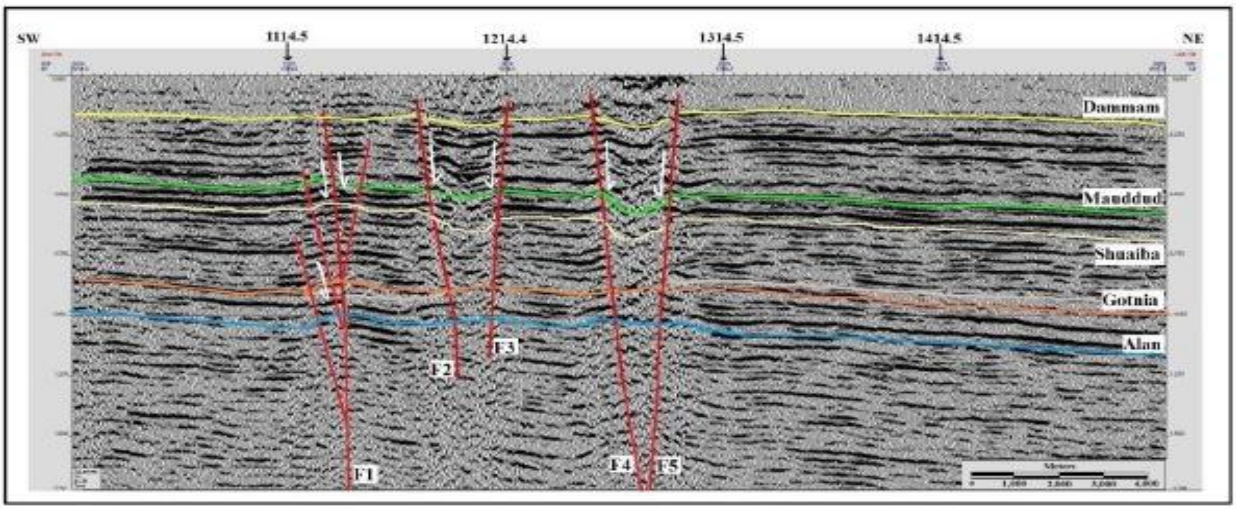

Fig (4): Seismic reflection section AR-38.

The flower structure in this fault system takes place due to strike-slip fault than dip slip inversion. In seismic section strike-slip faults are commonly characterized by simple to complex flower architecture. These vary from single to tightly clustered fault strands that are vertical or steeply dipping to upward spreading fault arrays that show either dominantly extensional displacements - Negative Flower Structure or Tulip Structure or dominantly high angle reverse displacements – Positive Flower Structure or Palm Tree Structure. It is common within a single strike slip fault system to find extensional and reverse displacement on the minor fault arrays [11]. Uplifting in lower levels of the fault along the main fault and dominantly extensional displacements in the upper levels of the fault system are developed Negative Flower Structure.

F2 and F3 are planar faults that cross all the sequence of Mesozoic upward to the Cenozoic reaching Dammam Formation (middle-late Eocene) which have steep angle apparent dip toward each other. F2 dips northeastward, whereas F3 dips southwest. They develop symmetrical graben structure in which the sequence bounded by two major normal faults dipping toward each other with approximately equal displacement. Thickening takes place from the onset of the Cretaceous sequence and lasted to the middle - late Eocene. It reveals the activities of the fault zone during deposition of the formations. The active graben subsidence is terminated by the late Miocene as indicated by the uniform thickness of the post-rift sequence in passing across the graben. F4 and F5 are planar faults that cross all the sequence of the basin Paleozoic, Mesozoic upward to the Cenozoic reaching Dammam Formation (middle-late Eocene) which have steep angle apparent dip toward each other (**Fig. 4**). F4 dips northeastward, whereas F5 dips southwestward. F4 and F5 develop symmetrical graben structure. The geometry and kinematic of this graben is similar the previous one. Because of the bad quality of seismic section in upper part near the earth's surface the end of subsidence activity cannot be determine accurately. It is important to mention that no strike-slip movement is affected or observed at two grabens.

Seismic reflection section AR-40

The name of this seismic-reflection section is derived from Abu-Jir survey. It passes through Abu-Jir Fault Zone west of Al- Habbaniya Lake (Figure 1). Five reflectors are picked by using synthetic seismograms of the nearest oil well. They are parallel to sub parallel to each other and represent tops of the following formations as shown in (**Fig. 5**).

1. Dammam Formation (middle – late Eocene).
2. Mauddud Formation (Albian).
3. Shuaiba Formation (Aptian)
4. Gotnia Formation (Callovian to early Tithonian).
5. Alan Formation (late Liassic).

Structurally, there are five major faults F1, F2, F3, F4 and F5 that represent Abu-Jir Fault Zone (**Fig. 5**). The width of the Abu-Jir Fault Zone is 8 km measured upon Dammam reflector. F1 and F4 are planar faults that cross all of the sequence reaching to the basement. The depth of basement in Abu-Jir area is between 5 and 7 km [7]. The main fault F1 has steep angle apparent dip toward northeast. It involves high angle fault flower. It contains one steeply dipping normal fault that divergent upward. The flower structure in this fault system takes place due to strike-slip movement. In this seismic section strike-slip fault is characterized by simple flower architecture. It is within a single strike-slip fault system to find extensional displacement on the minor fault arrays. Uplifting in the lower levels of the fault along the major fault and extensional displacements in the upper levels of the fault system are developed Negative Flower Structure.

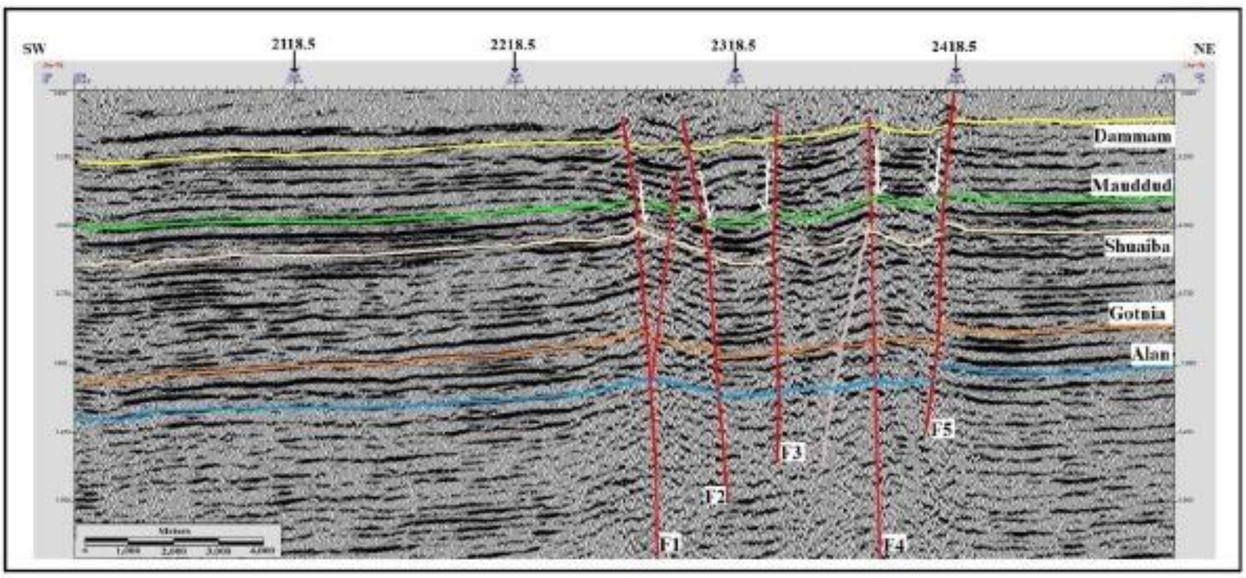

Fig (5): Seismic reflection section AR-40.

F2 and F3 are planar faults that cross all of the sequence of Mesozoic upward to the Cenozoic reaching to Dammam Formation (middle-late Eocene) which have steep angle apparent dip toward each other. F2 dips northeastward, whereas F3 dips southwestward (**Fig. 5**). They develop symmetrical graben structure in which the sequence is bounded by two major normal faults dipping toward each other with approximately equal displacement. Thickening takes place from the onset of the Cretaceous sequence and lasted to the Middle - late Eocene. It reveals the activities of the fault zone during deposition of the formations. The active graben subsidence is terminated by the late Eocene as indicated by the uniform thickness of the post-rift sequence in passing across the graben.

F4 and F5 are planar faults. F4 crosses all the sequence of the basin Paleozoic, Mesozoic upward to the Cenozoic till Dammam Formation (middle-late Eocene). F5 rises up to earth's surface (**Fig. 5**). Both faults have high angle apparent dip toward each other. F4 dips northeastward, whereas F5 dips southwestward. F4 and F5 develop symmetrical graben structure. The geometry and kinematic of this graben is similar the previous one. The geometry and kinematic of Abu Jir Fault Zone in this seismic section are often similar to the fault in seismic section AR-38 (**Fig. 4**) but two major normal faults of both grabens of the seismic section AR-40 (**Fig. 5**) are undergone to slight strike-slip movement due to the uplift especially the two major normal faults of the second graben.

Seismic reflection section AR-50

This seismic section is located north of the AR-40 but in the same area (**Figs. 1 and 6**). The length of the section is 42.7 km. Four reflectors are picked by using synthetic seismograms of the nearest oil well. The reflectors are parallel to sub parallel to each other and dipping slightly toward northeast. They represent tops the following formations (**Fig. 6**).

1. Dammam Formation (middle – late Eocene).
2. Mauddud Formation (Albian).
3. Gotnia Formation (Callovian to early Tithonian).
4. Alan Formation (late Liassic).

Structurally, the seismic section crosses Abu-Jir Fault Zone. It consists of typical model of strike-slip movement. The width of Abu-Jir Fault Zone is 8 km measured upon Dammam reflector (**Fig. 6**). There are two main high angle apparent dip faults, F1 and F2. The former crosses all the sequence, Mesozoic and Paleozoic reaching the basement. The depth of basement in Abu-Jir area is 5-7 km [7]. It is straight fault dips northeast which involves high angle fault flower. It contains some steeply dipping normal faults that divergent upward (**Fig. 6**). The fault flower composes of two sets of minor faults, synthetic and antithetic, dipping toward each other. F2 also crosses all the sequence, Mesozoic and Paleozoic, and reaching the basement. It is straight fault dips northeast which involves high angle fault flower. It contains two steeply dipping normal faults that divergent upward (**Fig. 6**). The fault flower composes one set of antithetic minor faults dipping opposite of the major.

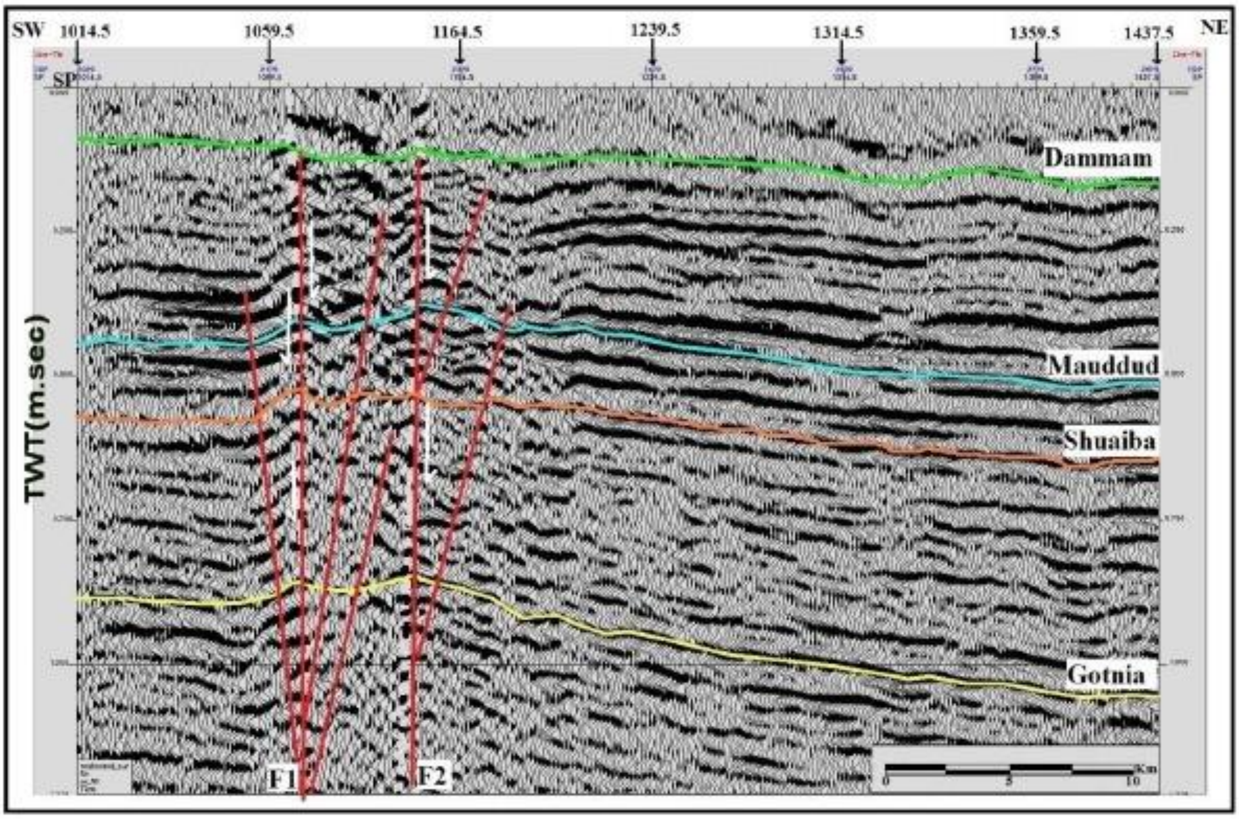

Fig (6): Seismic reflection section AR-50.

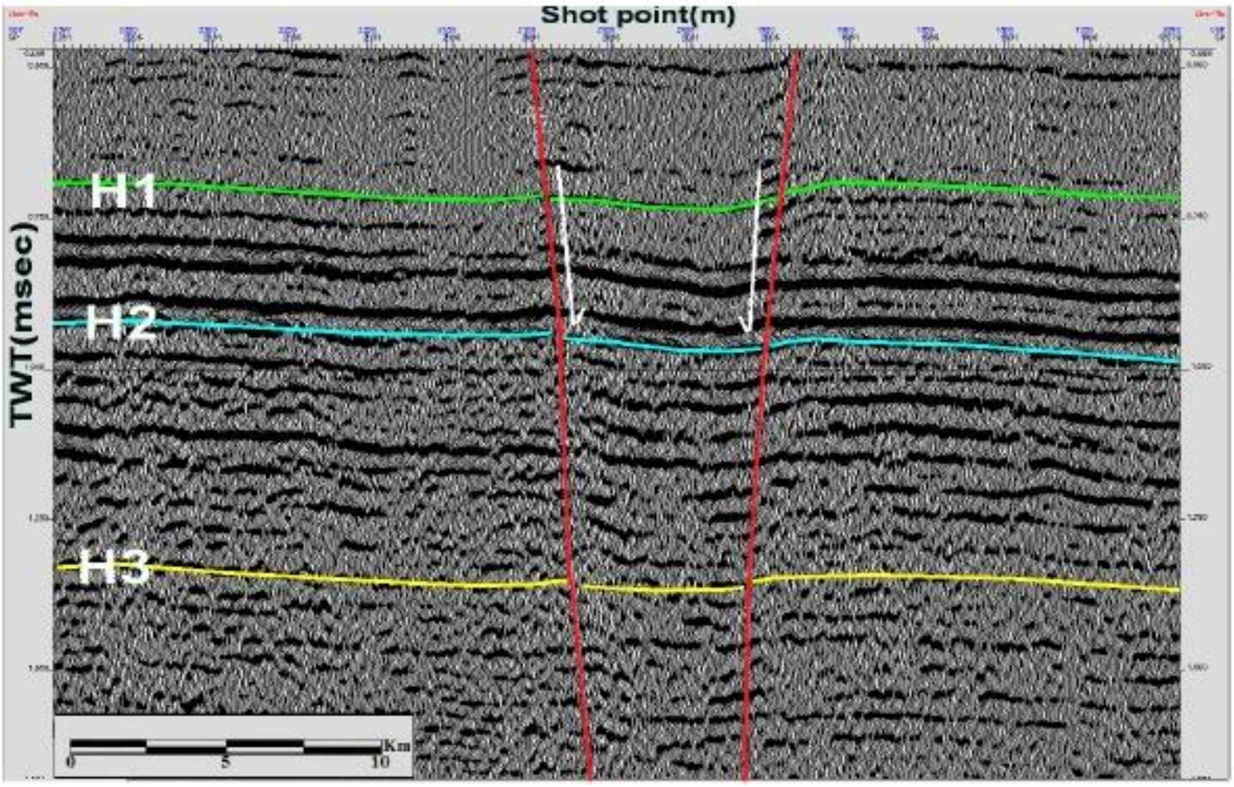

Fig (7): Seismic reflection section BW-7 (after [12]).

Strike-slip faults in this seismic section are characterized by simple to complex flower architecture. These faults vary from single to tightly clustered fault strands that are vertical or dip steeply to upward spreading fault arrays of dominantly extensional displacement. It is within a single strike-slip fault system to find extensional displacement on the minor fault arrays. Uplifting in deeper levels of the fault along the major fault and extensional displacement in the shallower levels of the fault system are developed Negative Flower Structure. Some horizons were draped over the tip of the faults to define synforms with axes parallel to the zone. Presence of these structures provides conclusive evidence to the occurrence of strike-slip movement along the fault zone imposed on the earlier normal one. Typical strike slip movement reflects that the earlier normal fault is suffered by strike-slip movement perfectly more than in the seismic sections AR-40 and AR-38 (**Fig.s 5 and 4**, respectively).

Discussion

Strike-slip movements of three seismic sections are mostly developed along pre-existing faults. The geometry and kinematic characteristics of Abu-Jir Fault Zone in seismic sections AR-38 and AR-40 (**Figs. 4 and 5**, respectively) are similar, both often consisting of normal faults, grabens, and strike-slip movement but the later increases from AR-38 to AR-40 (**Figs. 4 and 5**). Abu Jir Fault Zone in seismic section AR-50 subjected to strike-slip movement perfectly. Seismic section BW-7 south of Razzazah Lake appears Abu Jir Fault Zone as graben without strike-slip movement (**Fig. 7**) [12].

Effect of strike-slip movement on Abu Jir Fault Zone is decreased from seismic section AR-50 southeastward that reflects the movement comes from north and decreases southward due to the opening of Red Sea and collision between Arabia and Turkish Plate.

Tilt of the Mesopotamia sequence has taken place as a result of the collision between Arabian and Iranian Plates. It begins in Miocene and rapid subsidence takes place in Mesopotamian basin during mid-late Miocene [7]. The tilt makes extension in the upper levels of the sequence along the axis of flexure where the study area is presented. The normal faults of Abu Jir Fault Zone beneath the sag ponds are developed in early Cretaceous and several phases of extensions are occurred during Mesozoic and Cenozoic. The phases of extensions reactivated some of the normal faults sometimes reach to earth's surface (**Fig. 5**). Abu-Jir Fault Zone plays a major role in the hydrology of the aquifers. It lifts the water from lower hydrogeological units to upper formations through the faults, fractures and weak zone. The water of Abu-Jir Fault Zone contains dissolved hydrogen sulfide [12]. The sequence in the area of Abu-Jir Fault is mostly consisting of thick layers of carbonate rocks as soluble rocks. The dissolved hydrogen solution made the water as acidic solution. It becomes active in processes of dissolution by vertically flow water. The karstification of soluble rocks play important role to develop the sag ponds after fixing their locations by tectonic setting.

No detailed study measured displacement of Abu Jir Fault due to the strike-slip movement but the seismic sections of this research reveal that the movement increases.

northwestward and the major fault of the strike-slip fault crosses all the sequence of the basin till basement, therefore Abu Jir Fault Zone may classify as transcurrent. It extends hundreds kilometers northwestward. Not only sag ponds are developed along Abu Jir Fault Zone but also pressure ridge, Heet Pressure Ridge near Heet city, is developed. Strike-slip faults are rarely perfectly straight but rather curved back and forth to some degree. When a concavity on one side of the fault is carried against another on the other side the ground sags in, but where the opposite occurs, the ground rises in a pressure ridge. On the other hand, Abu Jir Fault Zone consists of some major faults which have 8 km width. Divergent and convergent steps of the major faults develop sag pond and pressure ridge, respectively.

Sag ponds can be occurred in either strike slip displacement or as transtension. The sag ponds of Abu Jir Fault Zone are appeared in response of strike-slip displacement than transtension due to characteristics of the sag ponds that summarized as:

1. Negative Flower Structure is developed by strike slip movement of vertical or steep angle major fault, whereas transtension takes place at oblique fault plane. All the major faults of the seismic sections are steep angle dip
2. Sense of the stress that generates during the opening of Red Sea and collision between Arabia and Anatolian is southward. Abu Jir Fault Zone has northwest - southeast trending in area of the sag ponds. When the stress that comes from north and strikes the fault zone well develop transpression no transtension.
3. No sag ponds are formed along Abu Jir Fault Zone without strike slip movement.

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