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Tectonic Study of Al-Thirthar, Al-Habbaniya, and Al-Razzazah Depressions, West of Tigris River, Iraq

A Thesis

Submitted to the College of Science, University of Baghdad in partial fulfillments of requirements for the degree of doctor of philosophy in geology

By

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بِسۡمِ ٱللَّهِ ٱلرَّحۡمَٰنِ ٱلرَّحِيمِ

هُوَ ٱلَّذِي جَعَلَ لَكُمُ ٱلۡأَرۡضَ ذَلُولٗا
فَٱمۡشُواْ فِي مَنَاكِبِهَا وَكُلُواْ مِن
رِّزۡقِهِۦۖ وَإِلَيۡهِ ٱلنُّشُورُ ١٥ ءَأَمِنتُم مَّن
فِي ٱلسَّمَآءِ أَن يَخۡسِفَ بِكُمُ
ٱلۡأَرۡضَ فَإِذَا هِيَ تَمُورُ ١٦

صَدقَ الله العَظِيم
سُورَةُ المُلكِ

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TO:

My country .... Iraq

My parents ....

My wife ....

My daughter .... Dr. Noor

My sons .... Dr. Omar,

Mustafa and Mo'omen

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The researcher

Abstract

The location of Al-Thirthar, Al- Habaniya and Al-Razzazah Depressions is in the central part of Iraq, west of Tigris River. The age of the exposed rocks ranges from Early Miocene to Holocene. They represent Euphrates Formation (Early Miocene), Fatha Formation (Middle Miocene), Injana Formation (Late Miocene), Dibdibba Formation (Pliocene-Pleistocene) and Quaternary sediments. The depressions represent the west margin of the Mesopotamia Zone along its boundary with Al-Salman Zone.

To study the tectonic of the depressions we used the results of reflection seismic data interpretations and satellite images. The selected seismic reflection sections reveal that the sedimentary basin beneath the three depressions is suffered several stages of extension because of location of the study area near the northeast passive margin of the Arabian plate. The first stage of the extension took place during Late Triassic followed by several pulses of extensions continued to the Miocene then reactivated some of the normal faults. The sedimentary basin underwent to strike slip movement in Miocene age.

New stage of extension took place during Late Miocene and continued to the Early Quaternary. The extension is created by the tilt of the Mesopotamian sequence due to the collision between the Arabian and Iranian Plates. The tilt generated tensile stresses along axis of flexure where the three depressions are located. The stresses do reactivation to some of the faults; therefore they reached near the earth surface and developed some of the surface geological features. One of the important surface features is the three depressions as well as forth one (Dibddiba Depression). It is located south of Al-Rzazzan Depression and in a same line of the three depressions.

The neotectonics studied by using remote sensing data that showed some tectonic activities. They are represented by two features of extension, the first feature is the development of the four depressions and the second is the deflection of the axes of each Al-Thirthar and Al-Razzazah depressions. The axis deflects from north-south to the N35°W-S35°E and N45°W-S45°E respectively due to sinistral strike slip movement of the transversal faults during Early Quaternary.

The extensional structures beneath the depression are grabens, horsts and normal faults. They are called The Lake Faults. They extend north-south and arcuated eastward. The Lake Faults control the development and location of the depressions.

The four depressions represent one geological feature. It extends from Abu-Jir Fault System south of Dibddiba Depression in the south to the Al-Thirthar valley in the north. The uplifting in area between Al-Habbaniya and Al-Razzazah Depressions with no reactivation of the normal faults beneath Al-Habbaniya depression prevented the four depressions to become one depression.

The reactivated faults play an important role in the development of the depressions due to the thinning of the sequence and raising the hydrogen sulfate-bearing groundwater from deep formations to the upper ones through the soluble rocks, gypsum and limestone. These processes made collapses in the area of depression supported by the last stage of extension and the horizontal movement of the groundwater.

Dibddiba Depression is filled by sediments of Dibddiba Formation (Pliocene-Pleistocene), and the deflection of the axis of Al-Thirthar and Al-Razzazah Depressions in Early Quaternary reflects that the age of the four depressions is the same age (Pliocene-Pleistocene).

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Chapter One

INTRODUCTION

1-1 Preface

Tectonics, in a general sense, refers to the sum of the physical processes that yield regional-scale geological features. Studies in tectonics consider such issue as the origin of mountain belts, the growth of the continents, the developments of sedimentary basins and others (Pluijm and Marshak, 2004). Neotectonics is the study of the young tectonic events which have occurred or still are occurring in a given region after its orogeny or after its last significant tectonic setup. The tectonic events are recent enough to permit a detailed analysis by different and specific methods while their results are directly compatible with seismic observations (Spyros, 1989).

Many workers used the relations between different geological techniques such as seismic reflection sections and remote sensing data, especially lineament features, to give a notion about tectonic evolution of many lakes in the global earth. High-resolution seismic reflection data from Great Salt Lake showed that the basinal sediment sequence is cut by numerous faults. This faulting showed evidence of varied timing is relative offsets, but included at least three events totaling about 12 m since about 13.5 ka (Colman et. al., 2002). The Edward and George lake basins are located in the western branch of the East African Rift System. Both basins consist of half grabens with main boundary fault located in the west, and are separated by a high relief zone (Laerdal and Talbol, 2002).

Tectonic evolution of Al-Thirthar, Al-Habbaniya and Al-Razzazah Depressions is studied through using interpretation of both several seismic reflection sections and two scenes of Landsat satellite images (ETM). ERDAS IMAGING v. 9.2, ArcGIS v. 9.3 and Rock Ware v. 1.5 softwares are used . Data of oil wells spreading in the study area and previous geological studies are used.

Study area is located approximately in the central part of Iraq west of Tigris River Figure (1-1). Al-Thirthar depression after 1956 became a lake. It was joined by channel network. It is connected by inlet channel with Tigris River and by outlet channel with Euphrates River. Al-Habbaniya depression joined Euphrates River by inlet channel and it has two outlet channels one returns back to the Euphrates and the other goes to Al-Razzazh depression. The latter is linked to Al-Habbaniya Lake by inlet channel. These closed depressions are used as flood reservoirs. Generally they extended NNW-SSE trend.

Al-Thirthar Lake is located west of Tigris River at 125 Km northwest of Baghdad city. It represents the south part of a large drainage basin. The basin extends northward to the Sinjar Anticline. It has an area of 31000 Km^2 (Al-Toash, 1996). Satellite image shows that the length of Al-Thirthar Lake is 75 Km measured at northwest-southeast direction and the maximum width is 30 Km. The lake is oriented north-south, then changes to N35°W-S35°E (Sissakian, 2011). Many valleys drain into the lake, the important one is Al-Thirthar valley. Maximum depth of the depression floor is 3 m below sea level. Its shore is at 60 m,a.s.l. The depth of the depression is approximately 63 m. The area of it at 65 m.a.s.l. is 2701 Km^2 (Abdul- Husain and Abul-Noor, 1991 in Al-Toash, 1996).

Al-Rzzazah depression is located west of Karbala city at 125 Km southwest of Baghdad city. It represents the east part of a large drainage basin. The basin extends southwest and westward crossing the Iraqi- Saudi Arabia border. It has on area of 85000 Km^2 (Al-Toash, 1996). Length of Al-Razzazah depression (in northwest-southeast direction) is 60 Km. Maximum width is 30 Km. Many valleys drain into Al-Razzazh depression, the important valleys are Hzaimi, Ghadaf, Abu Mindhar, Meela, Tabbal, Ubayidh and Hamir (Sissakian and Mohammed, 2007). Some of them come from Sudia Arabia territory. Topography of depression floor varies from place to place. The deepest point is at 16 m.a.s.l. The area of the lake at

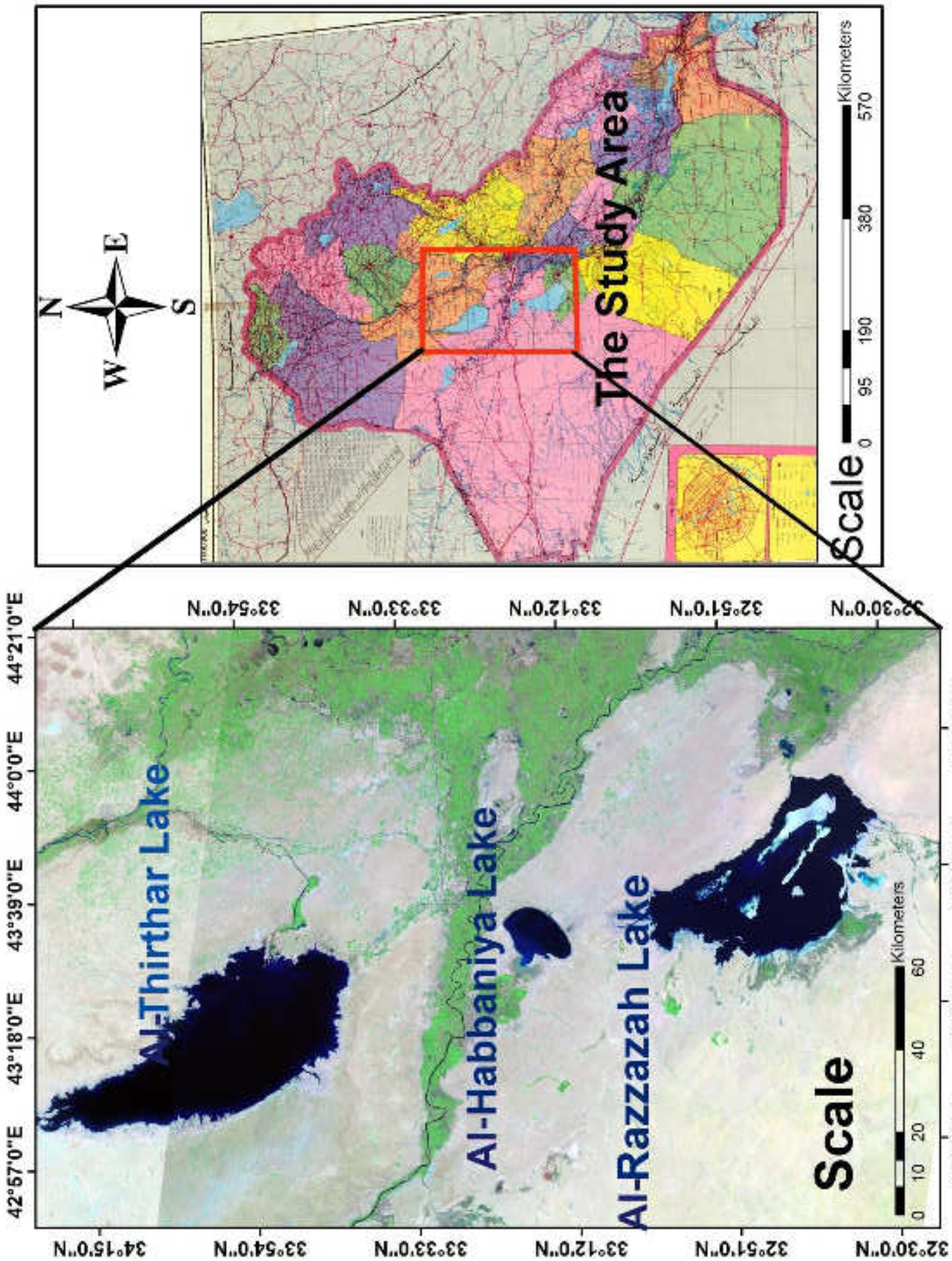


Figure (1.1) Location map of study area (Landsat satellite image 2002)

26 m.a.s.l. is 1050 Km^2 whereas it reaches to 1700 Km^2 at 37 m.a.s.l. (Al-Toash, 1996).

Al-Habbaniya Lake is small in comparison with the formers (Figure 1-1). It is located 60 Km west of Baghdad city. The elevation of the area is between 35-90 m.a.s.l. There is a belt of low hills surrounding the lake except the northeast side (Al-Shabanee, 2005). There are several short valleys drain into Al-Habbaniya lake, some of the valleys in Al-Habbaniya area drain into Euphrates River. Al-Habbaniya drainage basin is very small in comparison with Al-Thirthar and Al-Razzazah drainage basins.

1-2 Aims of the Study

This work aims to:

1- Perform a detail analysis for tectonic evolution and genesis of the three depressions (Al-Thirthar, Al-Habbaniya and Al-Razzazah) by interpreting the seismic sections and satellite images.
2- Study the tectonic history of the sedimentary basin beneath the three depressions by using the analyses of the structural features of several seismic sections.
3- Explore the relationship between the three depressions, if the depressions are one geological feature or not.
4- Study the neotectonic features of the area surrounding the depressions depending on satellite images, digital elevation models and topographic maps of the study area.

1-3 Previous Studies

Many studies are carried out to explain the regional tectonic divisions and tectonic evolution of Iraq including the study area, but for the lakes, no detailed study had been done before. The important previous studies are:

• NEDECO, (1959), in (Sissakian, 2011) determined many factors that integrate to develop Al- Thirthar depression. The two most important factors are summarized as: 1) The step-like profile of the bottom of the depression suggests a genesis in two successive phases of development; a) Process of wind deflation and the erosion of the sides by running water, which began in Pliocene- Pleistocene and lasted into the Holocene Period. b) A graben like subsidence of the bottom of the depression, during the Last Pleistocene or Early Holocene, resulted in the step-like profile of the eastern side. Rejuvenated erosion through the uplift of the plateau anticline in the south caused the step in the southern side to be removed. **2)** Climatic variations during the Pleistocene, the climate was characterized by the periodic alternation of pluvial and interpluvial periods. During the first pluvial period, at the beginning of the Pleistocene, erosion of the exposed folded Upper Miocene rocks went out. Selective wind erosion set in during the following interpluvial period, and further during the next pluvial and interpluvial period, already existing depression became deepened and widened.

• Al-Sakeni, j., (1984) there are several subsurface structures in the area of Al-Habbaniya and Al-Razzazah depressions. He determined the subsurface structures which depend on surface features. The important of these subsurface structures are folds. Oil structural traps are possibly present especially beneath Al-Razzazah Lake.

• Al-Toash, B. S., (1996) determined thirteen boundaries of paleo-shores in both Al-Thirthar and Al-Razzazah Lakes by using aerial photographs and topographic maps. The paleo-shores reflect the fluctuations of the water levels during Late Quaternary due to changes in rate of temperature and rain, hydrological conditions and water balance in the Quaternary Period related to now days.

• Marouf, N. Z., 1999. Indicated that the area north of latitude 33° N within the political boundary of Iraq is divided from structural point of view into Zagros thrust belt, Zagros simply folded belt, the extensional zone and Anah foreland fold-Abu Jir fault complex. The extensional zone contains two extensional structure systems; E-W trending extensional structures which are located in west side of the zone and NW trending extensional structures which are located in east side where the three lakes present. Important features of the latter system are Thirthar and Melih-Thirthar. They are simply high angle east dipping normal fault with slight thickening of many Mesozoic stratigraphic units eastward. Analysis of these extensional systems (based on seismic data) postulated that most of them were formed during the Triassic and rejuvenated locally intensively in the Upper Cretaceous. In all of these features, faulting is restricted to the pre-Tertiary sequences.

• Al-Shabanee, M. M. H., 2005. Geomorphological process interpretation of Al-Habbaniya area showed that the physical weathering exceeds the chemical one due to the climatic conditions. Longitudinal profiles of the main valleys indicate that they are in mature stage, and the drainage pattern dominate by the dendritic pattern with a parallel one in less degree, which means that the area has a little morphology with a gentle slope.

• Jassim, S. Z. and Goff, J. C., 2006. Divided Iraq territory into three tectonically different areas; stable shelf, unstable shelf and Zagros sutures. Stable shelf subdivides into Rutba, Salman and Mesopotamian Zones. The later zone has three depressions (eastern, central and western) resulting from the interaction between the dejection cones of the main rivers and the dejection cones of alluvial fans and the elevated monocline of Salman Zone. The western depression lies between Euphrates dejection cone in the east and the Salman Zone monocline in the west and includes Thirthar, Habbaniya, Razzazh, and Bahr Al Najaf depressions which may be tectonically controlled by the NW-SE trending Euphrates Boundary Fault and the N-S trending Thirthar fault line.

• Fouad, S. F. and Sissakian, V. K; (2010) stated that many of the buried structures are still active in the Mesopotamian Zone, indicating neotectonic movements. Their recent activity can be observed through their effects on the Pleistocene – Holocene stratigraphy. Different landforms, like abandoned river channels, shifting of river courses active and inactive alluvial fans and topographic expression of some subsurface anticlines, all together are good indications for neotectonic movements.

• Fouad, S. F., (2010). The geological setting of the Mesopotamian Foredeep with the tectonic framework of Iraq, have been reviewed and redefined according to the modern tectonic concepts of foreland basins, and new structural boundaries are introduced. The Mesopotamian foredeep represents the terrestrial part of the Zagros Foreland Basin. He bounds the stable interior of the Arabian Platform by Anah-Abu-Jir fault system.

• Sissakian, V. K., (2011). Al-Thirthar Depression was formed due to karstification and continuous sinking of a subsurface graben. At least two main karst forms were conjugated together to form the bowl shape of the present depression. He estimated the age of the development of the Al-Thirthar Depression to be most probably Holocene, and may be during the 17^{th} century, because Al-Thirthar Depression did not exist during Yaqoot Al-Hamawi (1226), Abin Al-Haq (1338) and in the map of Al-Idrisi (1664). Geologically, he determined the age based on the presence of gypcrete layer covering the plateau in the eastern side of the depression and along the eastern cliffs of the depression. The age of the gypecrte is Pleistocene-Holocene; therefore the depression must be developed after the formation of the gypcrete.

1-4 Climate

According to climate classification; the study area is located in hot and continental semiarid climate. It has two major seasons, hot and dry summer and cold with rare rain in winter, with two short transition seasons spring and autumn.

The climate factors obtained from Iraqi Meteorological Organization, Ramadi station for the period (1981 – 2001) and Karbala station for the period (1976 – 2000) are summarized in tables (1 - 1) and (1 - 2) respectively.

Table (1 – 1); Average climatic factors from Ramadi Station for the period (1981 – 2001).

Parameter	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Rainfall (mm)	22.26	19.24	17.22	20.75	7.12	----	----	----	----	10.2	22.81	16.3
T(C°)Max.	13.9	17.2	21.8	29	34.3	39.4	41.5	41	38.2	31.8	23.2	17
T(C°)Min.	2.6	7.4	8.9	14.4	18.6	23.1	25.1	24.4	20.9	12.7	10.3	6.1
Evaporation (mm)	5.83	10.4	21.5	85.99	168.	252.3	207.2	275.7	188.5	103	34.7	20.3
Wind speed (m/s)	2.06	2.68	2.69	2.44	2.68	2.85	3.09	2.78	2.07	1.69	1.85	1.85

Table (1 – 2); Average climatic factors from Karbala Station for the period (1976 – 2000).

Parameter	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Rainfall (mm)	15.57	15.32	21	10.24	4.74	-----	-----	-----	-----	4.7	11.21	16.22
T(C°)Max.	15.7	18.7	23.1	30.2	36	40.9	42.4	43	40.1	32.8	23.5	17
T(C°)Min.	5.20	7.20	10.8	16.8	21.6	25.8	28.2	27.6	23.9	18.2	11.4	6.9
Evaporation (mm)	6.52	12.44	32.56	101.2	207.6	328.2	419	377	249.1	116	32.2	9.43
Wind speed (m/s)	2.22	2.57	2.96	3.08	3.22	3.95	4.32	3.65	2.50	2.21	1.98	2.01

From above data the study area is under the influence of semiarid climate conditions. The processes that develop the depressions under these conditions of climate are weak.

1-5 Methodology

1-5-1 Materials

Several materials are used to perform the target of the research. They consist of topographic maps with scale of 1:100,000. They are used to derive the X and Y coordinates in UTM system and the elevation Z to generate grid for digital elevation models. Tectonic maps and geological map with scale 1:1,000,000 are used.

Data of oil wells and several seismic reflection sections are got from Oil Exploration Company. These seismic sections have different scales and they are used for detail analysis of tectonic evolution and genesis of the three depressions to study the tectonic history of the sedimentary basin.

Two scenes of Landsat satellite images (Enhanced Thematic Mapper. ETM) are downloaded from the website (Earthexplorer.usgs.gov). the two scenes are used in multi scales for Neotectonics and geomorphological studies. Several software are applied such as ERDAS IMAGING v. 9.2 for image enhancement and lineament map treatment, ArcGIS v. 9.3 for fitting the maps that derived from satellite images. Rock Ware v. 1.5 for rose diagram of lineament map, Sigma Plot software v. 3 for fitting curve and Photoshop for treatment and finishing.

1-5-2 Field Work

Three field trips are accomplished in the study area. Two of them are in Al-Habbaniya area in 6 / 5 / 2013 and in 22 / 7 / 2013, during the trips; the observations about the outcrops of the formations are achieved and geomorphological features are documented by photographs. The third trip was in Al-Thirthar area in 25 /7 /2013. Some of the lineaments are checked and documented by photographs, observations about stratigraphy and geomorphological features.

1-5-3 Office Work

Two scenes of Landsat satellite images (ETM) are enhanced by ERDAS Software then lineament map is drawn by using ArcGIS Software. Histogram and statistics of the lineament map are done by ERDAS Software. Rose diagram for the lineaments is developed by using Rock Ware Software. Data from above software are analyzed.

The reflectors of several seismic reflection time sections are picked by using synthetic seismogram of the oil wells. The extensional structures and strike slip movements are delineated in all seismic reflection sections. Data from the sections are interpreted.

1-6 Stratigraphy

Many workers studied the stratigraphy of area surround the three lakes. These studies include entire area such as (Buday, 1980; Jassim, et al., 1984; Sissakian, 2000 and Jassim and Goff, 2006) or partially area such as (Sissakian and Mohammed, 2007; Ma'ala and Al-Kubaisi, 2009 and Yacoob, 2011) because the three lakes are located at the boundary between different tectonic units; The

Mesopotamia Plain from eastern and Al-Jazira area and the Western Desert from western side of the lakes.

The age of the exposed rocks in study area is ranging from Early Miocene to Holocene. Generally, the oldest rocks crop out in the west of three lakes, in which Euphrates Formation (Early Miocene) is exposed in west bank of both Al-Habbaniya and Al-Razzazah Lakes. Al-Fatha Formation (Middle Miocene) appears in the west bank of Al-Thirthar Lake (Figure 1-2).

Injana Formation (Late Miocene) is exposed in north, south and east area of both Al-Thirthar and Al-Razzazah Lakes. Outcrops of Injana Formation show as patches within gypecrte. These outcrops spread in the area south of Al-Thirthar Lake and east of Al-Razzazah Lake. The formation extends as a narrow strip along east bank of Al-Habbaniya Lake. Dibdibba Formation (Pliocene – Pleistocene) exists in Dibdibba Depression. The later depression is the fourth one presents at the same line of the above three lakes. Dibdibba depression locates south of Al-Razzazah Lake. It appears as triangle shape in geological map of Iraq 1:1000000 (Al-Bdaiwi, 2012).

Quaternary sediment in this area include Al-Fatha fan conglomerate (Pleistocene) deposited in east area of Al-Thirthar Lake and also exist as a strip separates Injana Formation from Al-Fatha Alluvial Fan (Early-Middle Pleistocene). However gypcrete layer (Holocene) spreads south of Al-Thirthar Lake and along east side of both Al-Habbaniya and Al-Razzazah Lakes Figure (1-2).

The sedimentary history of the northeast part of the Arabian Plate is complicated by a series of transgressions, regressions, flych sedimentation and evaporates sedimentation. That is dominated by siliciclastic sediments, deposit in

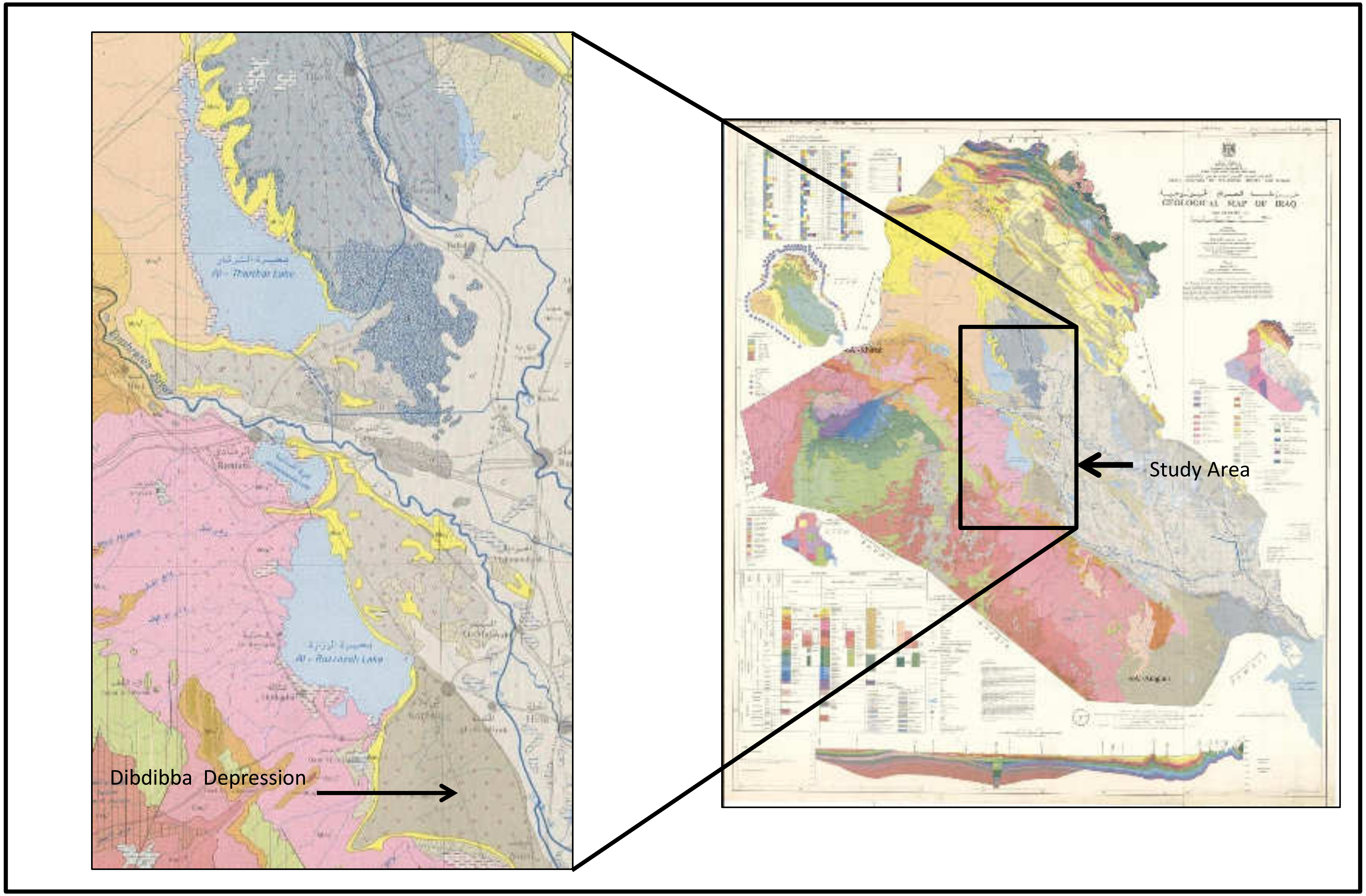


Figure (1.2) Geological map of Iraq where the study area is demonstrated (After GEOSURV Geological map of Iraq 2000) terrestrial and shallow marine environments. The stratigraphic section from the Cambrian to the present is almost complete, and breaks are minor (Al-Sharhan and Nairn, 2003).

Stratigraphic correlation between the formations of Mesozoic in Mileh-Thirthar well-1 (Table 1-3) and generalized stratigraphic column for Iraq Figure (1-3) illustrates that the sedimentary succession approximate complete with varieties in thickness and without significant breaks. Generally the thickness of the Mesozoic succession in study area is more than 3000 m; in Mileh-thirthar well the thickness without Beduh Formation is 3141 m. The thickness of sedimentary cover is 7-9 km. The little thickness is due to the uplift of basement rocks during Paleozoic and reduced subsidence during Mesozoic (Jassim and Goff, 2006).

The thickness of the Mesozoic sequence progressively increases from the west to the east. It begins with carbonate evaporate inner shelf facies and restricted lagoonal facies, they are represented by the Beduh and Geli Khana Formations. Followed by terrigenous clastics were derived from the Rutba Uplift, pass through carbonate with mudstone of shallow water then more uniform basin with relatively deep water sedimentation.

The Cenozoic succession usually consists of off-shore, open marine argillaceous marl and limestone of Aaliji and Jaddala Formations, and pass through Globigerinal limestone of Palani and Tarjil Frmations grads up into reef-forereef, reef and reef-backreef facies then shallow water to subcontinental environment. The thickness of the Cenozoic sequence in Mileh-Thirthar well is 631 m. The Quaternary deposits are developed in eastern margin of the three lakes. They comprise sediments of alluvial and fluvial environments.

Table (1.3) Melih Thirthar oil well (MTn-1),

Surface 184 m.a.s.l (Internal report, Oil Exploration Company)

FORMATIONS	DEPTH	THICKNESS
Fatha	Surface	184
Jeribe	184	72
Euphrates	256	24
Anah	280	20
Azkand	300	58
Tarjil	358	28
Palani	386	30
Jaddala	416	34
Aaliji	450	181
Hartha	631	71
Sadi	702	48
Tanuma	750	60
Mauddud	810	312
Nahr Umr	1122	65
Shuaiba	1187	41
Zubair	1228	340
Gotnia	1568	272
Najmah	1840	30
Sargelu	1870	242
Alan	2112	87
Mus	2199	55
Adaiyah	2254	148
Butmah	2402	393
Kurra chine	2795	655
Geli khana	3450	324
Beduh	3774	

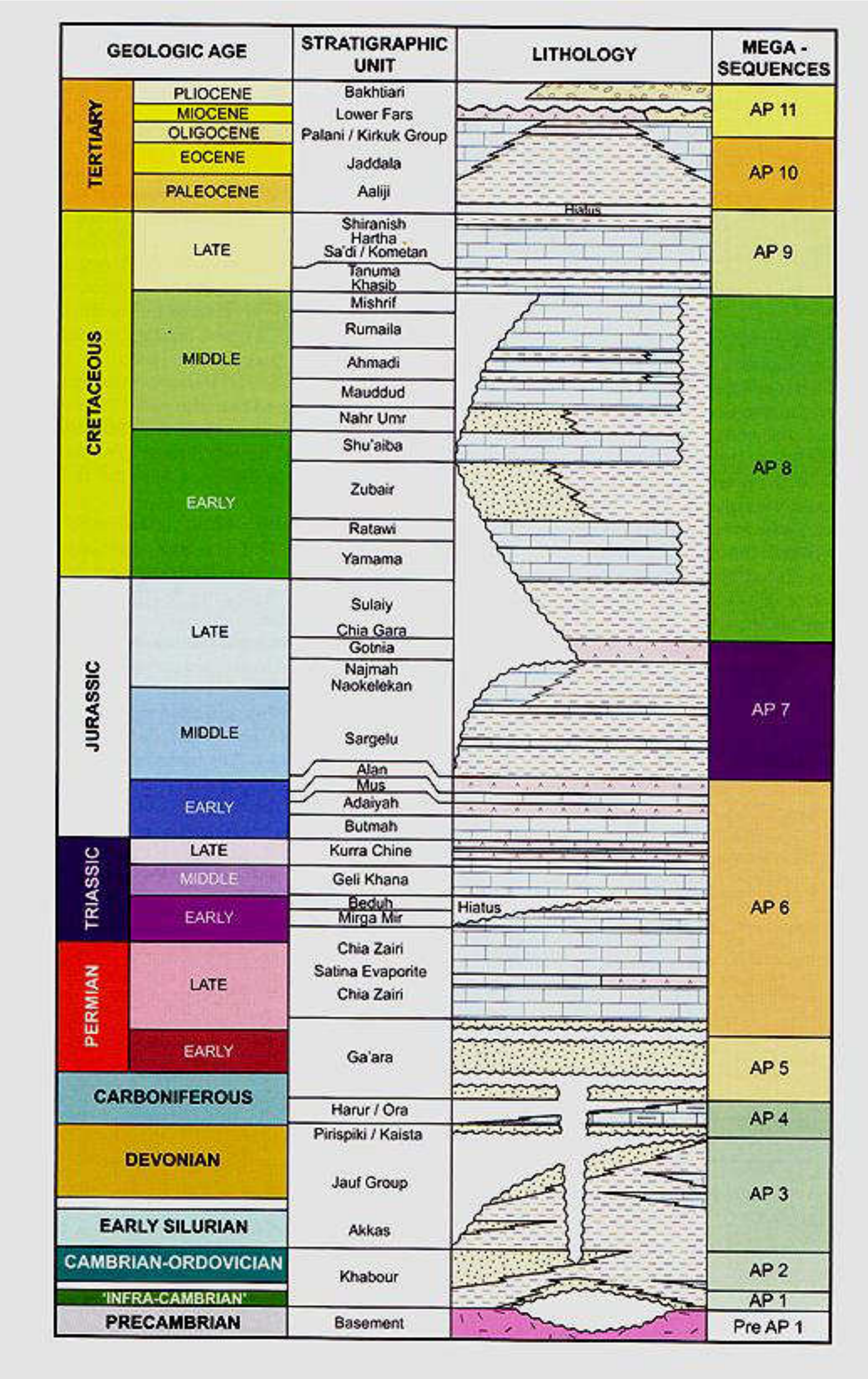


Figure (1-3) Generalized stratigraphy column for Iraq (Modified after Verma et al., 2004 in Aqrawi et al., 2010)

The following descriptions are for exposed formations and Quaternary sediments from oldest to youngest.

1-6-1 Euphrates Formation (Early Miocene)

The Euphrates Formation is the most widespread formation in the study area. It represents the west bank of Al-Habbaniya and Al-Razzazah Lakes (Figure 1-2). The Euphrates Formation in the type locality consists of shelly, chalky, well bedded recrystallized limestone (Bellen et al., 1959). It comprises of three units lower, middle and upper (Jassim et al., 1984). The Upper Unit (Unit C) occurring west of Al-Habbaniya and Al-Razzazah Lakes. It comprises of soft, fossiliferous bluish green marl, interbedded with thin beds of shelly recrystallized limestone or shelly oolitic limestone. Nevertheless, the Upper Unit (Unit C) is formed to be another formation, which is named as Nfyil Formation (Middle Miocene) (Sissakian et al., 1997 in Sissakian and Mohammed, 2007).

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 (Jassim and Goff, 2006).

1-6-2 Fatha Formation (Middle Miocene)

The Fatha Formation exposes in all west bank of Al-Thirthar Lake within Al-Jazira area (Figure 1-2). 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 (Bellen et al., 1959).

Generally, the formation can be divided into two members lower and upper (Jassim et al., 1984). The lower member is cyclic nature, each cycle starts with green marl, limestone and ends with gypsum. Locally, within one cycle one of the three facies is missing. Lateral variation and lens forms are common.

The upper member is exposed in the west of Al-Thirthar Lake. It consists of cyclic nature, like the Lower Member, with main difference in the constituents of each cycle that is the appearance of the red claystone and sandstone. The contact between lower and upper members is with first appearance of the red claystone.

The thicknesses of the Lower Member and Upper Member in the type section are 220 m and 400 m respectively (Jassim et al., 1984) whereas in Mileh Thirthar well 1, the nearest well to Al-Thirthar Lake, is 184 m (Table 1-3). The thickness in Khliesia well 1 is 515 m (Gaddo and Paker 1959 in Ma'ala and Al-Kubaisi, 2007). The thickness of Fatha Formation in study area is little in comparison with the thickness in Khleisia well and type locality. The formation deposits were formed in closed lagoon of hyper saline condition (Bellen et al., 1959).

1-6-3 Injana Formation (Late Miocene)

Injana Formation exposes in east bank of the three lakes as a narrow strip or scattered outcrops (Figure 1-2). Injana Formation, in type locality, consists of alternation of red, brown and grey claystone, siltstone and sandstone with rare fresh water thin limestone and gypsum horizons in the lowermost part (Jassim et al., 1984). In south of Al-Thirthar lake it is with same components of type locality, in the lower part, thin horizons of fossiliferous and oolitic limestone may occur locally (Ma'ala and Al-Kubaisi, 2009). In Habbaniya vicinity the Injana Formation consists of reddish brown, cross bedded sandstone, with green marl and red or green claystone, the uppermost sandstone beds contain clay balls, high organic layers containing carbonized leave prints occur, locally white chalk also occur in some horizons. Finally abundance of quartz arenites may indicate different source areas (Jassim et al., 1984) (Plates 1-1 and 1-2).

Thickness of Injana Formation in the type locality is 620 m. It is 20 m in Habbaniya vicinity and 5 – 10 m south of Al-Razzazah Lake (Jassim et al., 1984).

Depositional environment of Injana Formation is mixed brackish and fresh water, which reflect environment of estuaries or lagoons fed by rivers (Ma΄ala and Al-Kubaisi, 2009). The lower part of the formation seems to be transitional between the marine evaporate Al-Fatha Formation and the continental (fluvial) Injana Formation. It changes its facies especially in area between Ramadi and Najaf, within study area, which may indicate different source area, both Folded Zone and stable shelf, (Jassim et al., 1984).

1-6-4 Dibdibba Formation (Pliocene – Pleistocene)

Dibdibba Formation exists within study area only south of Razzazah Lake. The exposed parts are very limited and do not exceed few meters in thickness (Yacoub, 2011). (Hassan et al., 2002) described the Dibdibba Formation in Karbala-Najaf area as brown, yellow, white and grey sandstone and pebbly sandstone and determine the thickness of the formation as (3-15.5) m in the same area.

Depositional environment of Dibdibba Formation represents fluvial sedimentation in extensive sheets probably as large old alluvial fans (Jassim et al., 1984). The lower contact of the formation south of Al-Razzazah Lake is underlain unconformable by the Injana Formation, the contact is depend on the first appearance of sandstone or pebbly sandstone (Hassan et al., 2002).

Plate (1-1) Sequence of Injana Fn (green marl, limestone and sandstone) NE Al-Habbaniya Lake

Plate (1-2) Outcrop of cross bedded sandstone of Injana Fn NE Al-Habbaniya Lake

1-6-5 Quaternary Sediments

The Quaternary sediments in the west side of the Mesopotamia Zone are deposited by the interacting Tigris, Euphrates, Diyala and Adhaim Rivers, on the Alluvial fans emanating elevated area (Jassim and Goff, 2006). Many types of Quaternary sediments are developed unconformable on older formations in study area; all types of them are exposed in the east bank of three lakes. The Quaternary sediments develop by fluvial and alluvial activities, such as Al-Fatha Alluvial Fan and Alluvial Fan of Karbala-Najaf Plateau. The alluvial fans are derived from rivers passing through the Foothill Zone in the northeast or from desert wadis flowing from the desert plain in the west. These sediments take wedge shape, the greatest thickness of them parallel to margin of uplifted Foothill Zone, and then reduce in thickness toward southwest until arrive to the least thickness of sediment wedge in east bank of three depressions especially in Al-Thirthar depression. This status is an indication to neotectonics and genesis of the three depressions, which will be discussed later.

1-6-5-1 Al-Fatha Alluvial Fan (Pleistocene)

It is a huge alluvial fan, occupies the north part of the Mesopotamian Plain, which extends from Fatha in the north where the Tigris River enters the Mesopotamian plain, to north of Falluja in the south. The sediments of this fan are well exposed along eastern cliffs of Al-Thirthar depression, with lack these sediments in west bank of the depression.

(Yacoub et al., 1991 in Yacoub, 2011) divided Al-Fatha Alluvial Fan into two units. The lower unit comprises sandy gravels grading into well cemented and compacted conglomerate, which are often inter-bedded by sand lenses, the dominant size of the gravels ranges between (4 – 8) cm. The gravels are often rounded to sub-rounded, unsorted to moderate sorted, and composed mainly of chert and limestone in addition to igneous and metamorphic rocks.

The upper unit consists generally of gypcrete with various fractions of gravel, sand, silt, and clay. It is described as gypsiferous clastics because the percentage of the clastics exceeds 50%. The average gypsum content within the unit is (50-60)%.

Maximum thickness of Al-Fatha Alluvial Fan sediments may reach 40 m, the average thickness is between (12 – 20) m, and it reduces toward west. The thickness of the lower gravely unit in west bank of Al-Thirthar depression is (5 – 15) m and reaches around 37 m, whereas the upper gypcrete unit is (2 – 4) m thick, but occasionally reaches 6 m. The age of Al-Fatha Alluvial Fan is Pleistocene (Yacoub, 2011).

Al-Fatha Alluvial Fan sediments were laid down in continuously subsiding basin, deposited as a huge gravel fan. During the pluvial phases of early and middle Pleistocene when the braided rivers of Mesopotamia plain have high competence. Capacity, and discharge transport and deposit large size of sediments set up the conglomerate of the lower unit. The sediment components of upper unit of Al-Fat´ha Alluvial fan reduce in grain size, sand, silt, and clay, and reflect decreasing in energy of braided rivers that take place during late Pleistocene. The gypcrete deposition may reflect intensive evaporation from the surface solution and ground water rich in sulfate; the main source of sulfate is from Al-Fat´ha Formation which is exposed in Himreen and Makhoul anticlines (Yacoub, 2011).

1-6-5-2 Alluvial Fan of Karbala-Najaf Plateau

It was deposited at the peripheral parts of the western desert, which extend into the margin of the Mesopotamian Plain under the Holocene sediments. It comprises essentially of poorly-sorted gravely sand, sandy gravel and gypcrete, with subordinate layer and lenses of silty and sandy clay. The sands and gravels are composed mainly of quartz and feldspar, with less limestone pebbles and occasional acidic igneous and volcanic rock fragments. The tectonic effect of the Abu Jir-Euphrates Fault Zone may have played a role in the development of this fan.

1-6-5-3 Gypcrete (Pleistocene – Holocene)

Gypcrete is developed under climatic conditions marked by alteration wet and dry seasons. Capillary action brings to the surface the solution formed during the wet season and concentrates them depending on type of material and chemistry of water. Gypcrete exist not only in east bank of Al-Thirthar depression but also approximate surround of both Al-Habbaniya and Al-Razzazah depressions. Sissakian and Mohammed, (2007) have study these sediments in Habbaniya and Karbala vicinities. Gypcrete is covered by thin veneer of sand sheet and scattered pebbles. The percentage of SO_4 is highly variable. The thickness range is from (0.5 – 2.5) m.

1-7 Geomorphology

The current area extends on a broad space that reflects many geomorphologic characteristics as a result of intersection of structural, lithological and climatic processes in small regions of Mesopotamian plain, Al-Jezira area and western desert. Also tectonic history of the area has controlled the development of the main landforms and lithology. Generally, the structural-denudational units are missing in the west of Mesopotamian plain, but they develop on the adjacent provinces close to its boundaries (Yacoub, 2010).

Geomorphological features of the area surround the three major lakes are inferred by previous studies, field trips to Al-Thirthar and Al-Habbaniya Lakes and analysis of the satellite images.

1-7-1 Depressions

There are series of major depressions include; Al-Thirthar, Al-Habbaniya, and Al-Razzazah Lakes. They are located at the west margin of Mesopotamian Plain. They extend at NNW-SSE line Fig (1-1). Dibdibba depression is a forth one which is located, at a same line, south of Al-Razzazah Depression (Al-Bdaiwi, 2012; and Yacoub, 2011) (Figure 1-2).

1-7-2 Valleys

Valley is a landform in which a deep trough in the land is created by stream, the walls of the trough slope gently (Marshak, 2004). Many large valleys drain from Al-Jazira area; most of them drain into Al-Thirthar Lakes. Hundred Kilometers is the length of some valleys. The most important of them is Al-Thirthar valley. Its upstream end begins from Sinjar area. It has many tributaries along its course.

Al-Razzazah depression is the deepest area of a large drainage basin extends inside the Saudi Arabia near the border of Iraq and the Saudi Arabia (Al-Toash, 1996), also can be distinguished the basin by digital image of study area. All the network drainage patterns of the basin discharge its rain water in Al-Razzazah Lake. The major valleys are: Hzaimi, Ghataf, Abu Minthar, Meela, Tabbal, Ubayidh, Hamir, Saffawiyat Al-Shaikh, Saffawiyat Al-Ubaidat and khir. The valleys trend almost parallel to each other because of main slope direction is toward east and northeast. Some of these valleys have a small delta at its mouth Figure (1-4). Major valleys in Al-Habbaniya Lake and east side of Al-Razzazah Lake are rare because Al-Habbaniya drainage basin is small and the general slope east of the two lakes is eastward.

1-7-3 Plateau

Hamza (2007) describes the plateaus in western desert as one of the widest landform. The plateaus are surface formed during past geological periods on variable rocks. Some of the plateaus represent contact surface between geological formations, others are formed on member within geological formation. Plateau on clastic member of Nfayil Formation is developed west of Al-Razzazah Lake. Its surface is covered by Gypcrete and dissected by dendritic unfilled valleys. Scattering plateaus are observed west of Al-Thirthar Lake within Al-Fatha Formation.

1-7-4 Mesas and Hills

Mesas are common in the west side of the three lakes (Plate 1-3). They occur along the cliff, which separate the plateau from each other and are developed due to deep erosion along crossed joints that dissect the outer part of the plateaus. Some of the mesas are far from the cliffs. This indicates that the plateaus, from which the mesas are separated, have widely retreated (Hamza, 2007). Several mesas occur in the closest vicinity of Thirthar valley, some of them suffer from rill erosion and toppling, which reduced them to butte or hills (plate 1-4).

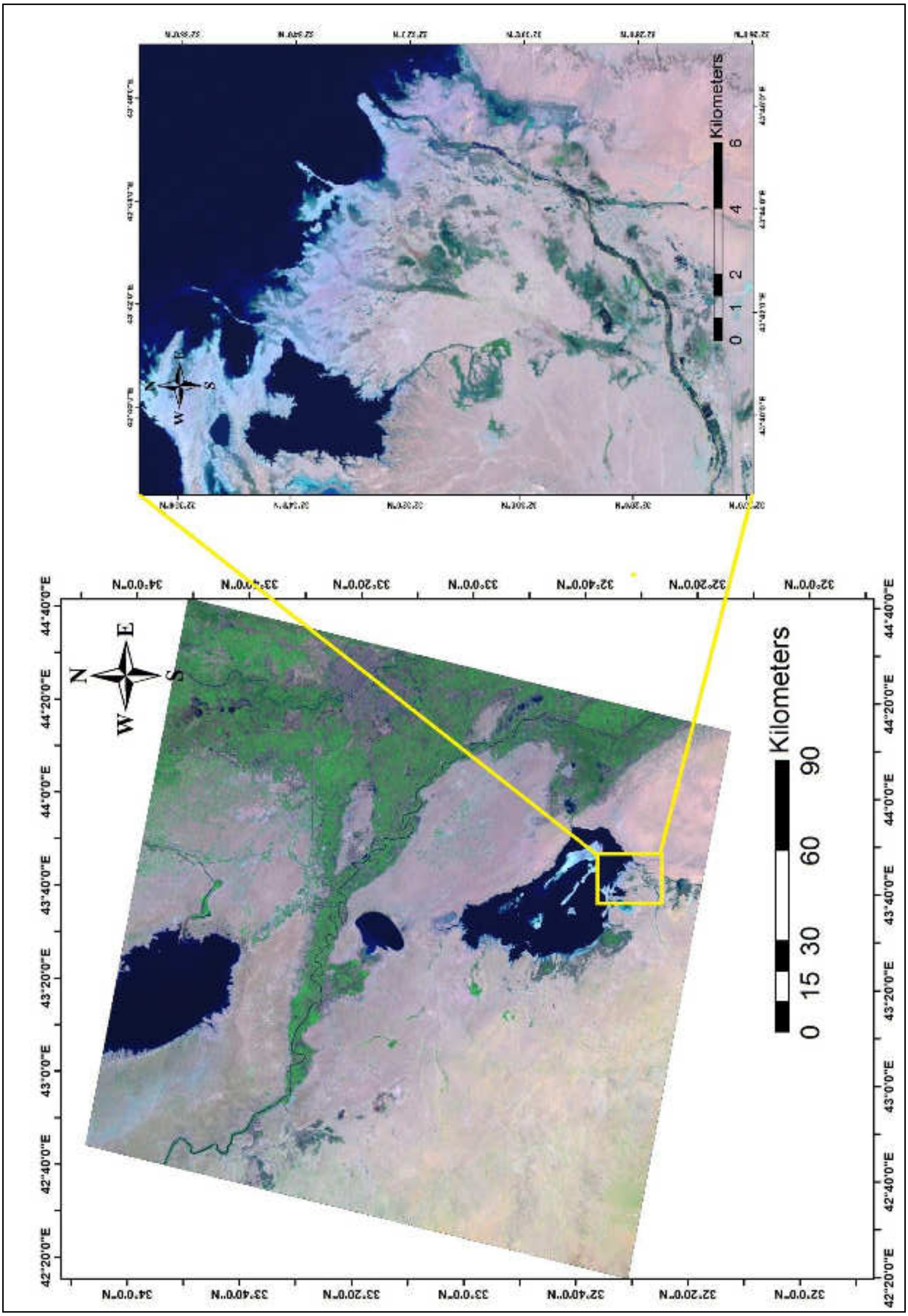


Figure (1-4) Small delta at mouth of the Ubayadh valley

Plate (1-3) Mesa within Al-Fatha Fn NW Al-Thirthar Lake

Plate (1-4) Hill in area northeast Al-Habbaniya Lake

1-7-5 Salt Marshes

Salt marshes are isolated drainless depression, which are developed in the karstic terrain such as Al-Jazira area and in the plateaus of western desert. The basic factor of karstification in study area is the present of soluble rocks (limestone and dolomitic limestone), as well as the extension evaporate exposure made the area a prone to solution and karstification. The sides of salt marsh are gentle sloping toward the depression centers, which are dissected by concentric valleys. The salt marsh depressions are filled with water during rainy seasons, and then become shallow pools and lakes; they dry up and leave thin salt crust during the summer season. Al-Thirthar depression was a salt marsh before inundate (Ma’ala, 2009).

1-7-6 Alluvial Fans

Alluvial fan topography is common in the study area, especially in the west margin of Mesopotamian Plain. Generally, all east side of Al-Thirthar Lake is covered by sediments of Al-Fatha Alluvial Fan. The surface of the fan is characterized by slight and broad undulations with shallow and wide valleys. It is covered by gypsiferous soil and gypecrte with residual gravels. The west boundary of the fan is terminated by east cliff of Al-Thirthar Lake. South of Al-Thirthar Lake, the boundary of the fan is diffused with the terrace sediments of the Euphrates River. Also alluvial fans of the western Mesopotamian Plain are covered the Karbala-Najaf Plateau (Yacoub, 2010).

North of Al-Thirthar Lake, there are small Alluvial fans constructed by Al-Thirthar valley, their lengths are less than 25 m and height less than 6 m (Ma’ala, 2009).

1-7-7 Flood Plains and River Terraces

Flood plains are well developed along Euphrates River. It is restricted along the meandering belts of the Euphrates, especially in Ramadi area between Al-Thirthar and Al-Habbaniya Lakes Figure (1-5). It is composed of silt, clay and mud. River terraces of Euphrates River are well developed in the same area. They extend northward and encounter the sediments of Al-Fatha Alluvial Fan south of Al-Thirthar Lake. Also flood plain and river terraces are developed along Al-Thirthar valleys (Ma'ala, 2009).

1-7-8 Sand Dunes

Sand dunes are well developed in two fields. The first one is in area south of Al-Razzazah Lake, low sand dunes (maximum height 2 m) are scattered in a strip of northwest-southeast direction, including the main trend of wind (Hamza, 2007).

The second area of the sand dunes is in the northwest margin of Al-Thirthar Lake. They are characterized by low dunes, less than 3 m in height. The trend is northeast southwest (Plate 1-5 and 1-6).

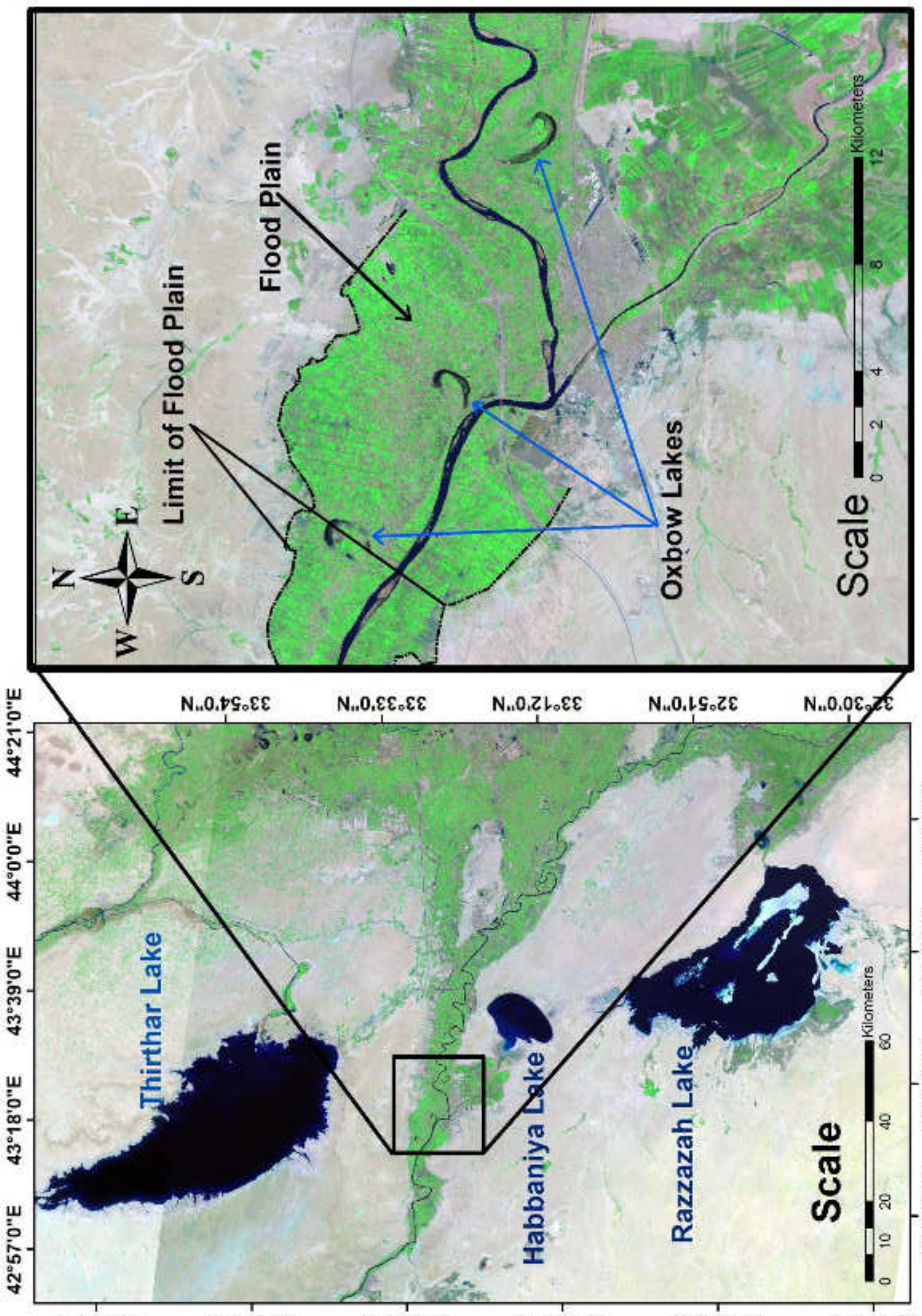


Figure (1-5) Flood plain, meandering and oxbow lakes along Euphrates River in Ramadi Area

Plate (1-5) Low sand dune near the NW margin of Al-Thirthar Lake

Plate (1-6) Longitudinal sand dune in the NW of Al-Thirthar Lake

1-8 Basement Depth and Fault Systems

Basement rocks play an important role in tectonic evolution and structural development of any terrain, especially if the terrain undergoes to contraction, extension or both, such as the current study area, e.g. master fault (detachment) in rifting almost connects with basement rocks, sometime formed beneath the Brittle-Ductile Transition (McClay, 2000).

Basement rocks in Iraq territory are not exposed and there is no borehole penetrated all sediment cover. Therefore data about depth and composition of the basement are estimated by several studies indirectly. A model of basement depth was prepared from geological data based on thickness of megasequences (Getech and Jassim, 2002 in Jassim and Goff, 2006). (Figure 1-6) shows a central basement high (at depth of 5-7 km) flanked by two major structural lows on either sides. This high is called Salman Zone (Jassim and Goff, 2006). Al-Thirthar, Al-Habbaniya and Al-Razzazah Lakes are located on the east flank of the high structure. The depth of the basement in the study area Figure (1-6) is approximated to be 7-9 km. These depth values are little in comparison with the depths of the basement in (Buday and Jassim, 1987).

(Jassim and Goff, 2006) interpreted three major Precambrian fault systems in Iraq and reviewed their influence on the thickness of the major stratigraphic intervals. They relied mainly on gravity data to identify faults, integrated with magnetic data and satellite imagery. The fault systems comprise the northwest-southeast trending (Najd Fault System), the northeast-southwest trending (Transversal Fault System) and the north-south (Nabitah Fault System) Figure (1-7).

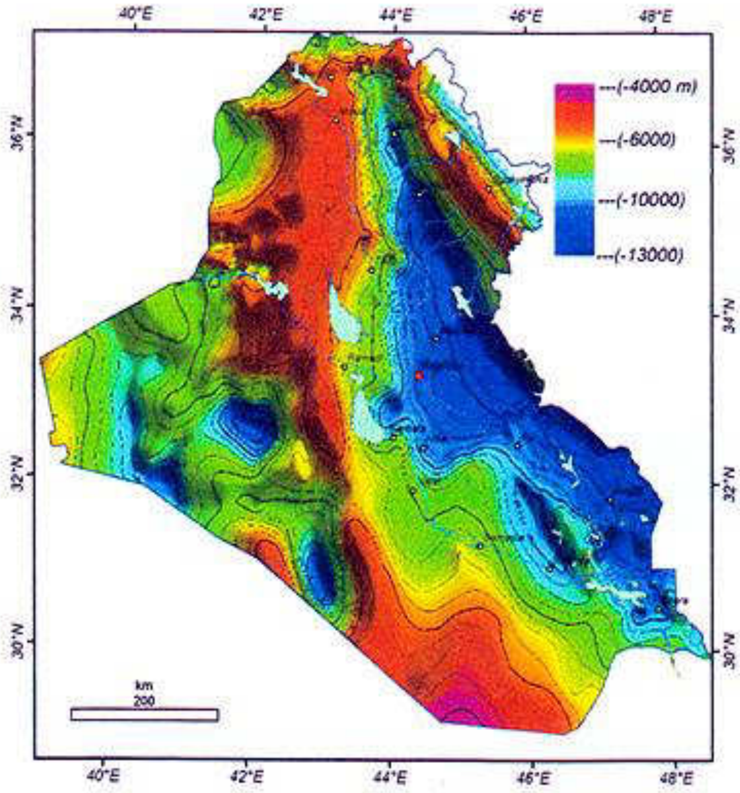


Figure (1-6) Depth to the Basement in meter (After Jassim and Goff 2006)

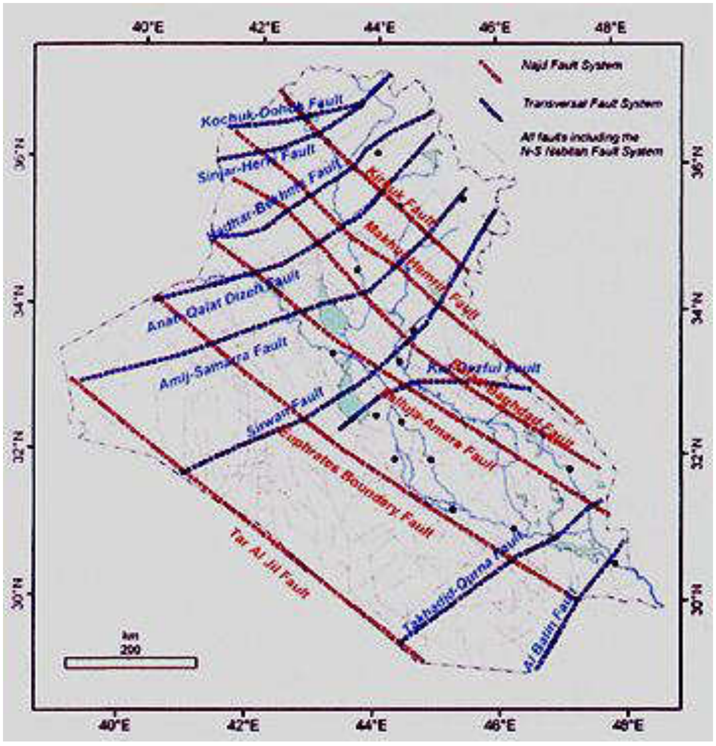


Figure (1-7) Tectonic zones of Iraq territory (After Jassim and Goff 2006)

These fault systems formed during Late Precambrian Nabitah Orogeny. Najd Fault system is very important in Iraq as it forms boundaries not only of Precambrian terrains but also of the tectonic zones especially in central, east and northeast Iraq.

The fault systems were reactivated at different times during the Phanerozoic, controlling the distribution of subtle structural highs and lows which influenced subsidence and facies patterns (Aqrawi et al., 2010).

1-9 Tectono-Physiographic Subdivisions in Iraq

The tectonic and structural subdivisions of Iraq territory are defined by earlier authors; (Henson 1951; Dunnington 1958; Ditmar et al., 1971 and 1972 and Buday 1973) draw different tectonic maps of Iraq. (Buday and Jassim, 1987) subdivide the Arabian Platform, relatively the phanerozoic sequence overlay the Precambrian basement complex, in Iraq into two shelves stable and unstable Figure (1-8). The boundary between stable and unstable shelves is delineated along eastern rim of Salman zone, from Al-Batain lineament northwest Kuwait extent northwest along Abu-Jir Fault System toward Hit vicinity then changes northward to meet Makhul-Hamrin range and turns to the west through Sinjar area where dies there.

Depending on above division, the unstable shelf is divided into three zones; these are from southwest to northeast Mesopotamia, Foothill and High folded Zones respectively. The three lakes Al-Thirthar, Al-Habbanyia, and Al-Razzazah, of study area are located in west part of the Mesopotamia Zone.

Fouad (2007) proposed that the boundary between stable and unstable shelves in Iraqi part of the Arabian Platform extend along Anah-Abu Jir Fault System Figure (1-9). Selective seismic reflection sections are chosen along Al-Thirthar

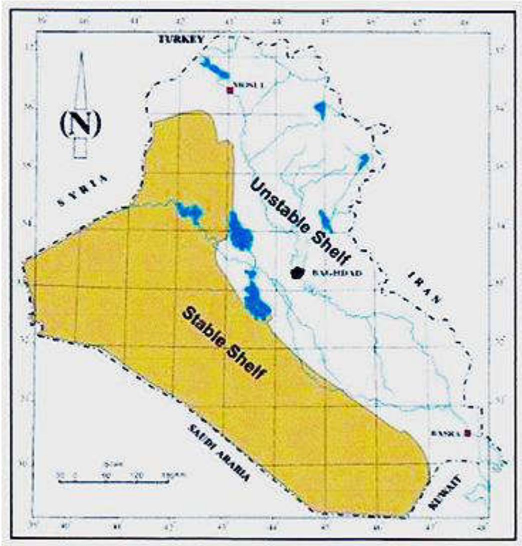


Figure (1-8) The boundary between the Stable and the Unstable Shelves of the Arabian Platform in the Iraqi territory based on (Buday and Jassim, 1987)

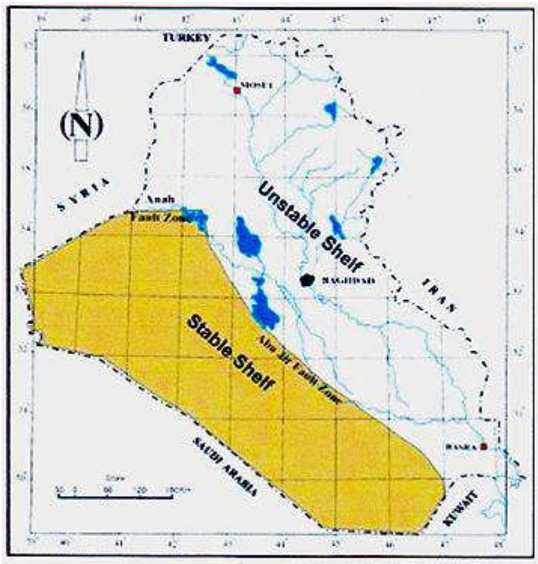


Figure (1-9) The boundary between the Stable and the Unstable Shelves based on (Fouad, 2007)

Valley where the preceding boundary is extended. The seismic data show that the Abu- Jir Fault System never continuous northward, but it turns in Hit vicinity westward to meets Anah Graben. The new boundary is parallel to Zagros and Torus Folds and Thrust Zone. It separates stable shelf from a far field stress associates with major collisional phase of the Alpine Orogeny.

The latest tectonic study consists of a tectonic and structural evolution of Mesopotamia foredeep (Figure 1-10). The Mesopotamia foredeep is a continental basin that lies between the Zagros deformational front from the northeast and the stable interior of the Arabian Platform. It is a potential region of subsidence in the Neogene, and a significant basin of alluvial sediment accumulation in the Quaternary. It is a mobile basin and contains several buried structures including folds and faults. Recent activity of some of these structures is recorded through their effects on the Quaternary stratigraphy and present geomorphological landforms (Fouad, 2010).

The Mesopotamia plain is formed above an earlier platformal and marginal basin. Accordingly, the Phanerozoic stratigraphic sequence of the basin can be broadly categorized into three major tectono-stratigraphic assemblages; Cambrian – early Permian intraplate, late Permian – middle cretaceous Neo-Tethys passive margin, and Late Cretaceous – present foreland basin assemblages (Fouad, 2010).

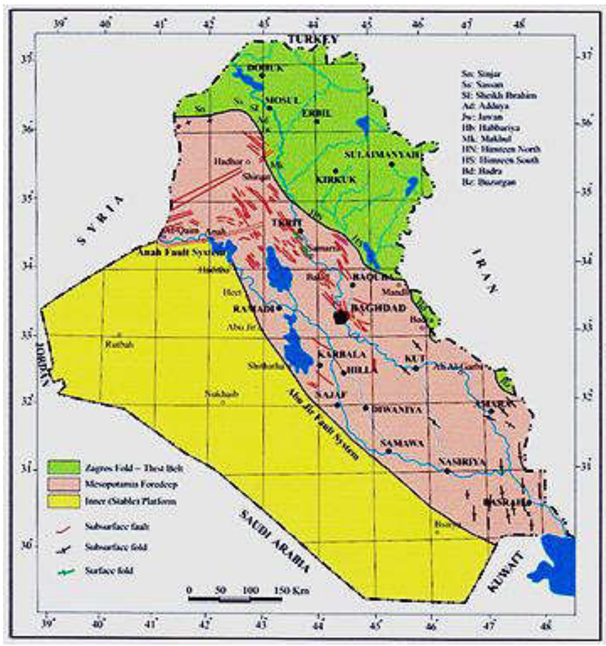


Figure (1-10) Structural map of the Mesopotamia Foredeep (After Fouad, 2010)

Chapter Two

REMOTE SENSING DATA APPLICATIONS

2-1 Introduction

In current research seismic reflection sections are used to detect the structural setting and the tectonic history of the three lakes. The shallow part of the seismic sections shows a bad quality of the recorded data due to the effect of noise. High-resolution seismic-reflection survey using 3.5/7 KHz, such as the study of depositional history and neotectonics in Great Salt Lake by (Colman et al., 2002) is absent in Iraq and no instrument and possibilities for this survey are available, therefore remote sensing technique becomes an important tool for studying neotectonics of the depressions as a last phase of tectonic evolution.

Remote sensing is defined as the acquisition of information about an object without being in physical contact with it. Information is acquired by detecting and measuring changes that the object imposes on the surrounding field, may be electromagnetic, acoustic, or potential. This could include an electromagnetic field emitted or reflected by the object, acoustic wave reflected or perturbed by the object, or perturbation of the surrounding gravity or magnetic potential field due to the presence of the object. Remote sensing is used in connection with electromagnetic techniques of information acquisition. These techniques cover the whole electromagnetic spectrum from low-frequency radio waves through the microwave, far infrared, near infrared, visible and ultraviolet regions of the spectrum (Elachi and Zyl, 2006).

Remote sensing is used as a tool to extract information for the land surface structure, its composition, but is often combined with other data sources providing complementary measurements. Structural mapping is the identification and characterization of structural expression. Structures include faults, folds and lineaments. Understanding structures is the key to interpret crustal movements that have form the present terrain (Campbell, 1996).

Two scenes of Landsat satellite Enhanced Thematic Mapper (Landsat-7 ETM) images 169-36 and 169-37 are used to cover the study area (Figure 2-1) and (Table 2-1). Landsat-7 ETM specialize a portion of electromagnetic spectrum range 2.08-2.15 µm (band-7). That deals with geological data. It is useful for discrimination of mineral and rock types. It has special resolution of 30 m. Therefore satellite (ETM) images are used to give the meaningful and appropriation uses by optical viewing and many software such as ERDAS IMAGING version 9.2 and ArcGIS version 9.3, to get data about lineament map of the selected area and determine the modern geological features as indications to neotectonics of the three depressions.

Spatial resolution of Landsat-7 ETM is 30 m for all multispectral bands except panchromatic and band 6, thermal; Panchromatic band has spatial resolution of 15 m. Merging bands are done by ERDAS software between panchromatic band with each multispectral band to increase the spatial resolution of the later from 30 m to 15 m. High resolution satellite imagery allows the lineaments and geological features to appear clearly.

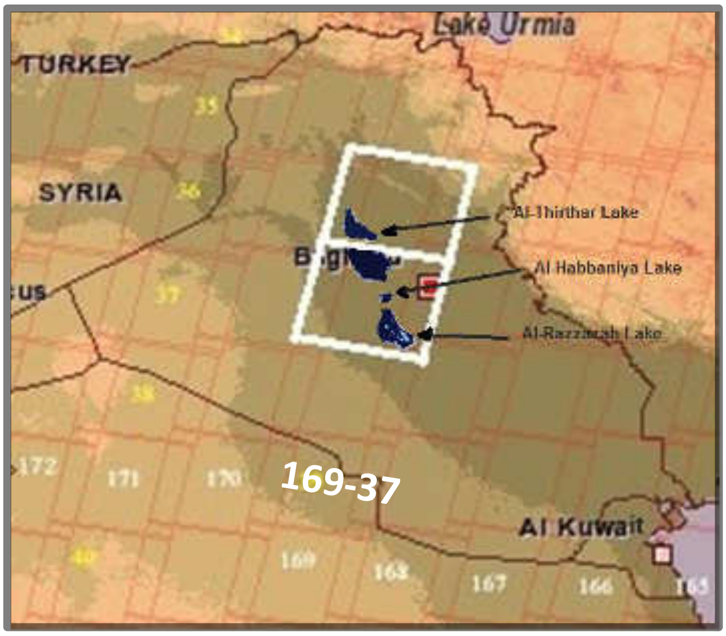


Figure (2.1) Landsat-7 image 169-36 and 169-37 are used for study area.

Table (2-1) Data of Landsat ETM image.

Locations	ETM Data			
	Path	Raw	Acq. date	Producer
WRS-2	169	036	16-04-2000	Earth sat
WRS-2	169	037	11-07-2002	Earth sat

2-2 Image Enhancement

Major digital image processes include histogram equalization, color composite and high pass filtering which are applied to enhance the digital images by use ERDAS IMAGING software.

2-2-1 Histogram Equalization

Enhancement stretching includes linear stretch and non- linear stretch. The former can be greatly affected by a random error that is particularly high or low in brightness values (Figure 2.2). For this reason, a nonlinear stretch such as histogram equalization is preferred. Histogram equalization brightness values are reassigned using an algorithm that exaggerates the contrast in range of the brightness values (Figure 2-3) (CCRS, 2003).

It is the first process applied to the satellite data. After default stretch the image pixels are reassigned new values and spread out across the entire value range, over the 0 – 255 levels. The resulting scene has a higher contrast.

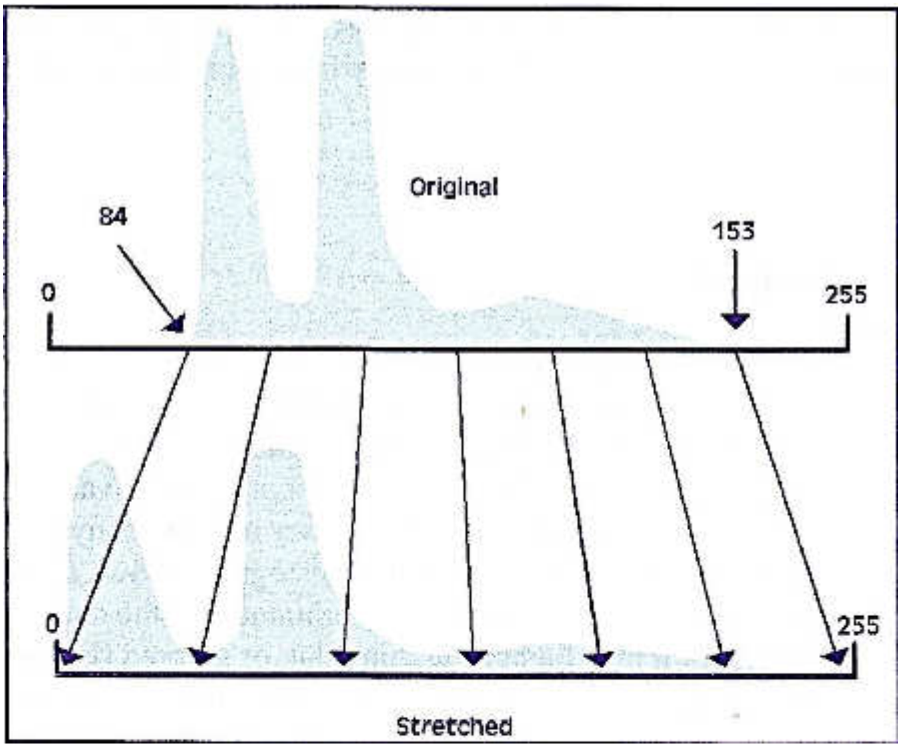
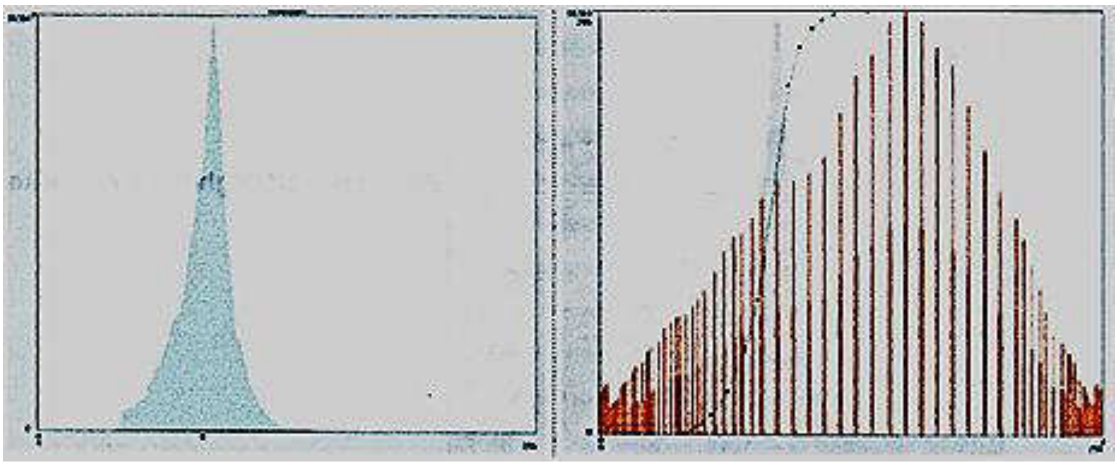


Figure (2-2) A linear stretch involves identifying the minimum and maximum brightness values in the image histogram and applying a transformation to stretch this range to fill the full range across 0 to 255 (After CCRS, 2003).



a. DN histogram shows that the majority of pixels are clustered together

b. After histogram equalization stretch the pixels are reassigned new value and spread out across the entire value range. The data maximum is subdued while the histogram leading and trailing edges are amplified the resulting image as an overall increase in contrast

Figure (2-3) Histogram equalization (After CCRS, 2003).

2-2-3Color Composite

When displaying an image on a computer monitor, the software allows the user to assign a band to a particular color. Because there are merely three possible colors (red, green, and blue) come from three bands of spectra can be displayed at a same time. The possible band choses coupled with the three-color combinations creates many numbers of possible color display choices. The optimal band choice for display will depend on spectral information needed, experience of the interpreter and the aim of the digital processes. A typical color/band designation of red/green/blue in band 3/2/1 (RGB) of Landsat displays the imagery as true-color (Canas and Barnett 1985).

Another useful composite is Bands 7, 4, 2 (RGB) known as a false-color composite (Figure 2-4). This composite displays features with color and contrast that differ from those observed in nature. 7, 4, 2 false color combination made it easier to identify linear patterns of vegetation, geological formation boundaries, river channels, geological weakness zone (Al-muthen, 2008).

2-2-3 High Pass Filter (HPF)

High pass filter, as a spatial filtering process, is a local operation in that pixel value in an original image are modified on the base of the reflectance levels of neighboring pixels. A simple high pass filter implemented by passing a moving window throughout an original image and creating a second image whose digital number at each pixel corresponds to the local average within the moving window at each of its position in the original image (Lillesand and Kiefer, 1987).

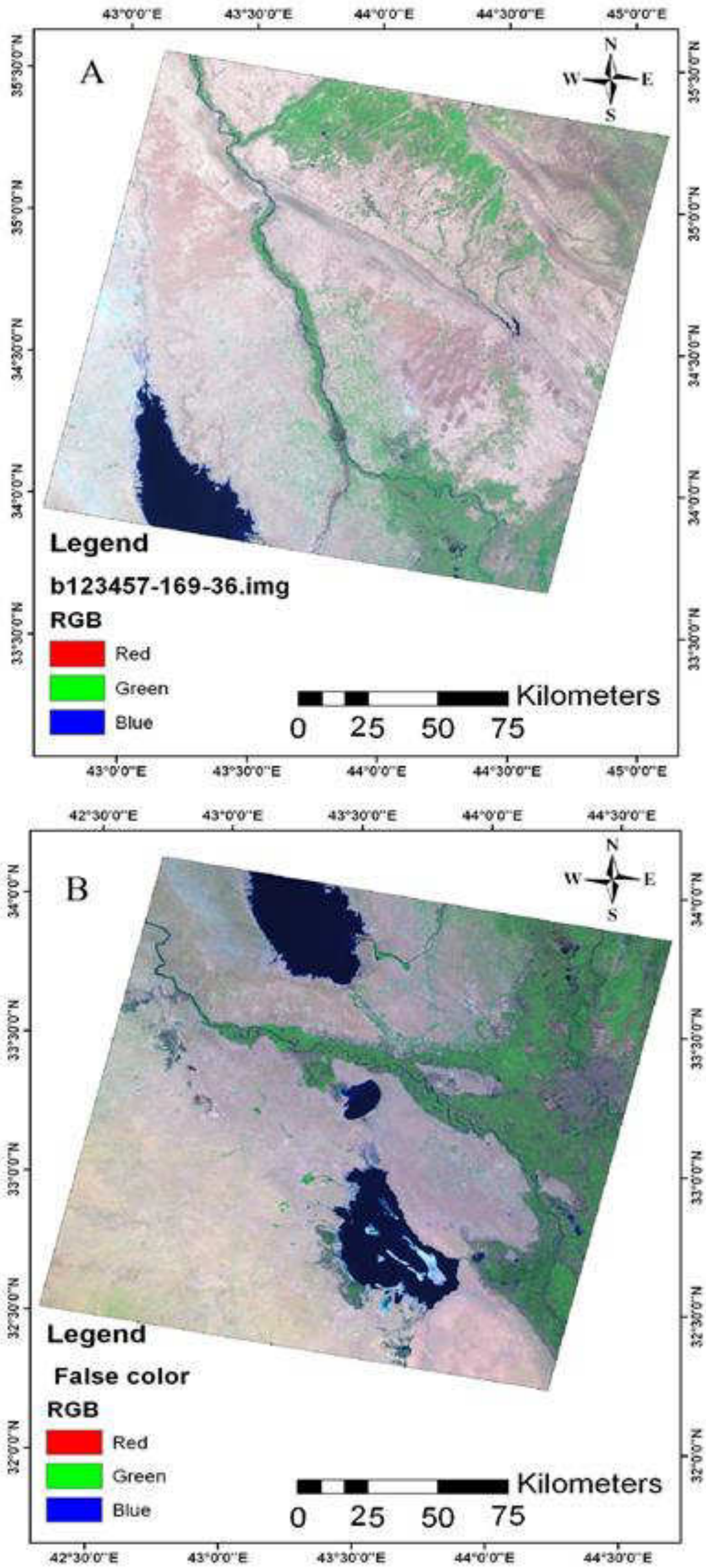


Figure (2-4) False color composite (A) image 169-36 (B) image 169-37

Because of the area cover by sediments, the variations become very slight, therefore high pass filter is used to exaggerate any variation in reflectance. 3 x 3 pixel window (kernel) is used for this process (Figure 2-5).

-1	-1	-1
-1	8	-1
-1	-1	-1

Figure (2-5) High pass kernel is used for HPF process

The convolution method is carried out by overlaying a kernel onto pixel image centering its middle value over the pixel of interest. The kernel is first placed above the pixel located at the top left corner of the image and moved from top to bottom, left to right. Each kernel position will create an output pixel value, which is calculated by multiplying each input pixel value with the kernel coefficient above it. The product of the input data and kernel is then averaged over the array (sum of the product divided by the number of pixels evaluated); the output value is assigned this average. The kernel then move to the next pixel, always using the original input data set for calculating averages (Jensen, 1996 and CCRS, 2003).

The equation of convolution in this process is;

$-1*DN\ X_1Y_1 + -1*DN\ X_1Y_2 + -1*DN\ X_1Y_3 + -1*DN\ X_2Y_1 + 8*DN\ X_2Y_2 + -1*DN\ X_2Y_3 + -1*DN\ X_3Y_1 + -1*DN\ X_3Y_2 + -1*DN\ X_3Y_3 = SUM/9$

Where X and Y are row and column of the image respectively, and DN is the digital number of the pixel.

High pass filter is applied to the data's image (Figure 2-6). It is used to highlighting borderline features such as roads, rivers and linear geological features by increasing the variety of grey level between different adjacent units. It reaches the digital image to accurate state in which can get good optical viewing to delineate the lineaments of study area.

2-3 Lineaments

There are many processes in which lineaments can be drawn as map such as color composite, principle component and others or by use kernels 5x5, 7x7 or 9x9 , but kernel 3x3 can delineates lineaments and detects any variation within digital image because of the size of features in the images.

Lineaments are straight or gentle curving features on earth's surface that are commonly expressed topographically as ridges, depressions, or aligned depressions. Structural analyses are conducted on regional scale, to provide a comprehensive look at the fault extent, lineaments and other structural features. Geological features are typically large (kilometeric scale) and applications therefore require small-scale imagery to cover the extent of the element of the interest (Shake and McHone, 1987).

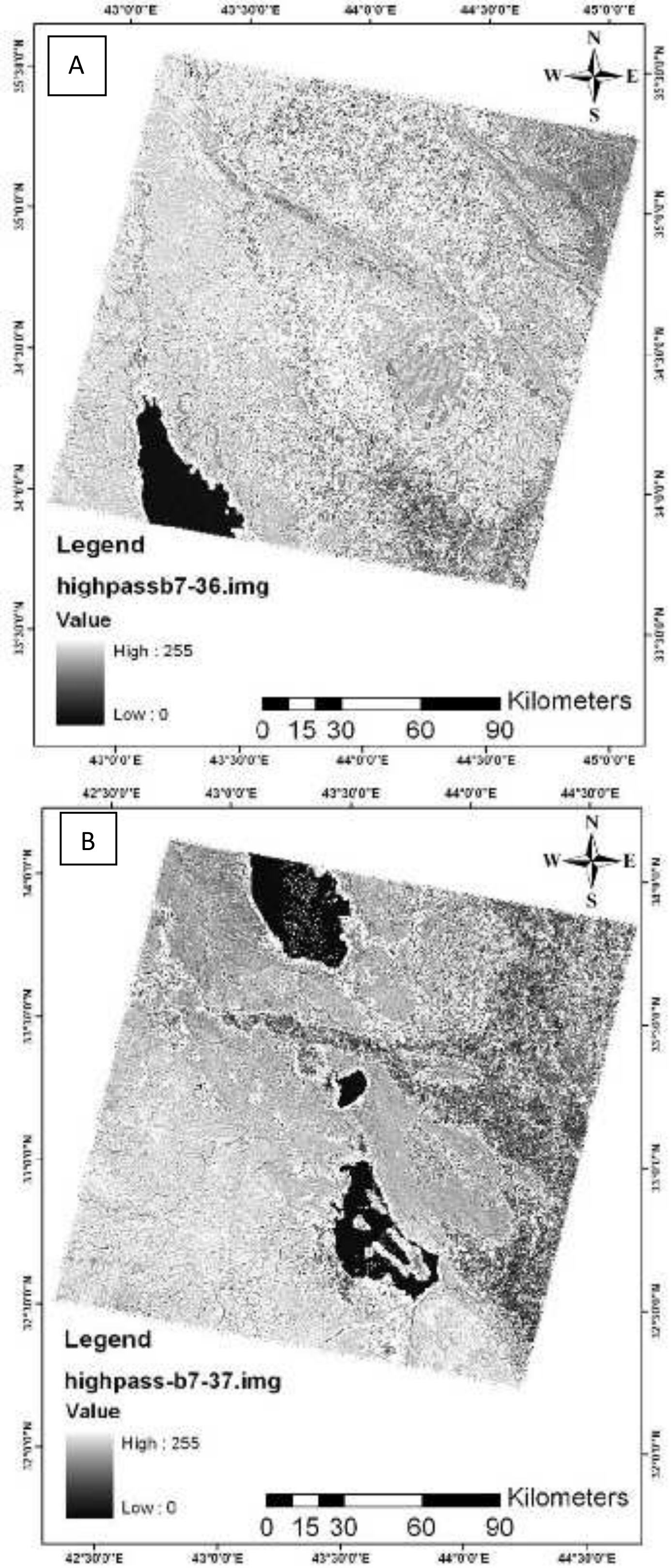


Figure (2-6) High pass filter is applied on (A) 169-36 image (B) 169-37 image

Lineaments are often apparent in the geological maps. They can appear obviously on aerial photographs or satellite images. It should be discriminates geological linear features from other linear features that are not due to geological structures. The knowledge and the experience of the user are the key point in the identification of the lineaments particularly to connect broken segments into longer lineaments (Wang, 1990). Some general features help to identify the lineaments can be listed as follows (Koc, 2005 in Kadhem, 2009).

a. Topographic features such as straight valleys and continuous scarps.
b. Straight rock boundaries.
c. Systematic offset and straight parts of river.
d. Sudden tonal variations.
e. Alignment of vegetation.

Two scenes of Landsat-7 imagery are used by ArcGIS Software to generate lineament map of study area (Figure 2-7) with check some lineaments in field work (Plates 2-1). Histogram and the statistics of the map are done (Figure 2-8). It is very difficult to detect structural features in an area where vegetation cover is dense. Lineaments are drawn by many scales (zooming) applied to appear local lineaments where zoom increases, versus reducing the zoom regional lineaments will be extracting clearly such as Abu-Jir fault system that appear west of Al-Razzazah lake.

The histogram illustrates the short lineaments less than 1 km are more frequency than other lineaments. They are concentric in surrounding area of the three lakes (Figure 2-7).

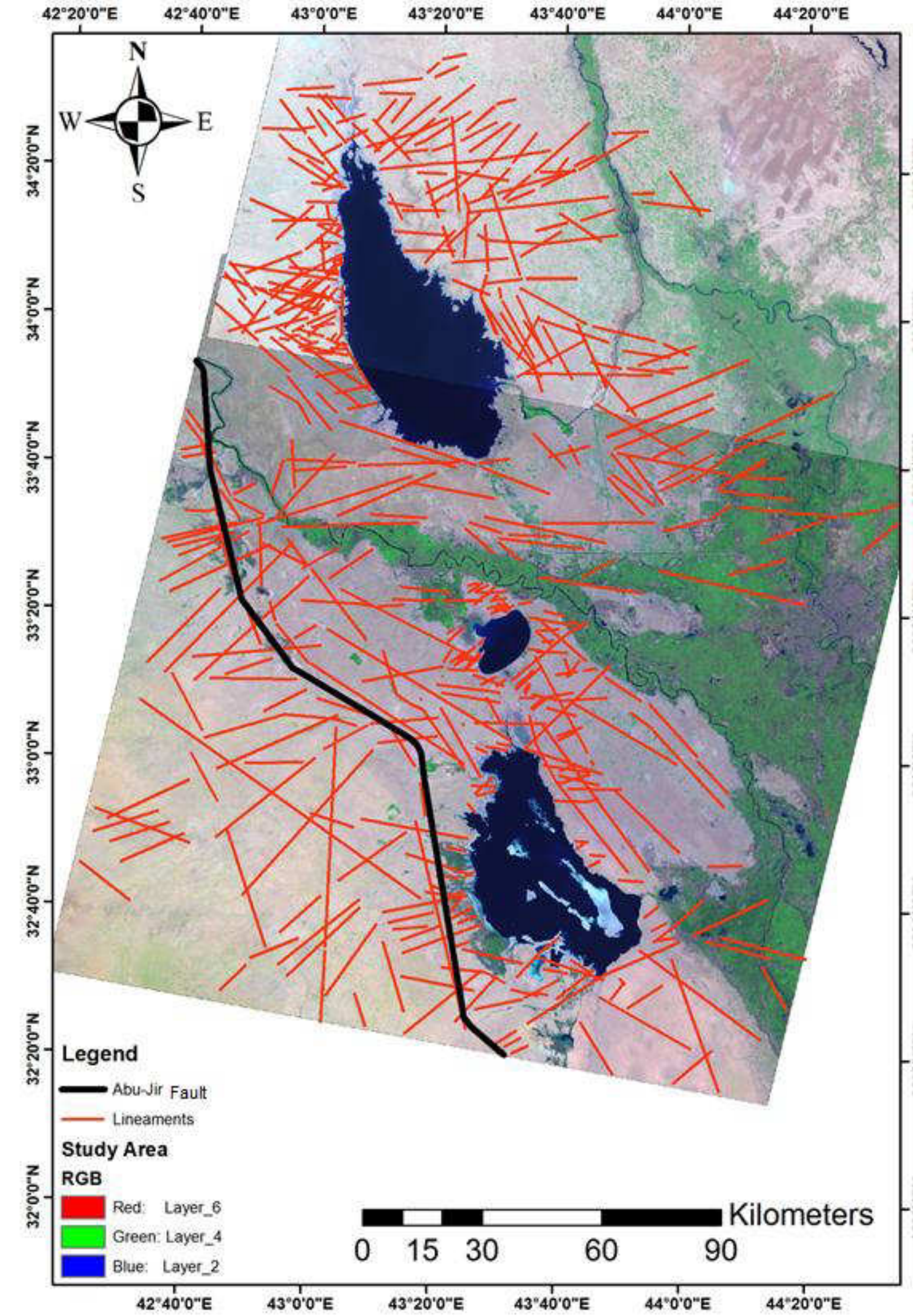


Figure (2-7) Lineaments projected on images of study area.

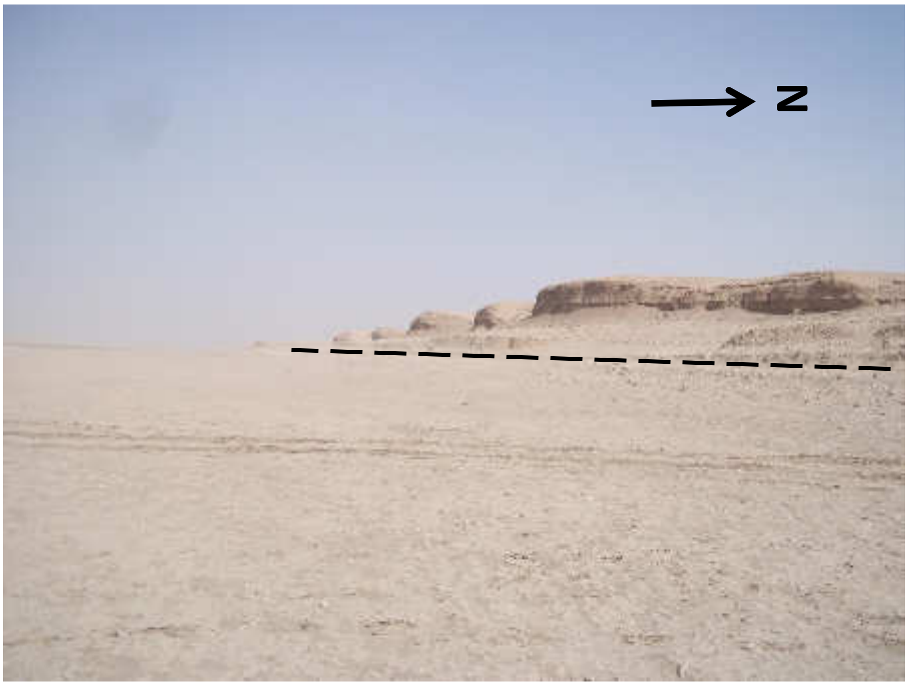


Plate (2.1) Lineament feature northwest Al-Thirthar depression

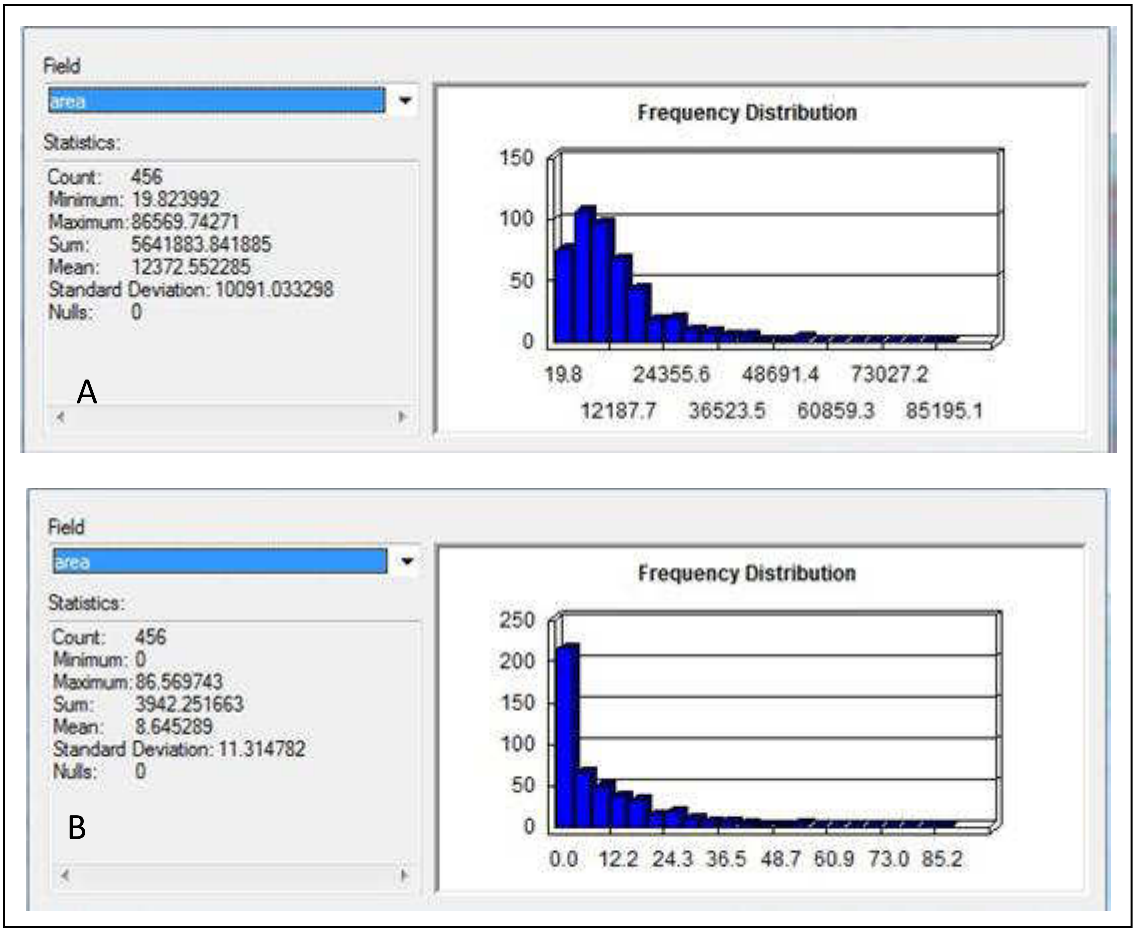


Figure (2-8) Histogram and statistics of the lineament map (A) in meters (B) in kilometers.

2-4 Lineament Analysis

Many authors such as (Wise et al., 1985, Shake and McHone, 1987 and Abalos et al., 1989) use different techniques to recognize and analyize the linear features on satellite images. They are very useful tools for tectonic studies especially when combined with geophysical and field data.

Rose diagram is drawn for lineaments of the study area by using Rock-ware version 15 software (Figure 2-9). The figure shows two groups of major lineaments trend in two different directions. The first group of lineaments trends east-west approximate perpendicular to the axis of three lake extents. The second group generally trends N60°E-S60°W approximate perpendicular to the most geological structures in unstable shelf. The lineaments of both groups east-west and northeast-southwest are parallel to east-west and northeast-southwest Transversal fault systems of the tectonic zones of Iraq according to (Jassim and Goff, 2006) (Figure 1-7). It is interesting to note where the cover rocks are in contact with basement, fracture pattern from the basement can be seen superimposed and passing into the cover rocks. Major topographic lineaments are often clearly related to structures and rocks as mapped on the Earth's surface, and increasingly, to postulate subsurface fractures (Shake and McHone, 1987)

The Transversal fault system in central of Iraq was reactived from Late Jurassic time onward. Some faults of these systems undergo sinistral strike slip movement in Quaternary time; at least 2 km of horizontal displacement is occurred along the Anah- Qalat dizeh Fault at Al-Fatha in the last few million years. Many foothill zone anticlines are segmented into separate domes and their fold axes are bent at the intersection with the transversal faults (Jassim and Goff, 2006). (Figure 1-7) shows that both Al-Thirthar and Al-Razzazah lakes are pyriform, and the axis of each one deflects to the east in the south half of them. The deflect of the axis may be due to sinistral movement of Amij-Samarra and Sirwan traversal faults that pass beneath Al-Thirthar and Al-Habbaniya Lakes respectively. Generally these lineaments play important role for the shape of the Al-Thirthar and Al-Razzazah Lakes.

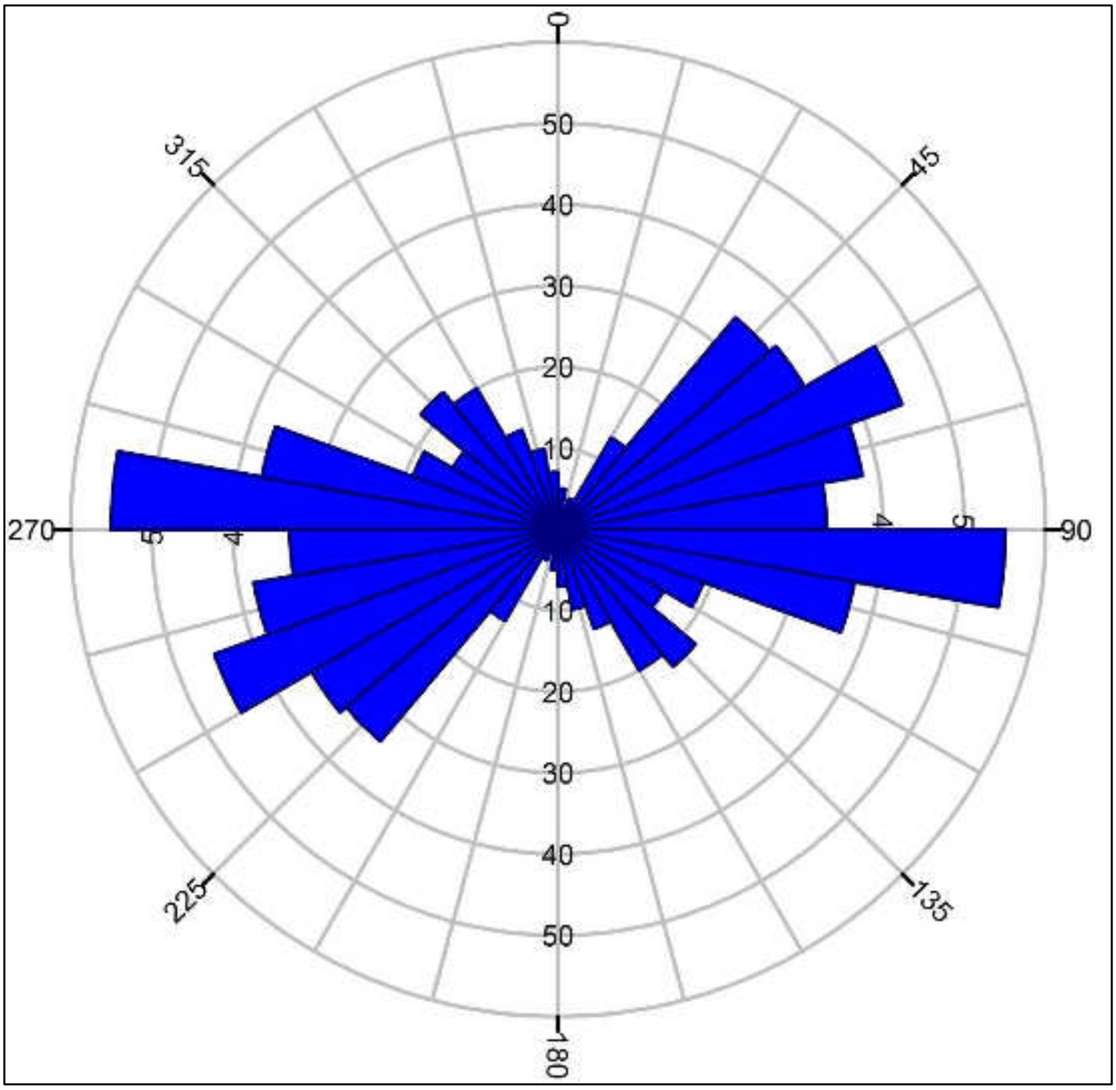


Figure (2.9) Rose diagram of lineament map of study area.

Third group of lineaments trends N45°W (Figure 2-9). It is parallel to subsurface normal faults spreading in extensional zone. They have northwest trend (Marouf, 1999 and Aqrawi et al., 2010). The lineaments dense in the eastern bank of the three lakes (Figure 2-7) and intersect the two major lineaments. The intersection makes small blocks and more intensity deformed region that effect strongly to the formation of the lakes. (Jassim and Goff, 2006) refer that Al-Thirthar, Al- Habbaniya , Al-Razzazah and Bahr Al Najaf depressions may be tectonically, control by the NW-SE trending Euphrates Boundary Fault and N-S trending Thirthar fault line.

NW-SE Fault System was reactived during Jurassic to Quaternary (Jassim and Goff, 2006). Also extension in upper part of study area succession is due to tilt of Mesopotamia sequence. Axis of the tilt or flexure develops along the boundary between Mesopotamia zone and Salman Monocline where the three depressions are located. Expressions of this extension can be observed in seismic-reflection profiles in next chapter.

Finally, not all lineaments develop from initial fractures in the basement. Some of the lineaments, especially the ones which are parallel to the axes of the depressions, represent fractures or joints in the sediment cover as a result of tectonic activities of Tertiary and Neotectonics.

2-5 Digital Elevation Model (DEM):

Digital elevation models are commonly built using data collected by remote sensing technique but they may also be built from land surveying. DEMs are the most common basis for digitally-produced relief maps, drainage modeling, land-use studies and geological applications. They are very useful where two optical images are acquired with different angles (Wilson and Gallant, 2000).

The Digital Elevation models of the three lakes are generated. They involve interpolating contour maps, which produced by direct surveying of land surface, aerial photographs and surveying central points. Surfer Software version 8 is used to show the study area in three dimensions. Figures are made in variant views. They are produced by grid, that is formed by data derive their values X, Y and Z from topographic map of 1: 100,000, where (X, Y) are coordinates in UTM system and Z the elevation. The values of elevations are taken by three stages:

1- Contour lines, the intervals are taken with respect to the curvature that exists in identical contour lines, therefore in straight contour line the points are taken approximate in same distance but they dense in curved parts of contour lines.
2- Control points such as bench marks that present in the contour map.
3- Grid of UTM coordinate is mostly depended in area away from contours. Points represent crosses of UTM grid are taken and determine their elevations by using two adjacent contour lines, the points located between them, then apply the following equation.

$$\boldsymbol{D_p = \frac{Z_i - Z_{min}}{Z_{max} - Z_{min}}}$$

Where

D_p = Proportional distance

Zi =Elevation of required point.

Zmax, Zmin are the highest and lowest two adjacent contour lines respectively.

This process is applied because the accredited software in empty area supposes values perhaps create some problems in 3D figures.

After getting the values X, Y, and Z. data were input in surfer software. Gridding is made according to density of the data, denser data gives accurate results. 3D figure draws custom-made the user by contour interval, coloring or others. Finally exaggeration to elevation is made to explain the topography of the depression area and surrounding (Figures 2-10, 2-11 and 2-12).

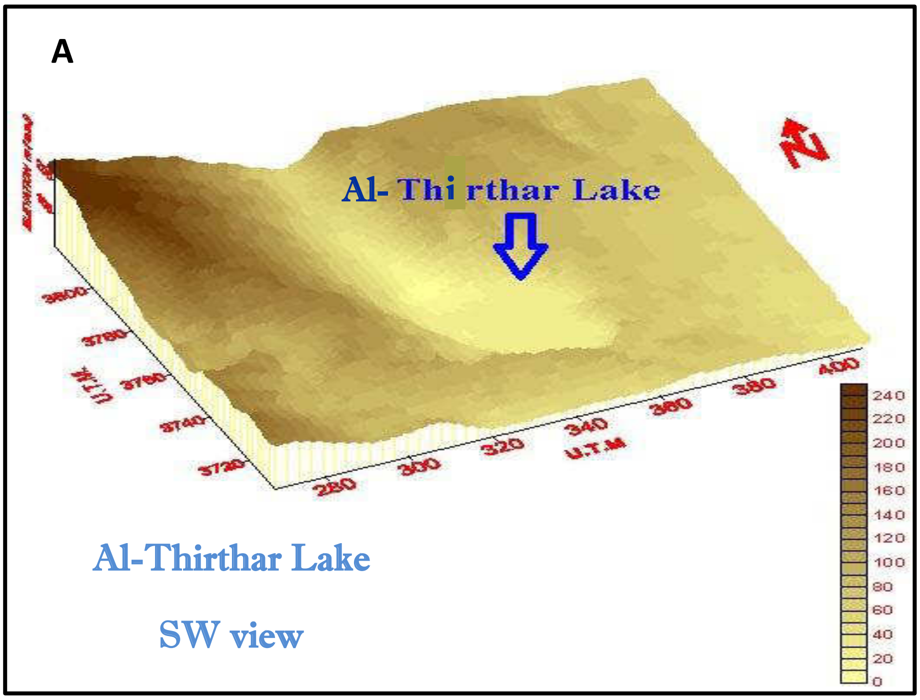
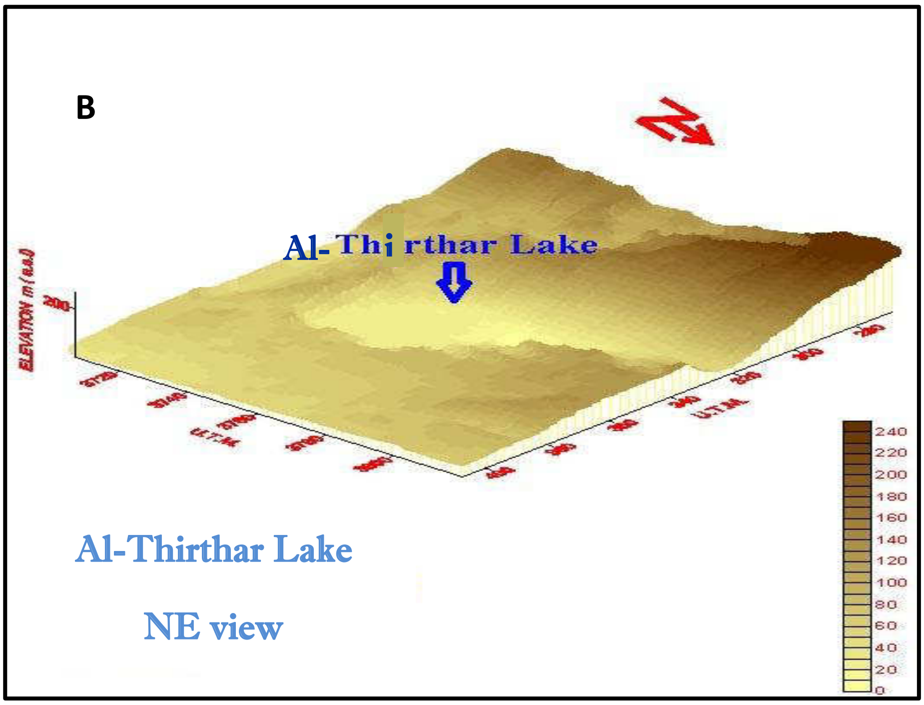
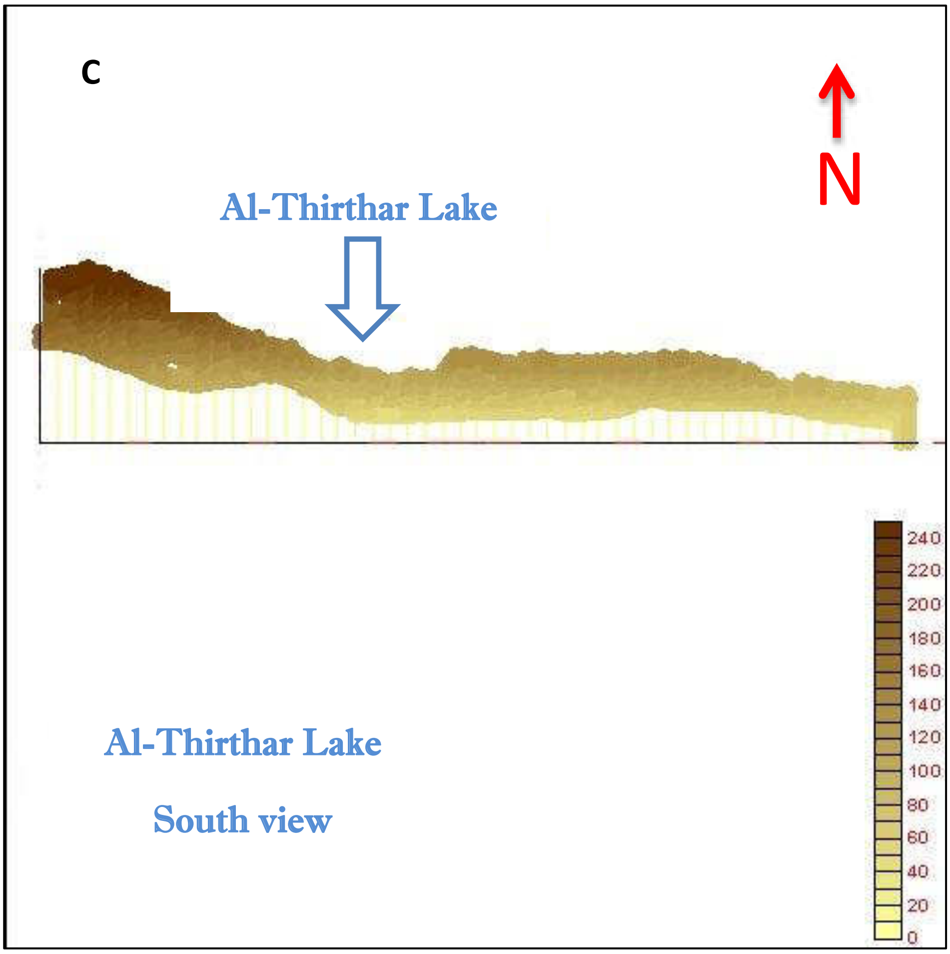


Figure (2-10) Digital elevation models of Al-Thirthar area (A) Southwest view (B) Northeast view and (C) South view


B
N
Al-Thirthar Lake
ELEVATION m (a.s.l)
U.T.M
240
220
200
180
160
140
120
100
80
60
40
20
0
Al-Thirthar Lake
NE view


C
N
Al-Thirthar Lake
240
220
200
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160
140
120
100
80
60
40
20
0
Al-Thirthar Lake
South view

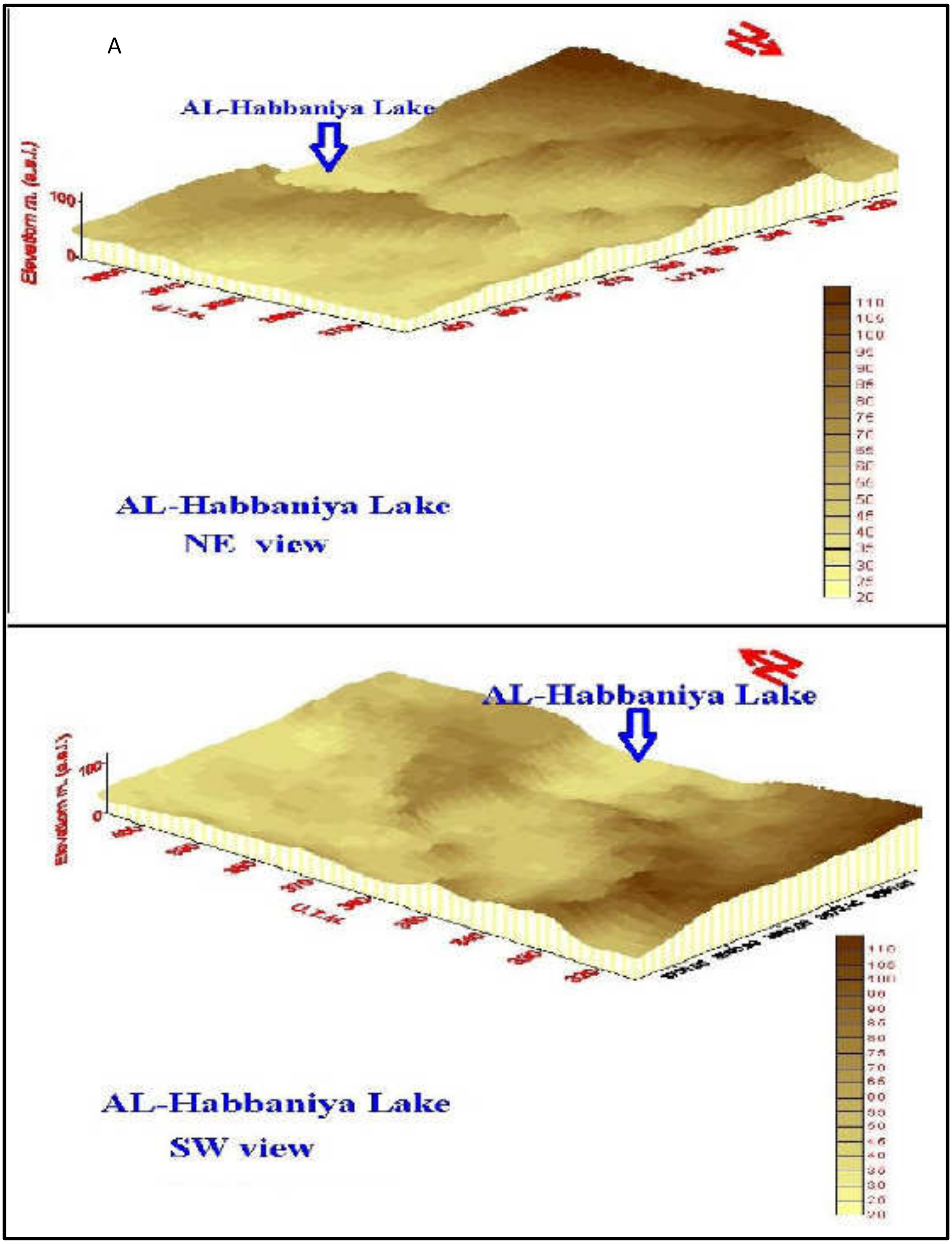

Figure (2-11) Digital elevation model of Al-Habbanyia area (A) Northeast view (B) Southwest view.

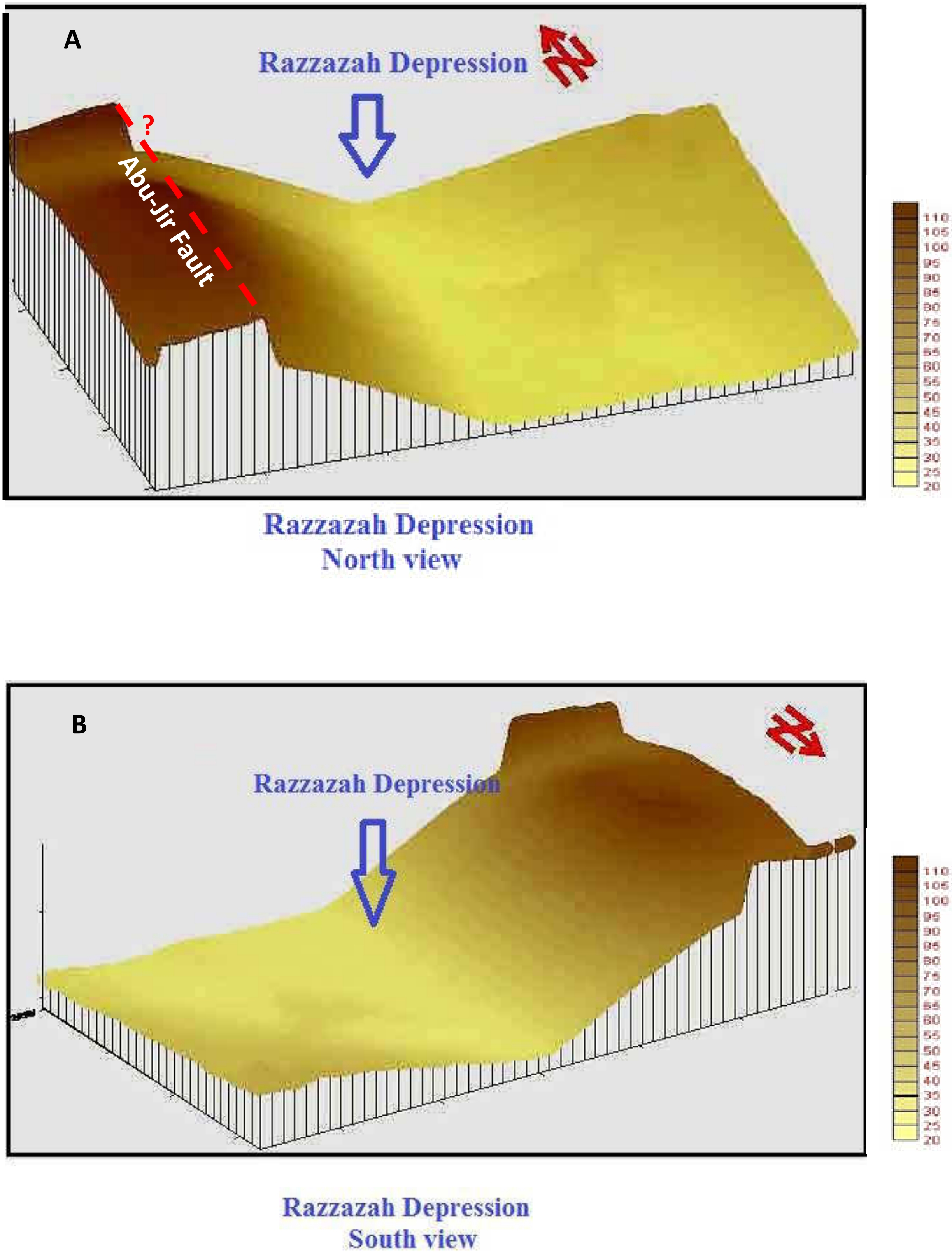

Figure (2-12) Digital elevation model of Al-Razzazah area (A) North view (B) South view.

2-6 Analysis of Digital Elevation Models

Digital elevation model of Al-Thirthar area (Figure 2-10) shows that the slope of the surround area is toward the axis of the depression. The slope in the west bank is gradual toward the depression. It has low gradient. Gradient is very low in the east bank of Al-Thirthar depression. Steep cliff east rim can be noted (Figure 2-10c). It represents the conglomerate of Al-Fatha Alluvial Fan.

Existence of the Quaternary deposit in the east bank and absent in the west bank (Yacoub, 2011) reflects that the east bank of Al-Thirthar depression is low area after Al-Fatha Alluvial Fan deposition, that took place due to subsidence of Mesopotamia basin during Tertiary time. Rapid subsidence during Middle and Late Miocene was in the Mesopotamia basin (Jassim and Goff, 2006). This subsidence of the sequence generates tensile stress in area of Al-Thirthar depression as well as in area of Al-Habbaniya and Al-Razzazah Lakes.

Al-Habbaniya depression is small. Distinct variation in gradient is not observed. Generally, the west and east banks have the same elevation. They have gentle slope toward depression. Hills, plateaus and ridges can be observed in the digital elevation model of Al-Habbaniya area (Figure 2-11).

Digital elevation model of Al-Razzazah depression shows elevated west bank relative to the east bank. The west bank has small steep ridge. Gradient in the west bank is greater than the east one. Abu-Jir fault system passes beside the west rim of Al-Razzazah depression, and may affect to the west bank of the depression (Figure 2-12).

2-7 Geomorphologic Landforms as Neotectonic Indicators:

Many indicators are observed in surrounding area of the three lakes. These indicators may represent neotectonic activities.

1- Recent tectonic activities of several buried structures including folds and faults are recorded through their effects upon the Quaternary stratigraphy and present geomorphologic landforms. They represent abandoned river channels and topographic expression of some active subsurface anticlines (Fouad and Sissakian, 2010) (Figure 2-13). Rolling topography in the north part of Mesopotamian plain, east of Al-Thirthar Lake, indicates subsurface anticlines that are still rising up such as Balad, Samarra, Tikrit and Baiji Anticlines (Al-Kadhimi et al., 1996).
2- Systematic conjugate joints in limestone of Al-Fatha Formation (Middle Miocene) in the northwest margin of Al-Thirthar Lake are good indication for tectonic activities after this time (Plate 2-2).
3- Abu-Jir fault zone system passes through the west margin of Al-Razzazah Lake. It appears as zone, very clear in the satellite image, and still active nowadays.
4- Al-Thirthar Lake is deep depression bordered in east side by cliff of conglomerate layer of Al-Fatha Alluvial Fan (Pleistocene). That is made by subsidence of east bank of Al-Tharthar Lake.
5- Lineament map of study area (Figure 2-7) shows few systematic groups of lineaments. Some of these lineaments, especially the short northeast ones, may represent tension or release joints in sediment cover, that develop as a result of mentioned above tensile stress during Pliocene –Early quaternary.
6- Local drainage divide lines are developed along crest of subsurface structure (Figure 2-14). It is located west Al-Habbaniya Lake and perhaps

represents active subsurface anticline or nose. (Al-Sakni, 1986) referred to a developed active subsurface structure named Nafata-Awasil structure extend from south Hit to east of Al-Habbaniya Lake in NW-SE direction. It is exposed by geophysical surveys (seismic, gravity and magnetic). They are done by foreign oil companies and drilled many oil wells in it. The area of local drainage divide line is perhaps developed in response to active Nafata-Awasil structure.

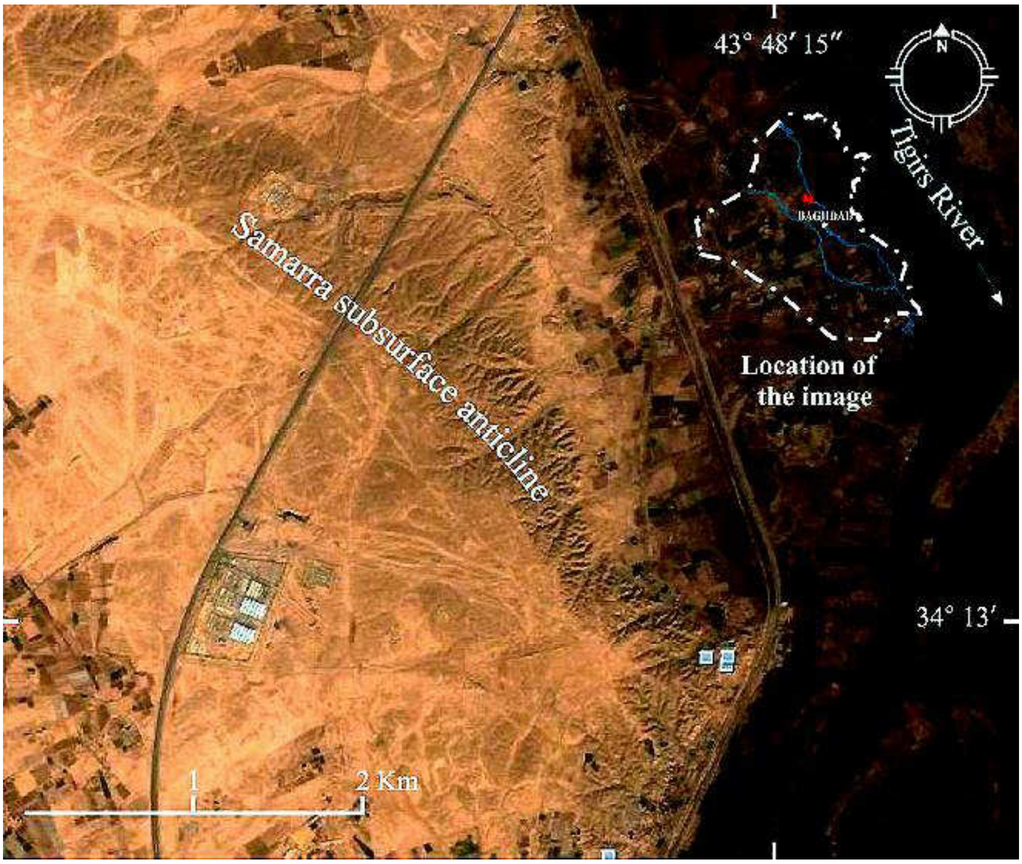

Figure (2-13) Active Samarra subsurface anticline, east of Al-Thirthar Lake (Enhanced from Fouad and Sissakian, 2010)

Plate (2-2) Limestone of Al-Fatha Formation northwest margin of Al-Thirthar Lake. Systematic conjugate joints good indication for tectonic activity.

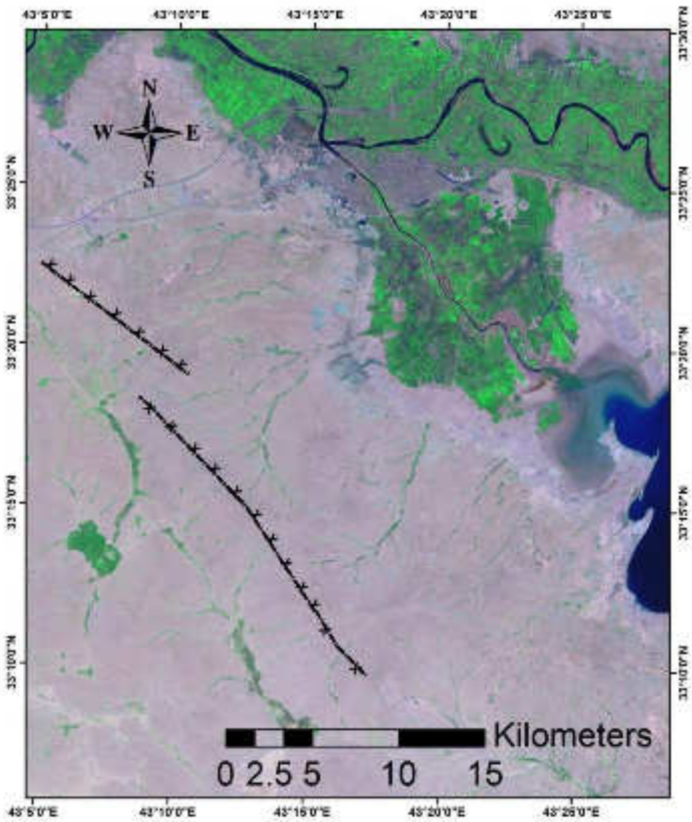

Figure (2.14) Satellite image shows the drainage divide developed along crest of subsurface structure

7- There are three stages of migration eastward of the Tigris River due to the uplifting of the subsurface structure and neotectonics (Figure 2-15). The first stage is during Pleistocene, the second stage is during Holocene and the last stage at the present time (Al-Jarrah, 1995). The location of the migration is in the east of Al-Thirthar Lake.

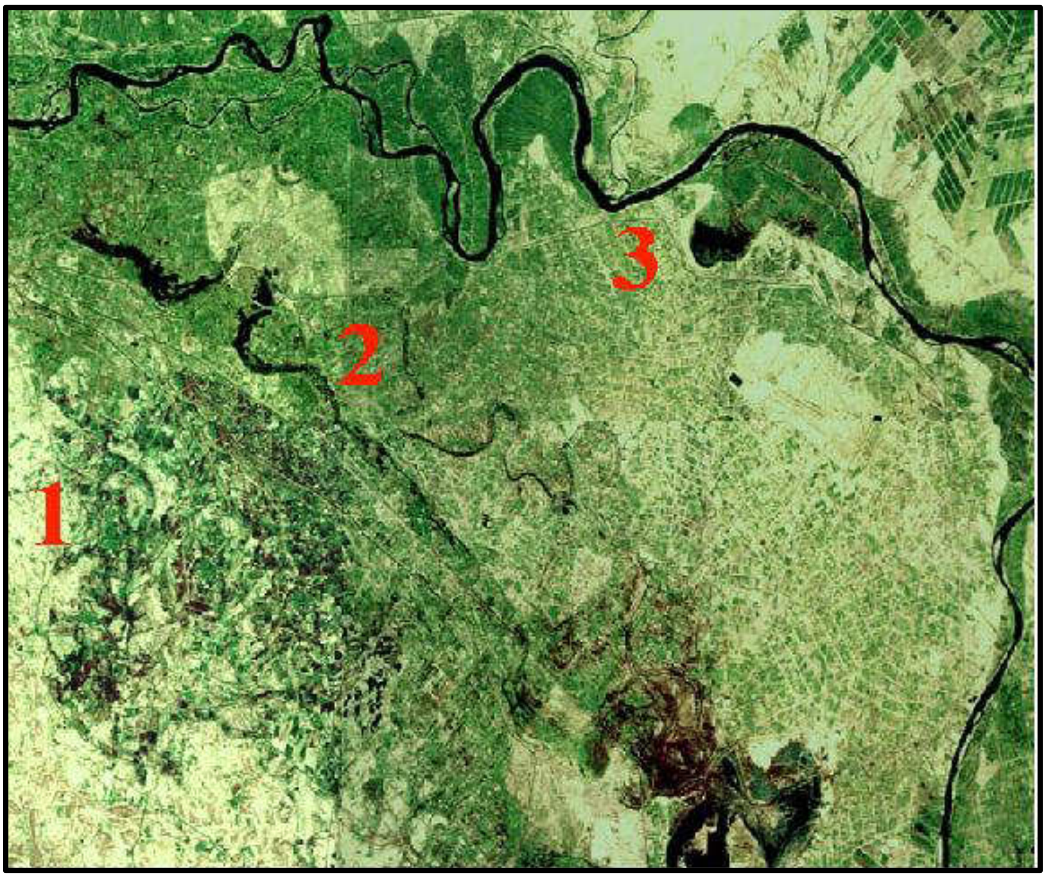

Figure (2-15) Migration of the Tigris River is eastward in three stages. A good indication of neotectonics east of the Al-Thirthar depression. (After Al-Jarrah, 1995)

Chapter Three

INTERPRETATION OF SEISMIC- REFLECTION SECTIONS

3-1 Introduction

Seismic reflection surveying is the most widely used and well-known geophysical technique. The current state of sophistication of the technique is largely a result of the enormous investment in its development made by the hydrocarbon industry, coupled with the development of advanced electronic and computing technology. Seismic section can now be produced to reveal details of geological structures on scales from the top tens of meters of drift to the whole lithosphere. Part of the spectacular success of the method lies in the fact that the raw data are processed to produce a seismic section which is an image of the subsurface structure (Kearey et al., 2002).

The seismic method is rather simple in concept. An energy source is used to produce seismic waves (similar to sound) that travel through the earth to detectors of motion, on land, or pressure, at sea. The detectors convert the motion or pressure variation to electricity that is recorded by electronic instruments.

There are many paths between source and receiver two of them are particular interest-reflection and refraction, two layers 1 and 2 differ in rock types, in the rate at which seismic waves travel (acoustic or seismic velocity), and density (mass per unit volume), When the seismic waves encounter the boundary between layers 1 and 2 some of the energy is reflected back to the surface in layer 1 and some is transmitted into layer 2 (Figure 3-1). If the seismic velocity of layer 2 is faster than in layer 1, these will be an angle at which the transmitted seismic wave is bent or refracted to travel along the boundary between layers. These two path types are the bases of reflection and refraction surveys (Gadallah and Fisher, 2009).

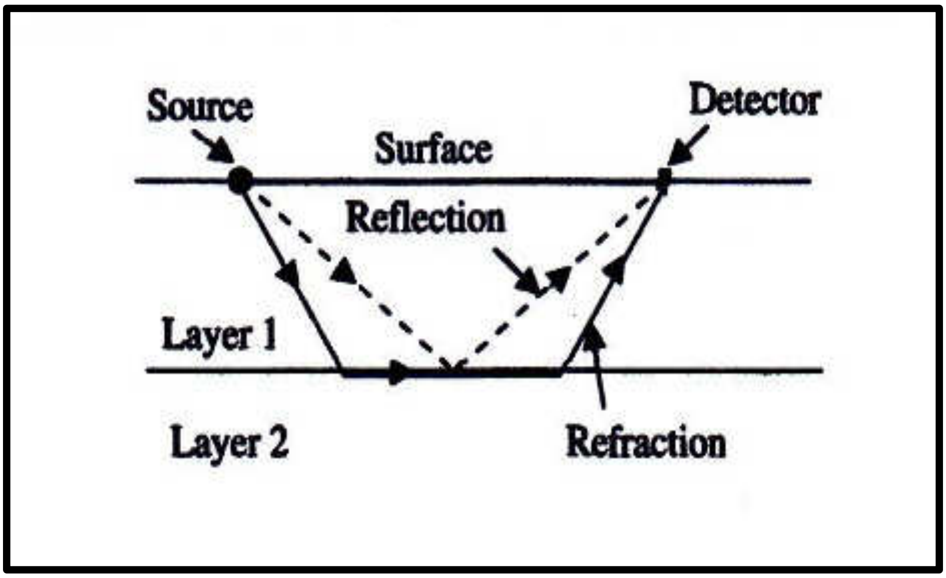

Figure (1-3) Travel paths of seismic wave propagation through different types of rocks (After Gadallah and Fisher, 2009).

Seismic reflection survey of the study area is done by Iraq National Oil Company in 1978-1979 where many authors use these seismic sections for their targets. (Marouf, 1999) uses several seismic sections to study the extensional structures in extensional zone e.g. Mileh-Thirthar, Al-Thirthar, Sammara and other structures (Figure 3-2). (Aqrawi et al; 2010) sketched regional geological cross-sections using seismic data, some of these cross-sections pass through the study area.

Six seismic sections were chosen (Figure 3-2), oriented in northeast–southwest directions, and approximately perpendicular to the subsurface geological structures. The most important structural features in study area are extensional structures. They have northwest – southeast directions, therefor many workers such as (Marouf, 1999, Aqrawi, et al., 2010 and Muhsin, 2012) used northeast-southwest trending seismic sections to study the normal faults in extensional zone of Iraqi terrain.

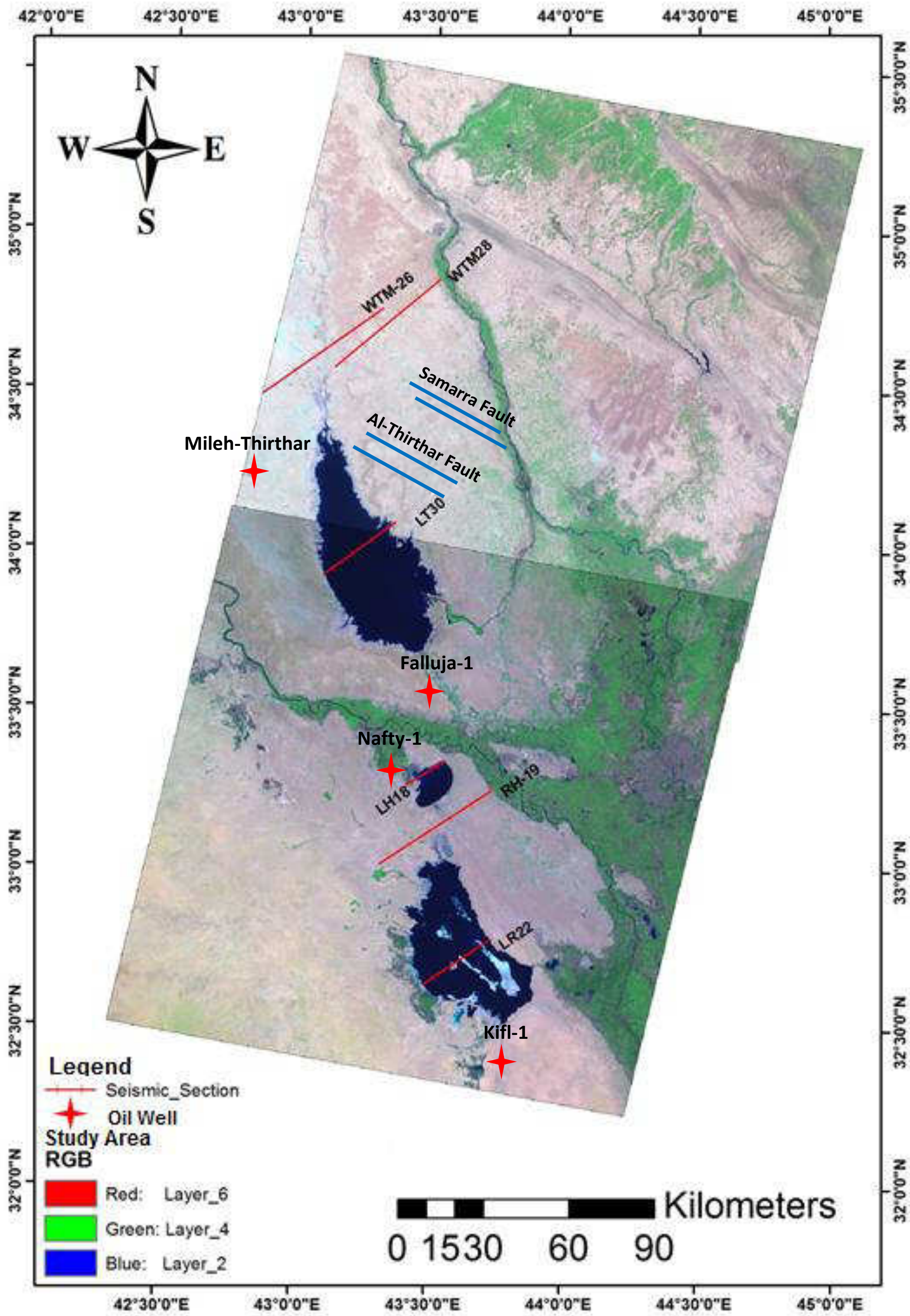

Figure (3-2) Satellite image shows the location of seismic sections and oil wells in the study area.

Some of the selected seismic sections were chosen outside the three lakes, but close to them and on the same trend, to study the influence of the stresses on the three depressions.

Many reflectors were picked in each section and defined basing on correlation synthetic seismogram and logs of the some oil wells around the study area. Picking of seismic reflectors and structural interpretations carried by the researcher and the identification of them were done with the aid of the geophysical department of the Oil Exploration Company.

There are three types of seismic reflectors depend on their qualities and continuities; good, fair or bad reflector. Bad quality is caused by many factors such as complex in a geological situation, fault existences, change in lithological facies, difference in field record parameters and noise nature. The quality and continuity of the reflectors are important tools for structural and stratigraphic interpretation.

3-2 Interpretation of Seismic-Time Sections

The geologic information is extracted by suitable analysis of the pattern of reflection event on the seismic interpreted section. Interpretations are correlated from line to line, and the reflection times of picked events are compared directly at profile interpretation. There are many approaches to the interpretation of seismic sections; the most impotent of them are structural analysis, which is the study of reflector geometry on the basis of reflection times, and stratigraphical analysis (or seismic stratigraphy), which is analysis of reflection sequences as the seismic expression of lithologically-distinct depositional sequences (Kearey et al., 2002).

There are no distinct surface structural features in study area, but the seismic reflection profiles show many subsurface structures, the most important are extensional structures such as normal faults, symmetrical graben, asymmetrical graben and horst.

Symmetrical graben is the sequence bounded by two major normal faults dipping toward each other with approximately equal displacement, while asymmetrical graben if one boundary fault has more displacement than the other. Half graben if the sequence is bounded by one boundary normal fault on one side and by continuous sequence of dipping beds on the other relatively downthrown side. Horst if the sequence is bounded by two major normal fault dipping away from each other (Ramsay and Huber 1987).

3D seismic survey for study area is missing in Oil Exploration Company (OEC), therefore 2D seismic sections are chosen. The latter are used widely for structural setting, petroleum exploration and tectonic evolution. Many analogue models of 2D extensional fault systems are designed by (Lowell et al., 1975) who classified their mode depend on pure shear; (Wernicke, 1985) classified its model based on simple shear. Other authors (Ellis and McClay, 1988, McClay, 1990 and 2000) developed models to simulate a continental rifting of the upper crust above the brittle-ductile transition (10 to 15 km depth).

Seismic sections and data of oil wells Mileh Thirthar -1 (Mt-1) table (1-3), Falluja-1 (F-1), Nafty-1 (Nf-1) and West Kifl-1(Wk-1) (Figure 3-2) are used to understand the tectonic evolution of Al-Thirthar, Al-Habbaniya and Al-Razzazah Lakes.

Generally, reflection qualities of selected seismic-time sections change laterally and vertically from good to fair quality. All of the selected sections are images getting from Library of (OEC) not in SEG-Y format. The later format is digital seismic sections allow to apply advanced software of seismic attributes such as amplitude, phase, frequency and geometrical attributes that are very important to identify reflectors and faults in 2D and 3D surveys (Kashihara and Hou, 2009).

No velocity data are provided for all seismic sections except seismic section WTM-26. The latter is also image and not in SEG-Y format; therefor using of software to find average velocities are impossible. All average velocities for latter section are depicted by hand. The structural features in each seismic section is described and interpreted from southwest to northeast.

3-2-1 Seismic-time Section WTM-26

The name of this seismic-reflection section is West Tikrit-Makhul no-26. It is located to the north of Al-Thirthar Lake and cross Al-Thirthar valley (Figure 3-2). Six reflectors were picked in this section depending on synthetic seismogram of well Mileh Thirthar (MT-1). They are ranged from good to fair quality. The reflectors represent top or within the following formations (Figure 3-3).

- Fat’ha Formation (Middle Miocene).
- Jeribe Formation (middle Miocene).
- Mauddud Formation (Albian).
- Shuaiba Formation (Aptian).
- Alan Formation (Late Liassic)
- Kurra chine Formation (Late Liassic).

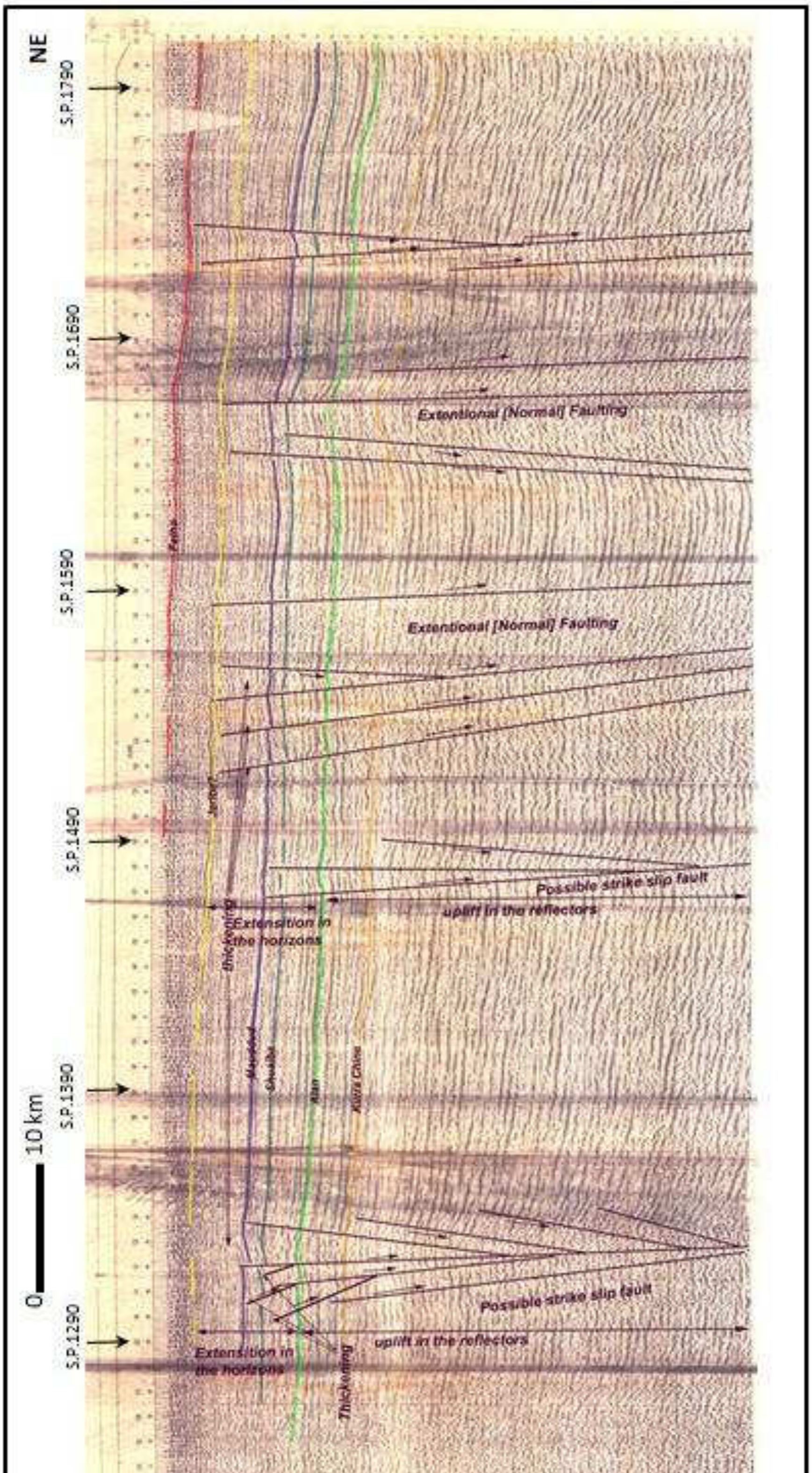

Figure (3-3) Seismic-Time Section WTM-26 (After OEC)

In general the reflectors are parallel to sub-parallel to each other, which are dipping toward northeast. Position of other formations in stratigraphic sequence of this section can be determined by correlation the reflectors with the formations of well Mileh Thirthar (Table 1-3), for example the rock sequence which is located between Mauddud and Jeribe reflectors represents the following formations Mauddud, Tanuma, Sadi, Hartha, Jaddala, Palani, Tarjil, Azkand, Anah, Euphrates, and Jeribe Formations, but it is difficult to the differentiate these formations as reflectors, because they have relatively similar lithology and densities, and some of them are too thin to produce strong distinctive reflectance.

Basin stratigraphy develops before; during and after extensional fault movement may be described as pre-, syn- and post-rift sequence (Williams et al., 1989). Formations from Shuiaba to Jeribe in this seismic reflection profile are syn-rift as indicate by the present of faulting and thickening. Sequence with uniform thickness inside and outside of the some extensional structures below the Shuiaba Formation represents pre-rift. No thickening and faulting in Fatha Formation therefore that is post-rift.

The seismic section shows high fault density. There is a main normal fault in the southwest part of section between shot points 1300 and 1345. It is a straight fault that crosses all sequence of Mesozoic and Paleozoic. The main fault has apparent dip angle of 76° toward northeast. It involves high angle fault flower. It contains several steeply dipping normal faults that divergent upward. The fault flower composes two sets of minor faults dipping toward each other. The minor faults (synthetic) are dipping in a same direction of main fault which have apparent dip of 60°, whereas the minor faults (antithetic) dipping opposite of the main fault which have apparent dip of 55°.

Flower structures can be occurred within seismic section in either strike slip displacement or as dip-slip inversion (McClay, 2000). 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 dip steeply to upward spreading fault arrays that show either dominantly extensional displacements - negative flower structure or dominantly high angle reverse displacements – positive flower structure. It is common within a single strike slip fault system to find extensional and reverse displacement on the minor fault arrays (Figure 3-4) (McClay, 2000).The correlation between the fault system and the positive and negative flowers in (Figure 3-4) illustrates that the fault system develops negative flower structure, uplifting in lower levels of the fault along the major fault and dominantly extensional displacement in the upper levels of the fault system.

The width of the fault system measures on Alan reflector is 8 km (shot point spacing is 200 m). It has distinct displacement especially on Shuaiba and Mauddud reflectors that forms a simple rollover anticline in the upper part of the flower. The maximum displacement of this fault on Mauddud reflector is 79 m (comes at shot point 1317 from one way time 0.025 sec multiply average velocity 3150 m/s).

Thickening takes place from the onset of the Cretaceous sequence and lasted to the Middle Miocene. It reveals the activities of the fault system during deposition of the formations. The geometry and kinematic are similar in this fault system and Abu-Jir fault system in both seismic sections AR-50 south of Hit city and AR-18 west of Al-Razzazah Lake (Figures 3-5, 3-6 and 3-7).

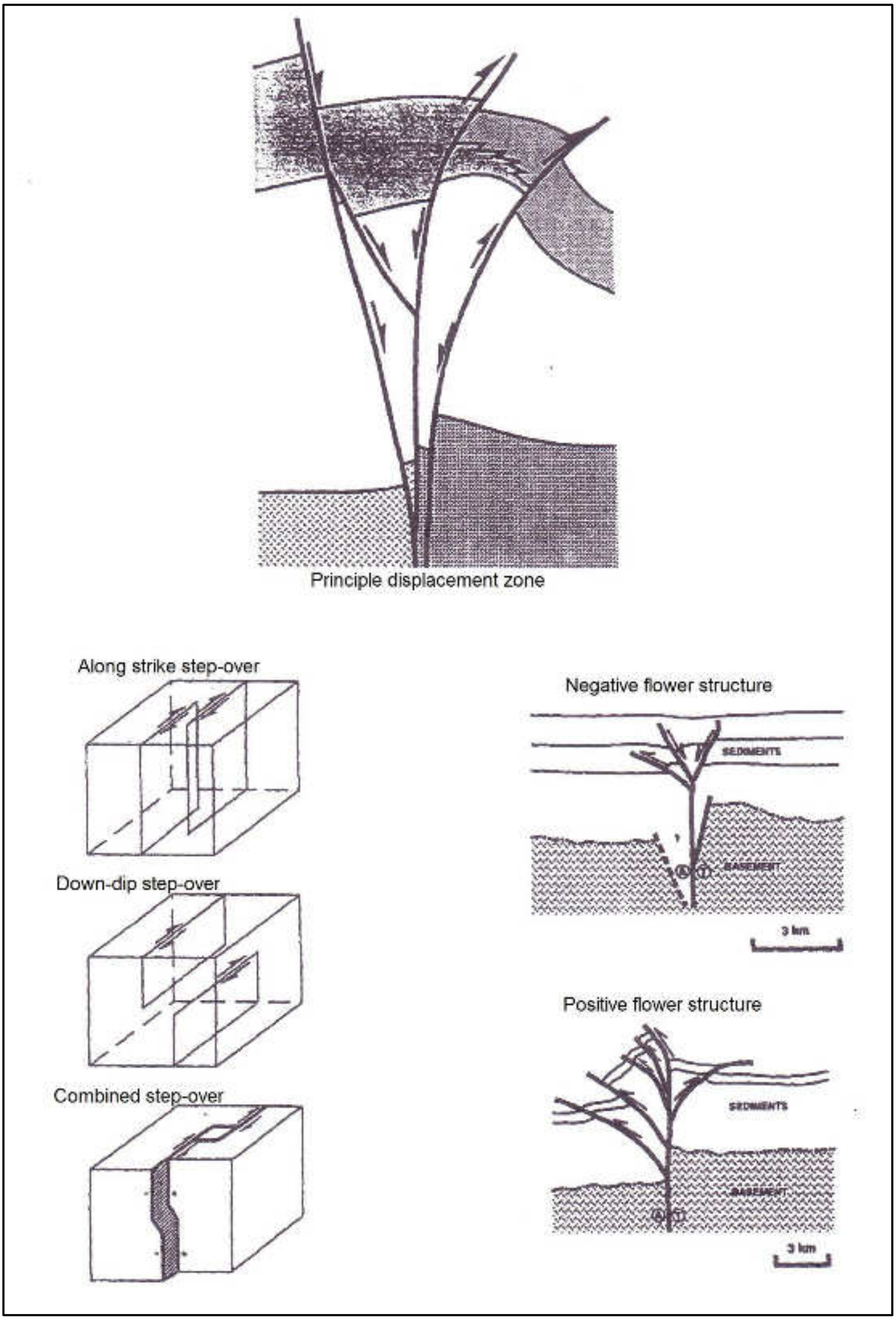

Figure (3-4) Flower structure characteristic of strike-slip fault system. (After McClay, 2000)

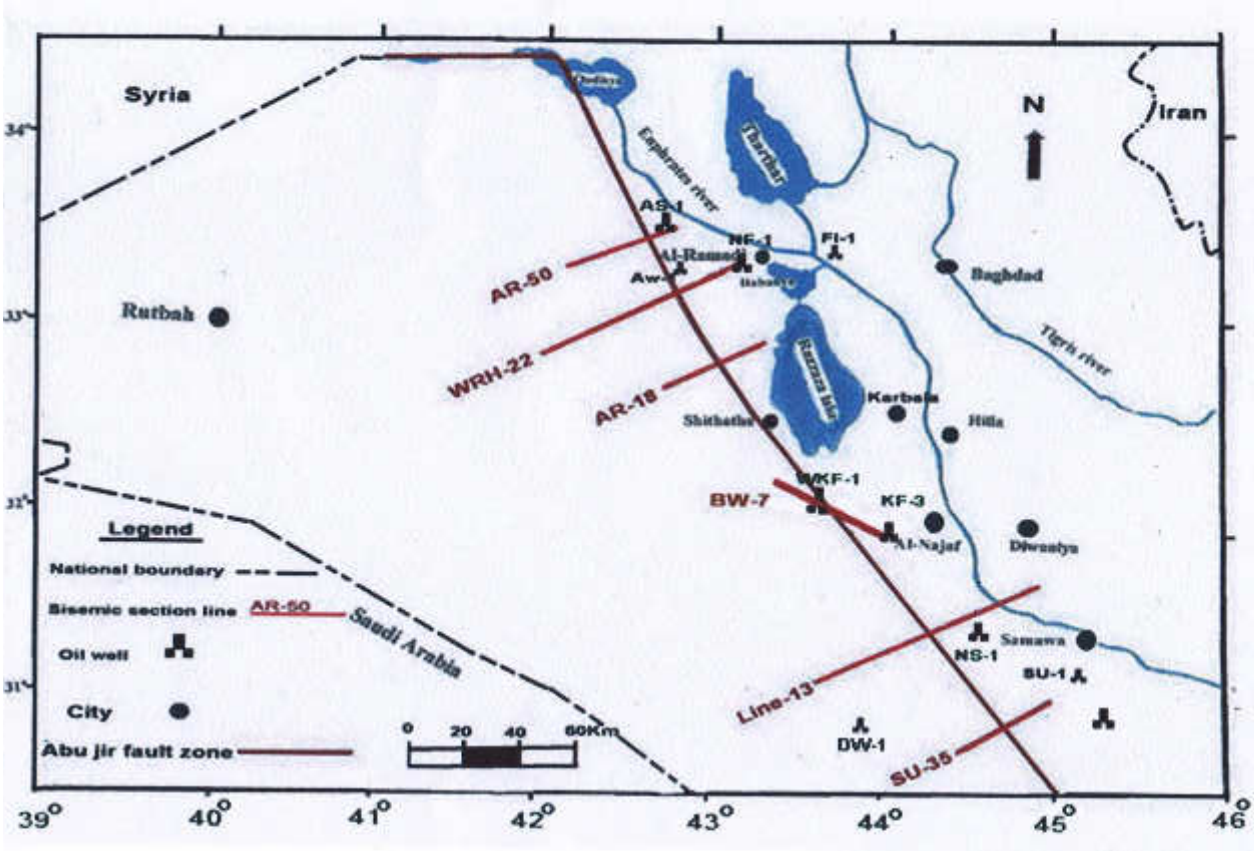

Figure (3-5) Location map of seismic section lines AR-50 and AR-18 (After Als'adi, 2010)

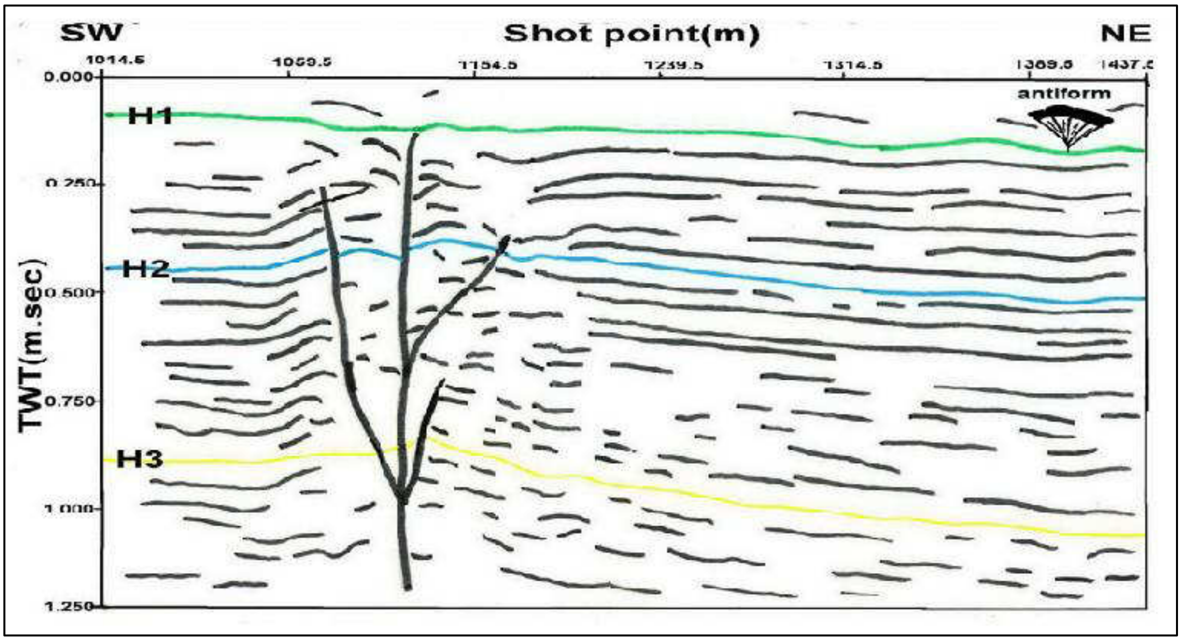

Figure (3-6) Line drawing of seismic section line AR-50 (After Alsa'di, 2010)

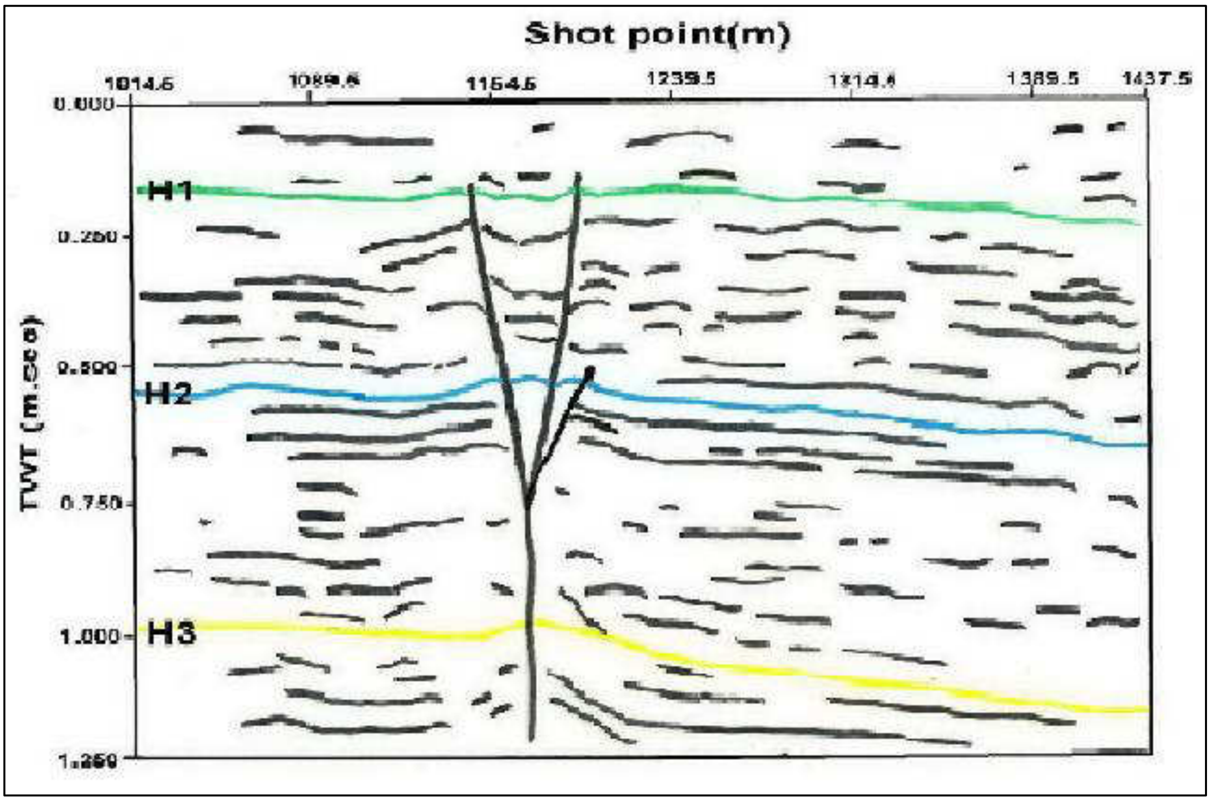

Figure (3-7) Line drawing of seismic section line AR-18 (After Als'adi, 2010)

In the middle of the seismic section, to the right of the first fault system beneath the shot point 1490, there is another fault system. It consists of main normal fault has apparent dip of 70° to the northeast that associates with two antithetic minor faults have apparent dip of 77°. The width of this fault system on Alan reflector is 2 km. The architecture, kinematic, and dynamic of this fault are similar to them in first fault system. They have same tectonic history.

Three normal faults are existed in the middle of the seismic section between shot point 1517 and 1554. They are straight faults that have apparent dip of 60°. They penetrate basement rock and across all sequence of Paleozoic and Mesozoic upward to the Cenozoic reach to Jeribe Formation (Middle Miocene). They form simple domino structure, and have simple rollover anticlines in the upper part of the faults within Shuaiba and Mauddud Reflectors.

Simple graben and horst are presented in the northeast half of the seismic section between shot point 1584 and 1665. Both margins of the graben are in opposite dip direction and divergent upward. Apparent dip of the southwest and northeast margins are 78° and 72° respectively, therefore that is approximate symmetrical graben. It is cross all sequence of the section includes Jeribe reflector. The width of it on Jeribe Reflector is 12 km. The northeast margin of the graben is also representing the southwest margin of the neighboring horst. Both margins of the horst are in opposite dip direction and convergent upward. The apparent dip of the northeast margin of the horst is 72°.

There are two normal faults in the northeast end of the section. One of them crosses lower part of Mesozoic and all Paleozoic sequence and passes through the basement. The another has apparent dip of 74° and associate with minor fault (synthetic). Both the normal fault and its minor fault cross Jeribe Formation and reach to the Fatha Formation.

Fault propagation folds are showed in this section, that are developed on Jeribe and Al-Fatha reflectors. They are gentle and shallow structures because they are in the first stage of the development that overlying steeply dipping normal faults. These folds in this seismic profile are easier to identify because they are unaffected by the distortion beneath faults, and their syncline have large radii of curvature. (Ian et al., 2000) mentioned that the growth folds are related to steeply dipping normal faults that propagated upward, resulting in broad, upward-widening fold overlying strata (Figure 3-8).

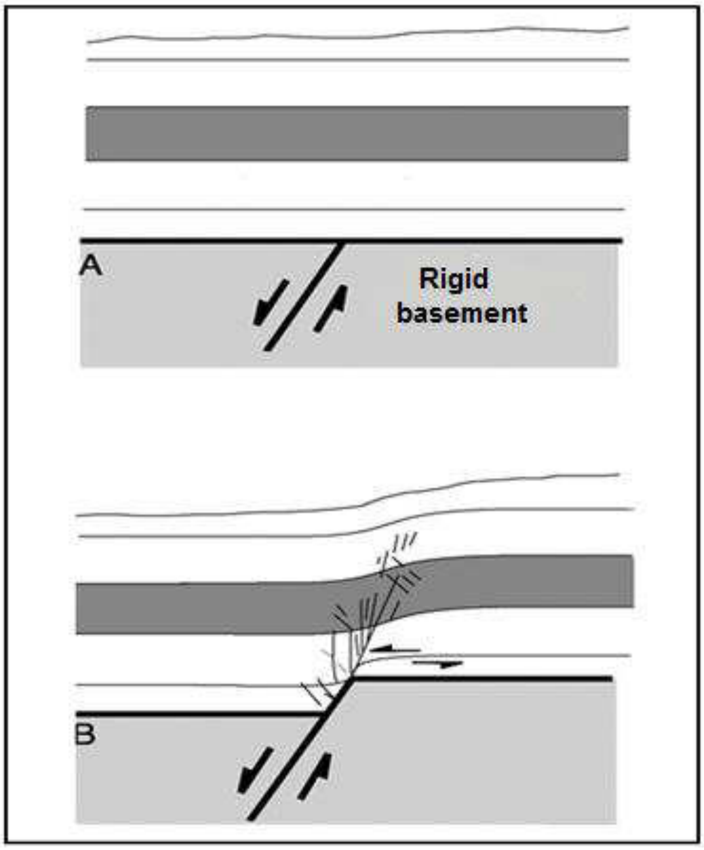

Figure (3-8) Fault propagation folds in the first stage of development that form in upper part of sediment cover due to steeply dipping normal fault associates with the basement. (After Ian et al, 2000).

3-2-2 Seismic-Time Section WTM-28

The name of this seismic-reflection section is derived from west Tikrit-Mak'hul. It is located near the north rim of Al-Thirthar Lake Figure (3-2). Several reflectors are recognized by use the synthetic seismogram of well Mileh Thirthar. All reflectors are good quality and continuity except the younger one which is good quality in the northeast and fair quality in the southwest part because it becomes near to the earth surface where many factors are affected by the signal quality such as weathering. The reflectors represent top of the following formations from the younger to older Figure (3-9).

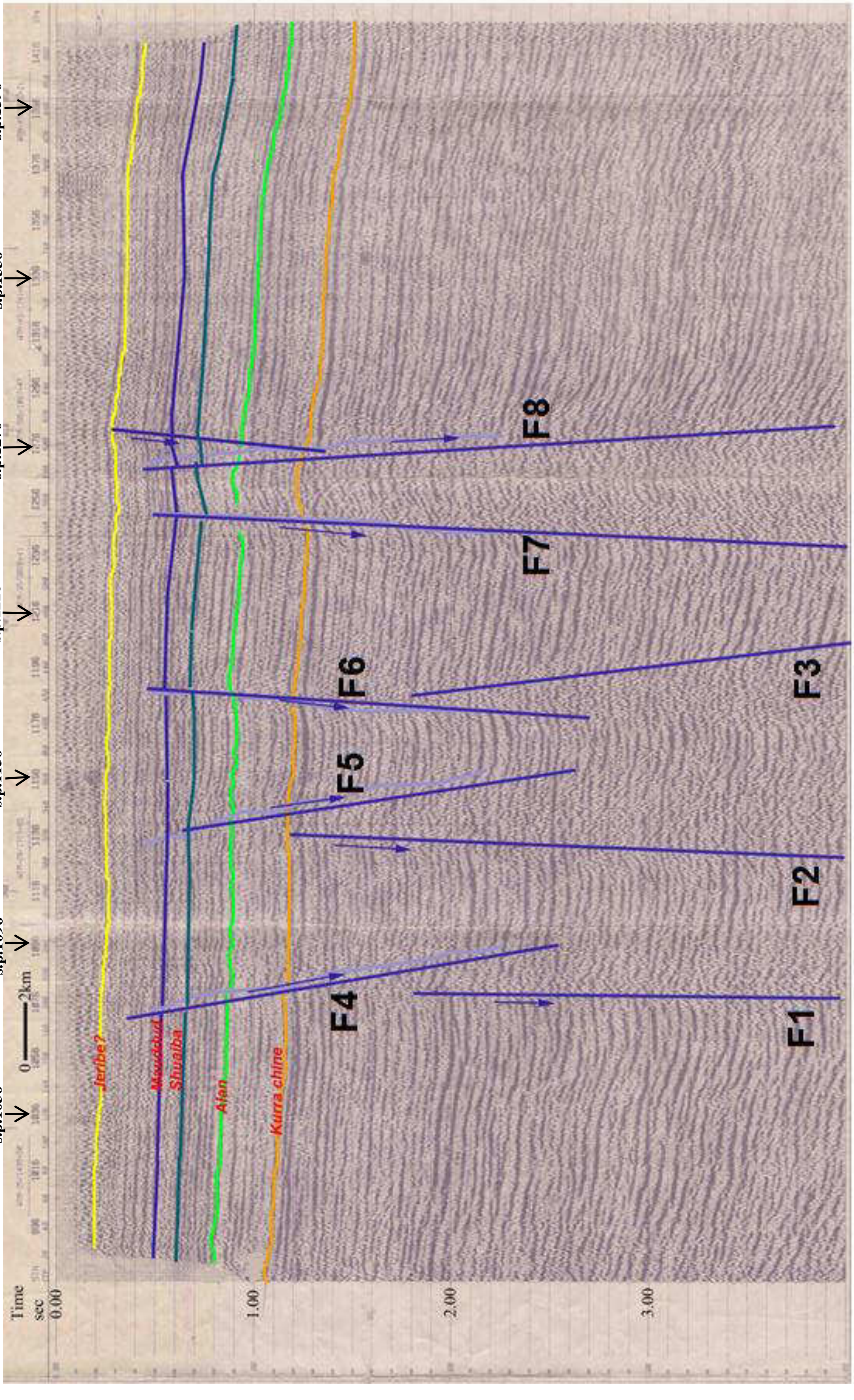

Figure (3-9) Seismic-Time Section WTM-28 (After OEC)

• Jeribe Formation (Middle Miocene)

• Mauddud Formation (Albian)

• Shuaiba Formation (Aptian)

• Alan Formation (Late Liassic)

• Kurra chine Formation (Late Triassic)

Layering and reflectors are dipping toward east and northeast due to subsidence of Mesopotamia Foredeep.

The seismic section shows some of the normal faults (F_1, F_2 and F_3) developed in Paleozoic sequence and terminated in Early Mesozoic. Other normal faults (F_4, F_5 and F_6) exist within Mesozoic sequence. The setup of these faults reflects that the area suffers of two phases of extensions. The first phase developed the normal faults (F_1, F_2 and F_3) during Early Mesozoic. The normal faults (F_4, F_5 and F_6) are formed by second phase of extension during Late Mesozoic. The normal faults F_7 and F_8 are developed in the first phase and reactivated in the second phase of extension.

There is normal fault (F_4) subsist in the southwest part of the seismic-reflection profile. The profile shows approximate symmetrical graben in the middle, between shot point 1136 and 1186. Both margins of the graben (F_5 and $F_{6)}$ are approximately straight line. Central part of the graben develops by progressive slippage on both margins of a conjugate fault set. It has slight displacement and subsidence. The width upon Mauddud Reflector is 5 km approximately.

Horst structure exists to the right of the central graben between shot point 1250 and 1266. Inversion in dip direction of the strata is made inside the horst.

Minor (secondary) normal fault is found in the right shoulder of the horst and associated with it. Sliding along the horst faults would be compensated by additional down bending (Withjack and Pollock 1984). Gentle fold (fault propagation fold) is above the horst and its secondary normal fault.

A slight thickening (syn-rift) is observed especially in rollover anticlines in upper part of the horst structure within Jeribe formation. The slight thickening is an indication of fault movement during post deposition of Mauddud Formation. Displacement inside the horst on Shuiaba reflector is measured. The value of displacement in one way time seismic section is 0.015 sec, approximately 49 m if the average velocity on Shuaiba Reflector in WTM- 26 is 3250 m/s.

The normal faults of the section are planar. They have steep dips in opposite direction, some of them have northeast dip direction and others dipping toward southwest. The apparent dip angles of the faults range between 60°-70°. Generally, the normal faults dipping in the direction opposite to the strata appear to have a greater dip than identical normal faults dipping in the same direction as the strata. Their apparent dips are 70° and 60° respectively.

No listric or flatten is developed in the lower part of the faults may be due to the lithology of the Paleozoic sequence (competent rocks of limestone and sandstone) Faulting in competent rocks runs planar and high angle whereas it runs in low angle within incompetent layers (Boyer and Elliott, 1982). Incompetent evaporate rocks are rare in Paleozoic succession, but shale is presented in some of the succession such as Akkas, and Ora Formations. Thicknesses of these formations are thin compared with the other formations. The shale encounters to high temperature and lithostatic pressure that increasing the density of the shale by either metamorphism or compressibility, which make the shale behave as competent rocks.

The normal faults intersect all sequence of Paleozoic and Mesozoic upward to Neogene or to the top of Jeribe Formation. Normal faults in extensional zones are curved toward a mid-crustal master fault or detachment within a zone of brittle-ductile transition (Gibbs, 2002) or die out with the sedimentary cover or basement (Ramsy and Huber, 1987).

The configuration of the fault system in the seismic section is similar that in the northeast half of the seismic sectionWTM-26, but the deformation in the seismic section WTM-26 is greater than in the seismic section WTM-28. The extensional structures in the seismic section WTM-26 reach to the Jeribe Reflector. The normal fault and its minor fault in the northeast end of the section reach to the Fatha Reflector whereas the structural extensional in the WTM-28 do not reach to the Jeribe Reflector except the minor fault.

3-2-3 Seismic-Time Section LT-30

The name of this seismic-reflection section is Lake Thirthar-30. It passes through the middle of the lake Figure (3-2). Many reflectors are picked by using synthetic seismograms of Mileh Thirthar oil well. They are good to fair quality except the younger one is bad quality. These reflectors represent top of formations, sometime within formation. They are from the younger to older (Figure 3-10).

• Hartha Formation (Late Campanian-Early Maastrichtian)

• Mauddud Formation (Albian)

• Shu'aiba Formation (Aptian)

• Gotnia Formation (Callovian to Early Tithonian)

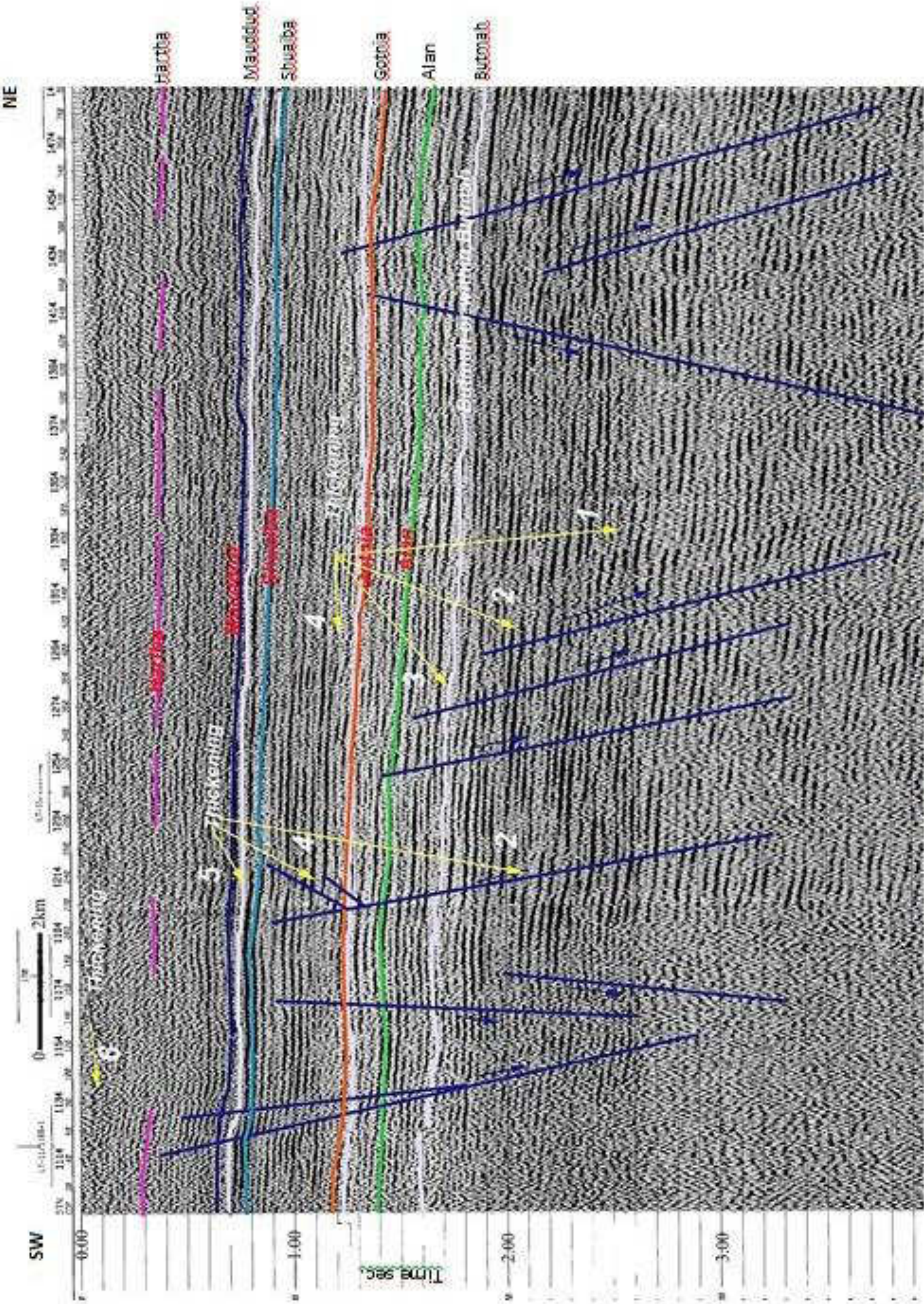

Figure (3-10) Seismic-Time Section LT-30 (After OEC)

• Alan Formation (Late Liassic)

• Butmah Formation (Liassic)

All reflectors dip slightly toward northeast. The geometry of reflectors shows many subsurface high angle normal faults. Most of these normal faults are dipping toward northeast and the other are dipping southwest. There are some extensional structures such as symmetrical and asymmetrical grabens and horsts. The configuration of the extensional structures; normal faults, graben and horst from southwest to northeast respectively in this seismic section is similar to that in the seismic WTM-26.

Some normal faults, especially the fault in the southwest of the section, influence the whole sequence up to the Hartha Formation. It associates with secondary fault that crosses all reflectors to the Shuiaba. Both the normal fault and its secondary fault effect on the earth surface where the thickening no. 6 is developed.

Thickening cycles suggest normal movement phases on the faults during sediment time. They support the activities of normal faults in this section during Mesozoic Era. Thickenings are distributed by following locations. Thickening in locations 1 may took place during Early Triassic, whereas thickening in location 2 developed during Late Triassic where Kurra chine Formation is deposited. Thickening in location 3 took place within Butmah Formation during Early Jurassic. Thickening in location 4 occurred during Early Cretaceous where the deposition of Ratawi / Yamama Formations whereas in location 5 took place during the Albian deposition of Maddud Formation. Finally the thickening in location 6 occurred during the Miocene deposition of Jeribe and Al-Fat'ha Formations and it may be continuous till now.

Presence of many movement phases in this section, under the Thirthar Lake, from Early Mesozoic to Neogene may reflect active tectonic history of the normal faults. The extensional faults play important role in the origin of Al-Thirthar depression.

Finally, data about the velocity in this seismic section is absent, however depend on average velocity of the Shuaiba reflector in seismic section WTM-26 at depth 800 ms is 3250 m/s. The one way time of the normal faults measures upon the Shuaiba reflector is 0.013 sec. The displacement of the fault is 42 m. Marouf (1999) mentioned that fault displacement below or within the seismic resolution (40~50m) are observed in Al-Thirthar and Mileh-Thirthar structures.

3-2-4 Seismic-Time Section LH-18

The name of this seismic-reflection section is Lake Habbaniya. It passes through Al-Habbaniya Lake Figure (3-2). Six reflectors are picked by using synthetic seismogram of the nearest oil well. Some of the reflectors are good quality and the others are fair. These reflectors represent top or on events within the following formations Figure (3-11).

- Dammam Formation (Middle – Late Eocene)
- Hartha Formation (Late Campanian – Earle Maastrichtian)
- Mauddud Formation (Albian)
- Shu'aiba Formation (Aptian)
- Gotnia Formation (Callovian to Early Tithonian)
- Alan Formation (Late Liassic)

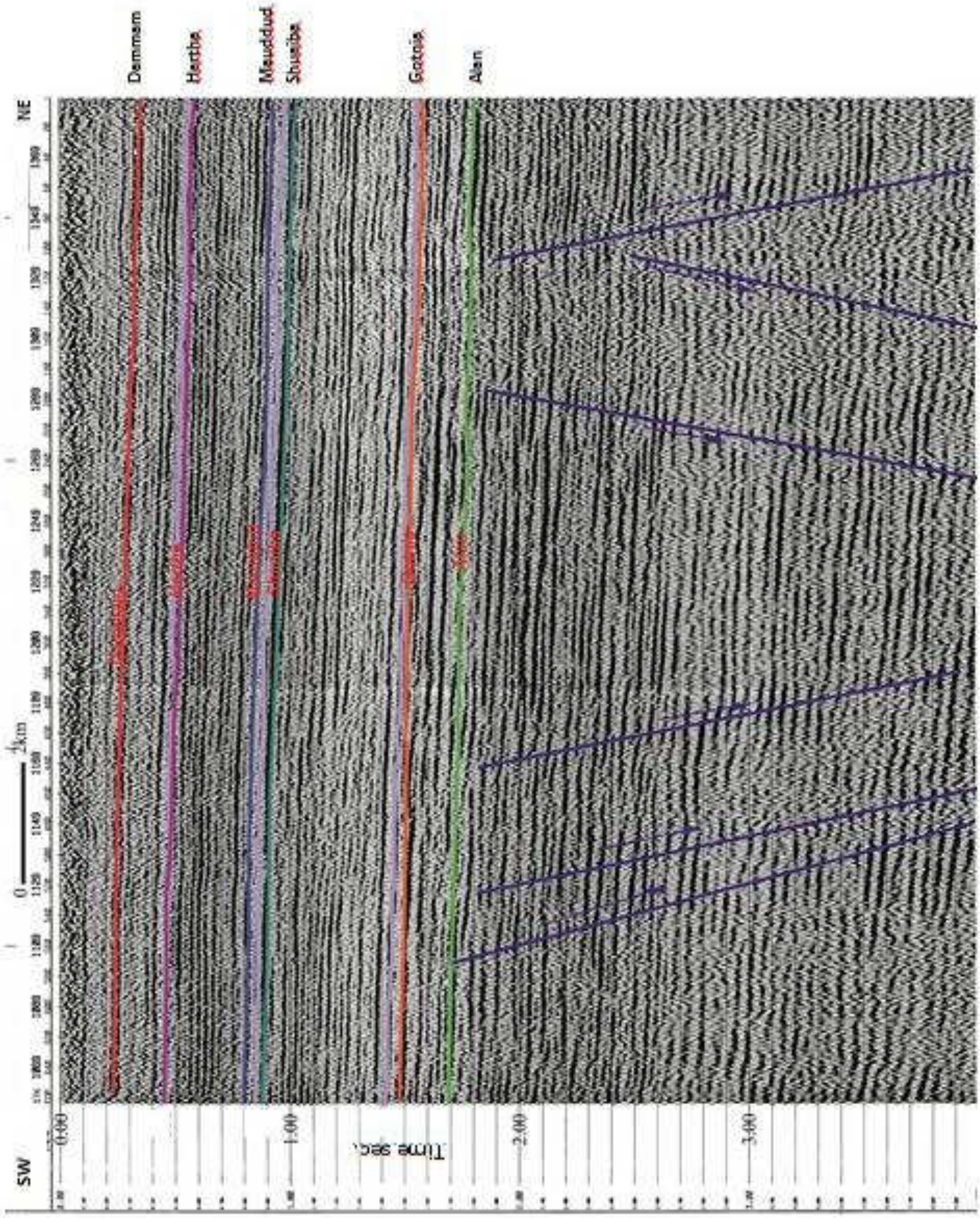

Figure (3-11) Seismic-Time Section LH-18 (After OEC)

There are two sets of faults are shown in this seismic profile. One of them dips toward northeast and another toward southwest. All of these normal faults influence the pre-Alan sequence.

As in the previous seismic profiles there are some extensional structures e.g. two normal faults in the southwest part of the section, the first beneath shot point 1105 and another beneath shot point 1125. Symmetrical graben in the middle between shot point 1169 and 1289. Its width under Alan Reflector is 6 km. Horst in the northeast part between shot point 1289 and 1329. It has width of 2 km measures under Alan Reflector. All of these extensional structures have slight displacement; therefore the basin appears normal without disturbed by normal faults. The configuration of these extensional structures is exact of that in seismic section LT-30.

Normal faults, thickening or other structural features are absent in the sequence of middle and upper Mesozoic, and Cenozoic. This absence reflects no tectonic effects during or after the deposition of upper part of the basin beneath AL-Habbaniya depression.

3-2-5 Seismic-Time Section RH-19

The name of this seismic-section section is abbreviation of Razzazah-Habbaniya no. 19. It locates between Habbaniya and Razzazah Lakes Figure (3-2). Six reflectors were picked which characterized by good to fair quality and disturbed by faulting that represent top of the following formations (Figure 3-12)

• Dammam Formation (Middle – Late Eocene)

• Hartha Formation (Late Campanian – Earle Maastrichtian)

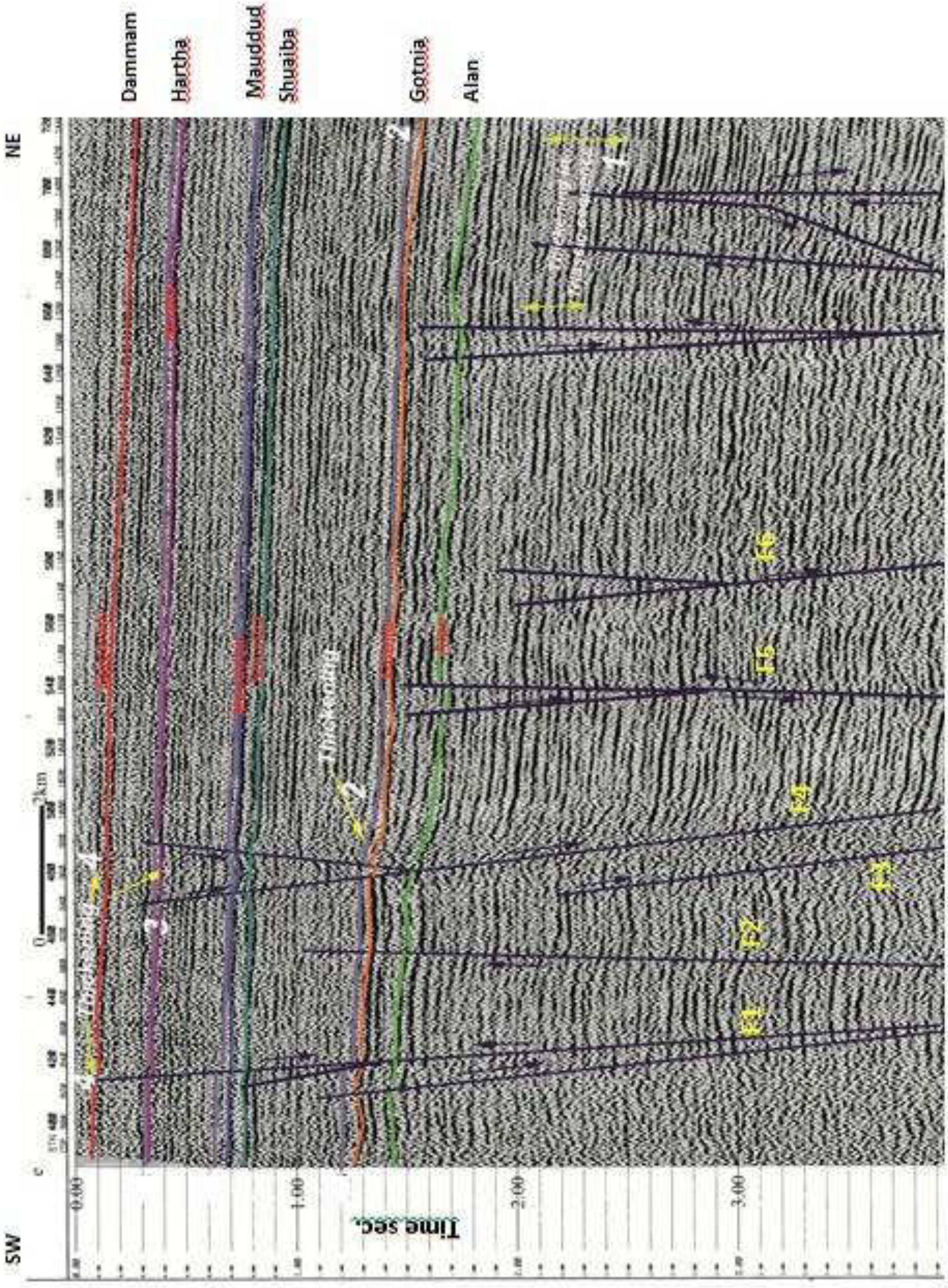

Figure (3-12) Seismic-Time Section RH-19 (After OEC)

• Mauddud Formation (Albian)

• Shu'aiba Formation (Aptian)

• Gotnia Formation (Callovian to Early Tithonian)

• Alan Formation (Late Liassic)

All reflectors are dipping toward northeast, toward Mesopotamia Foredeep. Several faults disturbed the continuity of the reflectors. The main fault (F1) in the southwest part of the section is presented under shot point 413. It has two minor faults (synthetic). It displaces all the sequence from basement and Paleozoic rocks up to the Dammam Formation (Middle-Late Eocene) reach to the earth surface. The fault behaves as normal fault in the upper part where cuts the Shuaiba Reflector upward to Dammam. The displacement on the Dammam reflector is 0.02 sec. The sequence below Alan Formation is uplifted locally. The fault (F1) with (F2) develops graben structure above Alan Formation. The association of local antiform and normal displacement is very good indication on strike slip movement.

Two normal faults (F3 and F4) are showed to the right of the graben at shot point 468. The fault (F3) influences the sequence from the basement to the Triassic sequence. The second normal fault (F4) cuts all sequence upward to the Hartha Formation. It has antithetic minor fault. The fault and its minor fault develop small graben within the Mesozoic sequence. Thickening in location 3 is inside the graben, layer thickness inside the graben is greater than the outside, that good indicator for extension in upper part of the basin.

Thickening in location 4, above Dammam Formation, may be within Miocene sequence reveals reactivation the faults during Mesozoic until Neogene. Both faults F2 and F4 construct horst structure.

Two normal faults F5 and F6 are located in the middle seismic reflection profile. Each one has antithetic minor fault. Both faults F4 and F5 develop asymmetrical graben structure. There is a horst structure constructed by faults F5 and F6. Presence of interlink simple grabens and horsts reflect that the study area is undergone to extensional processes.

Several faults are occurred in the northeast part of the section. Some of them are normal faults and the others underwent reverse movements. Thickening in Triassic sequence, location no. 1 reflects activation of these faults during Triassic. Thickening above Gotnia Formation, location no. 2, indicates the reactivation of faults during Early Cretaceous.

Uplifting in some sequences of the extensional structures reveals strike slip movements that take place along pre-existing extensional structures. Some of these faults, especially the approximate vertical ones, suffer from uplifting due to right lateral strike slip faults and develop negative flower. (Lowell, 1985) observed that change of sense of slip along the same fault parallel to both strike and dip of faults and formation of either negative or positive fault flowers, or both, are all indications of wrench displacement along a major high angle strike slip fault.

The normal fault FI may reach to the earth surface where the formations of Miocene age are exposed. Extension during Miocene is presented in response to the tilt of the Mesopotamia sequence.

The tectonic history of the faults likes that in Abu-Jir Fault System. They have similar behaviors. The sedimentary basin is suffered from extension during Mesozoic and Neogene until Miocene time. Strike slip movements are took place during Miocene. The fault beneath the depressions and the Abu-Jir Fault

System are tectonically associated. They are convergent south of Al-Razzazah Depression.

Faulting in this seismic reflection profile is done by extension during Mesozoic and Cenozoic. The extension took place in pulses or phases. Four phases of extension can be distinguished by thickening. Thickness variation in sequence is a good indicator of tectonic subsidence and reflects fault activation during that time.

Indications for extension in Paleozoic are absent. The first phase took place during Triassic may be from Early Permian whereas the second phase was during Late Jurassic-Early Cretaceous when Gotnia Formation is deposited. The third phase of extension was during Maastrichtian when Hartha Formation deposited and the last phase acted during Late Eocene when Dammam Formation was deposited.

The study area suffers from extensions may be along extensional detachment associates with the rifting phases of the northeast margin of the Arabian Plate, but without contracted phase of Alpine orogeny. Simple negative flowers reflect dextral due to progressive of the sea-floor spreading in the Red Sea and Gulf of Aden during late Miocene time, accompanied by further left lateral strike slip fault along the Dead Sea fault.

3-2-6 Seismic-Time Section LR-22

The name of this seismic-reflection section is derived from Lake Razzazah. It passes through the middle of Al-Razzazah Lake Figure (3-2). Abu-Jir fault system is located to the west of this seismic section. Six reflectors are picked by using synthetic seismogram of nearest oil well. They are good to fair quality except Hartha reflector which has bad quality in the southwest half. They represent top or within the following formations Figure (3-13).

• Hartha Formation (Late Campanian – Earle Maastrichtian)

• Mauddud Formation (Albian)

• Shu'aiba Formation (Aptian)

• Gotnia Formation (Callovian to Early Tithonian)

• Alan Formation (Late Liassic)

• Kurra Chine Formation (Late Triassic)

The reflectors are parallel to sub parallel to each other. They dip toward northeast. Structural, six normal faults (F1 – F6) present in the southwest half of the section. All these faults dip toward northeast. They penetrate the basement and cross all Paleozoic sequence and part of Mesozoic sequence. Alan and Gotnia reflectors are displaced by normal fault (F3).

Symmetrical graben exists in the northeast half of the section between shot points 1440 and 1487. The width of the graben beneath Shuaiba Reflector is 4.7 km. The graben cuts Alan and Gotnia reflectors and reach to shuiaba Formation (Aptian). Slight subsidence takes place inside the graben. The southwest and northeast margins of the graben (F7 and F8) are equivalent to the normal faults F1 and F2 in seismic reflection profile RH-19 respectively. Symmetrical horst

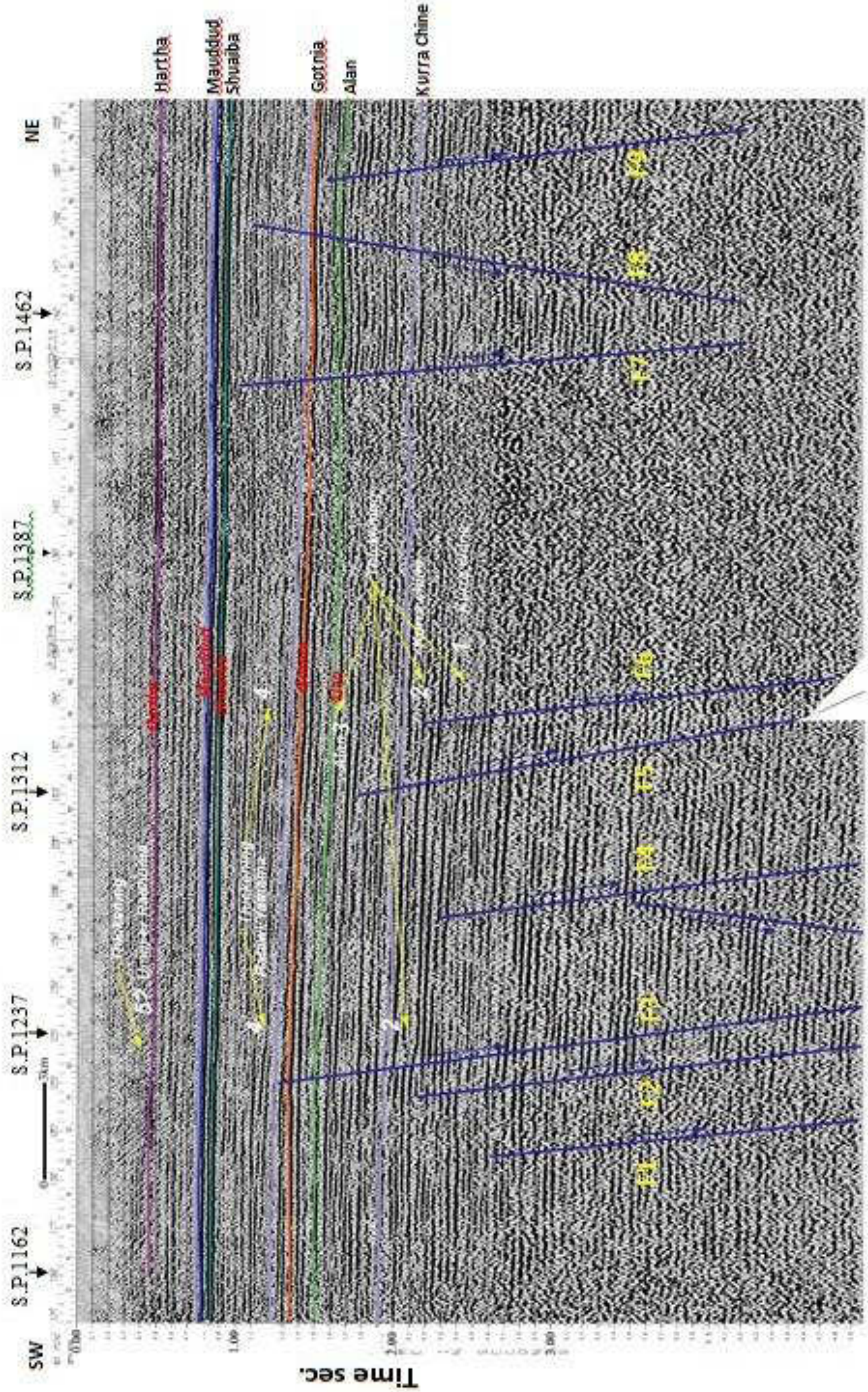

Figure (3-13) Seismic-Time Section LR-22 (After OEC) exists to the northeast of graben. Slight dipping upward of the sequence is inside the horst. The northeast margin of the horst (F9) is equivalent the normal fault F4 in seismic reflection profile RH-19.

Thickening in locations 1, 2, 3 and 4 associated with activities of the normal faults during Mesozoic. Thickening in locations 1 and 2 developed during Late Triassic where the Kurra Chine Formation was deposited whereas thickening in location 3 formed in Alan Formation (Late Liassic). Thickening in location 4 took place during late Berriasian to Early Valanginian age when Yammama / Ratawi formations were deposited. Uncertain thickening in Emm er Rdhuma Formation (Middle-Late Paleocene) may result when the seismic section becomes bad quality near the earth surface due to weathering.

3-3 Discussion

The configuration of the extensional structural features, normal faults, graben and horst, are appeared in all seismic reflector profiles. They are in order from southwest to northeast respectively, also they have same geometrical characteristics, and therefore the extensional structures (normal faults) are regional features. They trend north-south and arcuate westward along the axis of three depression. It is important to mention that fourth depression (Dibdibba depression) is located south of Razzazah Lake along same axis of the lakes. The author believes that the locations of the depressions are controlled by underlying normal faults.

The graben structure is also present in two other sections that are located south of Razzazah Lake. The first section is BW-7 (Figure 3-14) (Alsa'di 2010) and the second one is line-13 (Figure 3-15) (Al-Ethawi 2002) see also(Figure 3-6). Graben in two later sections represents Abu-Jir fault system. Extensible and

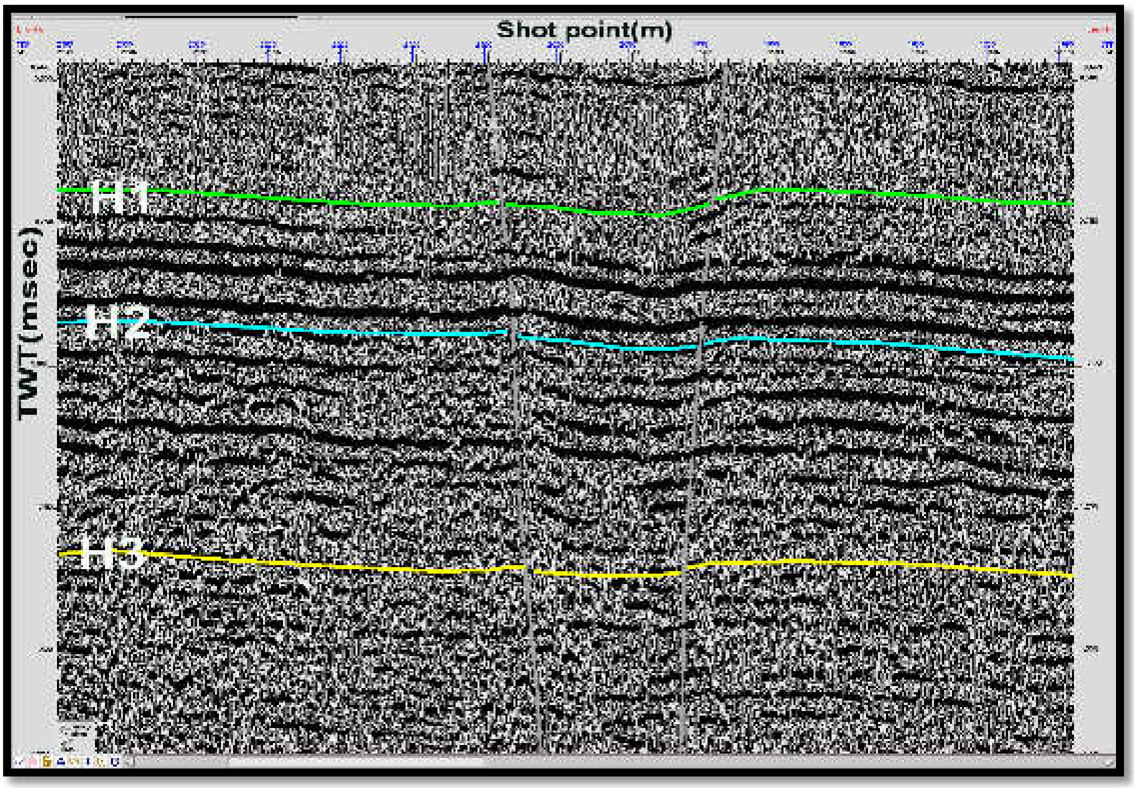

Figure (3-14): The seismic section line BW-7 (After Alsa'di, 2010).

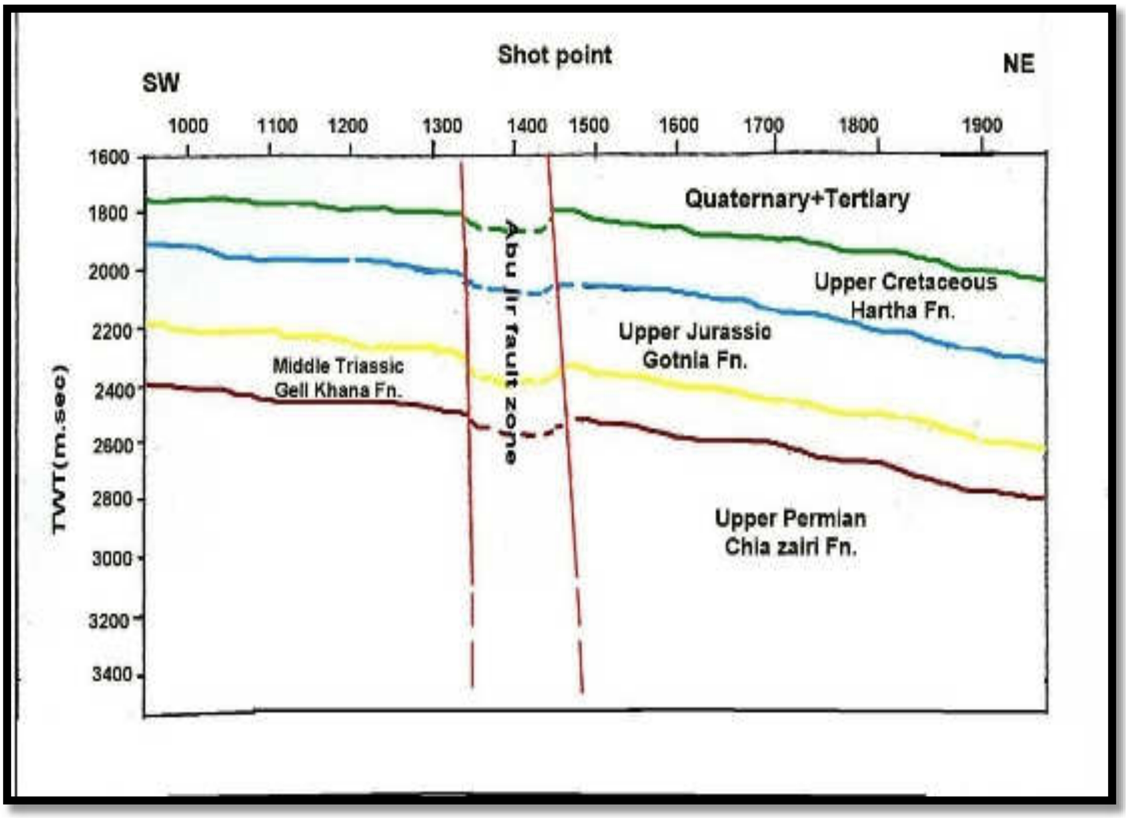

Figure (3-15) Two way time seismic section line-13 (Al-Ethawi, 2002) join of the extensional structure with Abu-Jir Fault System reveal the association between them. Continuous activities on the Abu-Jir fault system affect hugely on the activities of the extensional structures. Thickenings exist in many levels are good indications for the relation between them and give a good interpretation for continuous activities of the extensional structures especially during Mesozoic and Cenozoic. The author believes that the later phases of the tensions come not only from the movement of the basement blocks but also from activities of the uppermost asthenosphere especially that the Abu-Jir Fault System crosses the whole lithosphere. Gas and sulfurous water are discharged by the Abu-Jir fault system in Hit vicinity; heavy oil and sulfurous water in the Abu-Jir Spring, and flow out of the gas in other places are good indication that the Abu-Jir Fault System may cross all lithosphere and affected by asthenosphere activities.

3-4 The Formation of Extensional Structures

The seismic-reflection profiles show many extensional structures. They are normal faults, symmetrical and asymmetrical grabens and horsts. Secondary structures associate with extensional structures such as minor normal faults, rollover anticlines and forced folds are developed in study area. All these types of extensional structures and their secondary structures are common in extensional zone (Withjack and Pollock, 1984, and Gibbs, 2002). No previous studies mentioned the extensional structures, therefore “The Lake Fault System“ is named by this study. The Lake Fault System is developed by the extension of northeast passive continental margin of the Arabian Plate during Mesozoic.

The study area suffered from several phases of extensions as a result of the rifting and opening of the New-Tethys and Southern New-Tethys during the

Mesozoic and Tertiary. Some faults of the Lake Fault System underwent from strike slip movement during Miocene and the others suffer from new phase of extension due to tilt of the Mesopotamia sequence. The tilt generates extension within axis of the flexure.

The seismic section show that the dipping is directed forward the northeastward and the thickness increases in the same direction across the Lake Fault System, that delineate not only extend of the depressions but also the west boundary of the Mesopotamia basin.

Chapter Four

TECTONIC EVOLUTION AND GENESIS

4-1 Introduction

The Arabian Plate formed by accretion of terranes along active continental margin during Late Precambrian time. However, the subsequent evolution of the northern margin of the plate is in Paleozoic. Evidences for the opening of the Neo-Tethys during Late Permian-Early Triassic and a southern branch of the Neo-Tethys in Late Tithonian-Cenomanian time are extending along the northern margin of the Arabian Plate. Late Cretaceous-Tertiary subduction and overthrusting along the northeast margin of the Arabian Plate has fragments, and frequently destroyed and evidence of Permian-Early Cretaceous extensional tectonic events. The Arabian Plate is a part of the African Plate during much of the Phanerozoic Eon until the Oligocene Epoch. The Red Sea rifting begins in the Eocene, but the separation of Africa and Arabia takes place in Oligocene.

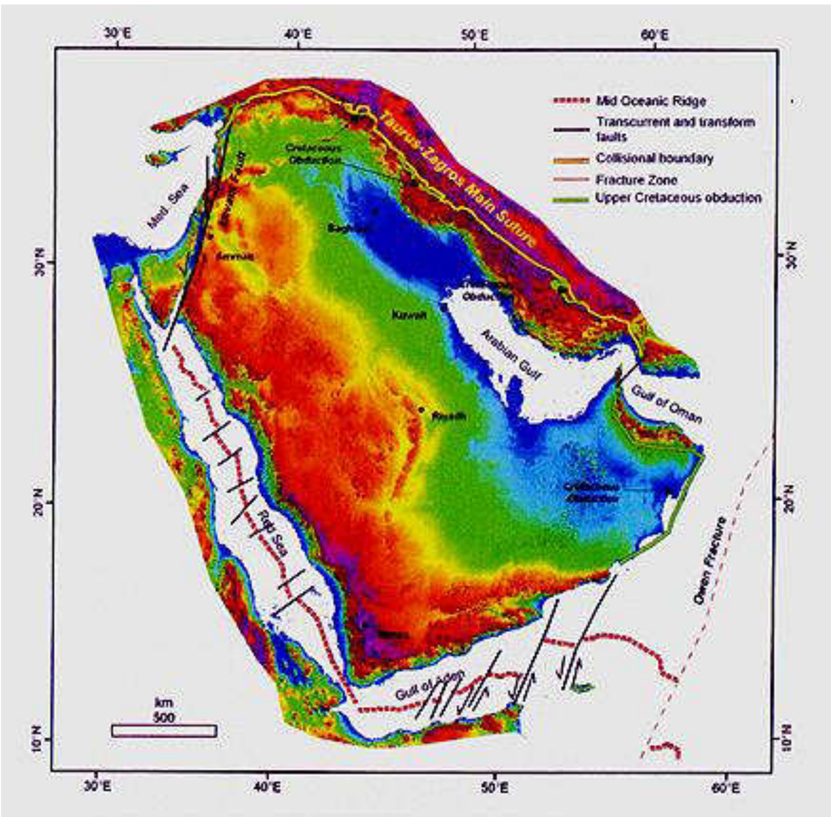

Figure (4-1) The Arabian plate boundaries at the present (Jassim and Goff, 2006)

Since then the Arabian plate is slowly moving northward toward Eurasian plate. The collision between the Arabian Plate and the Turkish and Iranian plates push up the Zagros mountain of Iran (Jassim and Goff, 2006) (Figure 4-1).

4-2 Structures

Knowledge of the deep structure of Iraq is based mainly on gravity-magnetic and thousand kilometers of seismic data. Recently published regional seismic line available is a southwest-northeast oriented profile through the study area, east of Abu-Jir Fault (Mohammed, 2006 in Aqrawi et al., 2010) (Figure 4-2).

The study area is almost a flat terrain in general. Significant surface structures are rare, but reflection-seismic profiles reveal many structural features including high angle faults and gentle folds. The faults are dominant and comprise of several extensional structures e.g. normal faults, grabens and horsts. Also negative flower of strike slip faults are developed. The movements of strike slip fault are showed in both seismic profile RH-19 between Al-Habbaniya and Al-Razzazah Lakes and north of Al-Thirthar depression within seismic section WTM-26.

The extensional structures of lakes are developed in all seismic sections of the study area. They are developed as normal faults, graben and horst from southwest to northeast respectively, therefore they are regional structures. They pass beneath the three depressions. The strike of the extensional structures is northwest – southeast. They meet Abu-Jir fault zone south of AL-Razzazah Lake. It's important to mention that the Abu-Jir Fault Zone behaves as extensional structure south of Al-Razzazah Lake where it meets the extensional structures of study area. Both Abu-Jir Fault Zone and extensional structures are associated tectonically.

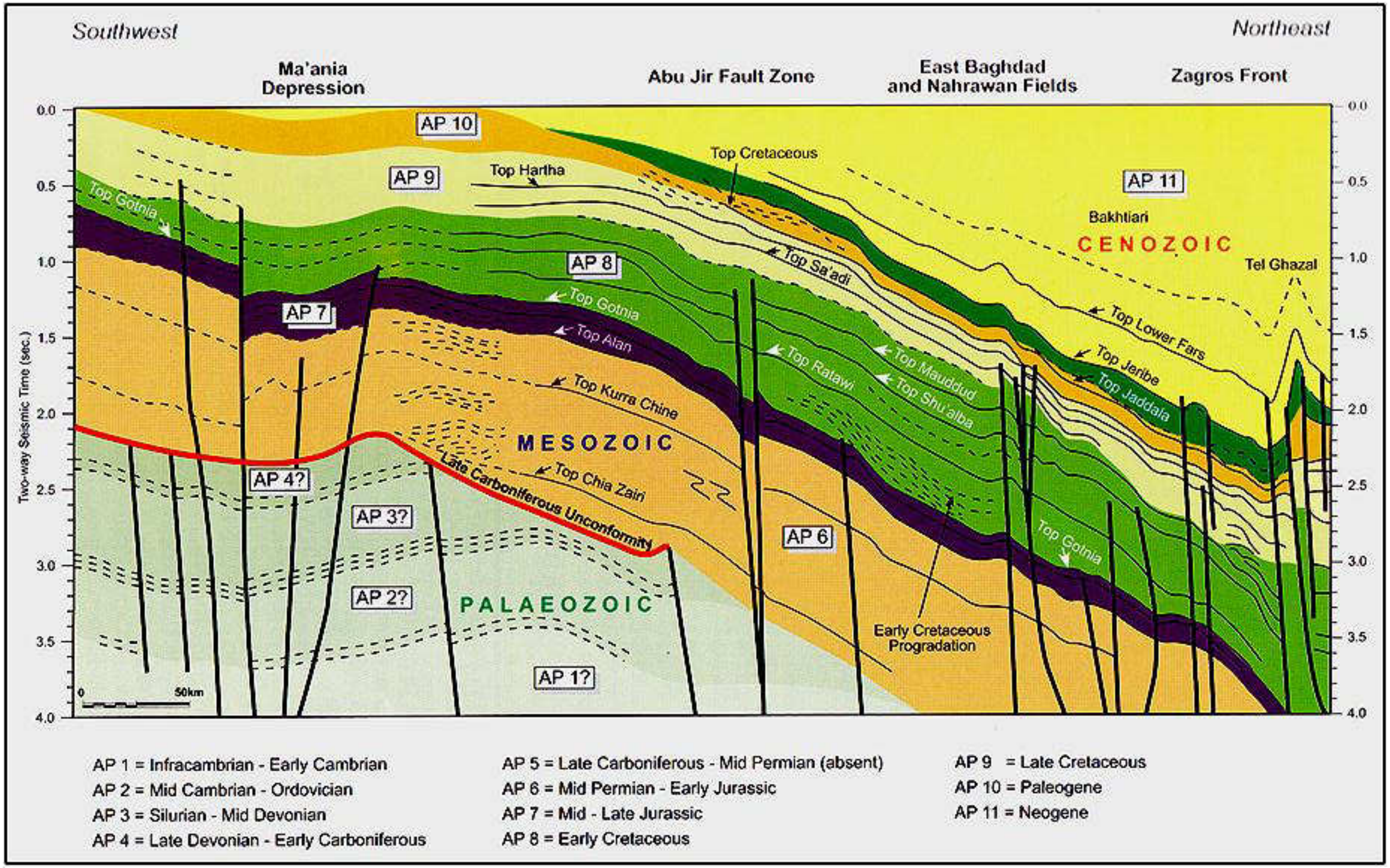

Figure (4-2) Two way time regional seismic derived from seismic reflection extended from extended from west to east of Iraq (After Mohammed, 2006 in Aqrawi et. al. 2010)

All folds shown in seismic sections are fault propagation folds, that are developed above the extensional structures. They are gentle folds.

4-3 Tectonic Setting

Generally, all tectonic zones of unstable shelf in Iraq territory are suffered from three types of stresses; extension coincide with rifting of northeast margin of Arabia, compression due to the collision between Arabian and Iranian Plates and strike-slip faults as a result of rotation of Arabia due to the opening of Red Sea and Gulf of Aden. The study area is undergone extension and strike slip faults slightly, as well as to another type of extension as a result of the tilt of the Mesopotamian sequence. The tilt makes extension in the upper levels of the sequence along the axis of flexure where the three lakes are presented (Figure 4-2).

4-3-1 Early Paleozoic-Late Paleozoic uplifting

During the Paleozoic, the Middle East behaved as a relatively stable and passive continental margin. The Paleozoic succession on the east and north part of the Arabian Plate consists of a relatively uniform section, with prevailing continental and epicontinental conditions reflecting epiorogeny uplifting. Evidences of Caledonian deformation are totally lacking, but the time at which deformation occurred elsewhere may be represented by times of sea-level changes. The effects of the Late Paleozoic Hercynian orogeny in the Middle East are reflected by uplift accompanied by erosion (Al-Sharhan and Nairn, 2003). The seismic data at this level in study area are not clear and can’t be used to interpret the Paleozoic tectonic history.

4-3-2 Late Triassic- Early Jurassic Extension

Extensional faulting through the sequence of Late Triassic–Early Jurassic is observed in some seismic reflection profiles of the study area. Extensional structures synchronize with simple thickening formed in these sections reflect the first phase of extension. Seismic reflection section LR-22 shows simple thickenings in Kurra Chine Formation (Late Triassic), these thickenings continue upward to Alan Formation (Early Jurassic) (Figure 3-10). Thickenings also in Late Triassic- Early Jurassic sequence are in the seismic-reflection profiles RH-19, LT-30 and WTM-26.

Thickening in Paleozoic sequence is absent; therefor it is representing pre-rift deposit. The age of the extensional structures is late Triassic-Early Jurassic.

4-3-3 Late Jurassic Extension

Thickening is presented through Gotnia Formation (Late Jurassic) in three seismic reflection profiles; RH-19, LT-30 and WTM-26. This thickening is synchronous with reactivation of extension during Late Jurassic time. Second phase of passive margin evolution in the study area is took place at that time.

4-3-4 Cretaceous- Miocene Extension

There is evidence, from some seismic reflection profiles, of thickness variations in the Early Cretaceous-Campanian succession. Theses thickenings which coincide with extensional structures are good indications to another phase of tectonic extension in that the study area suffered from it. Seismic reflection profile LR-22 contents thickening in Ratawi/Yamama Formation (Early

Cretaceous). Also thickening exists in seismic reflection profile RH-19 within Hartha Formation (Late campanian-Early Maasteichtian). Thickening in seismic reflection profiles LT-30, WTM-28 and WTM-26 within Shuaiba Formation (Aptian) and Mauddud Formation (Albian) are observed.

Briefly, the study area, remains as a part of continental passive margin during Paleozoic until Miocene. Reaching the normal faults to Miocene sequence reflect the reactivation of the extensional structures as a result of progressively development of the passive margin. The study area is suffered from extension during approximate Mesozoic and Paleogene times.

4-3-5 Miocene strike-slip faults

In Oligocene time, the Arabian plate begins to migrate northeastward in response to the start of sea floor spreading in the Gulf of Aden and the Red Sea (Al-Fares et al., 1998 in Aqrawi et al., 2010).

Strike-slip movements are mostly developed along pre-existing faults as a result of rotation of Arabian Plate. Strike slip movement develops in Abu-Jir Fault System (Marouf, 1999), also develops in Balad Structure (Muhsin, 2012).

Seismic reflection profiles WTM-26 and RH-19 show negative flowers of strike slip faults where may be developed as a result of the rotation of Arabia. Both of the seismic sections are near the Abu- Jir Fault System.

4-3-6 Miocene-Pleistocene Extension

The oldest exposed rocks in the west of the three lakes are in Early and Middle Miocene age. The exposed rocks in the east are Injana Formation (Late

Miocene), but almost covered by Quaternary sediments, therefore any surface structural features developed younger than Miocene will be vanished or missing. On the other hand the reflection in the seismic sections near the earth surface is bad quality; therefore the continuation of the normal faults to the earth surface in all sections is difficult. Enhanced seismic sections may appear the continuous of the faults.

Nevertheless, there are some surface geological features reflect that the area suffered from extensions during this time. The Iraqi geological map 1:100,000 shows that the three depressions and the fourth one of Dibddiba depression are one extensional feature (Figure 4-3). Sediments of Pliocene-Pleistocene are deposited as a strip between Al-Khirish, west of Iraq to Al-Amghor in the south. The strip is limited by older rocks, Cretaceous and Eocene from the southwest and Eocene and Miocene from the northeast (Figure 4-3). Younger sediments are deposited between older rocks in this area is took place due to extensional feature (Al-Bidaiwi, personal communication). Another surface extensional structure is along the inland sabkha deposition. It deposited as straight strip facing to rocks of Eocene and Miocene.

Tilt of the Mesopotamia sequence is took place as a result of the collision between Arabian and Iranian Plates (Figure 4-2). The tilt generated extension zone along the axis of flexure, west of the Abu-Jir Fault System. The four depressions are within the zone of extension.

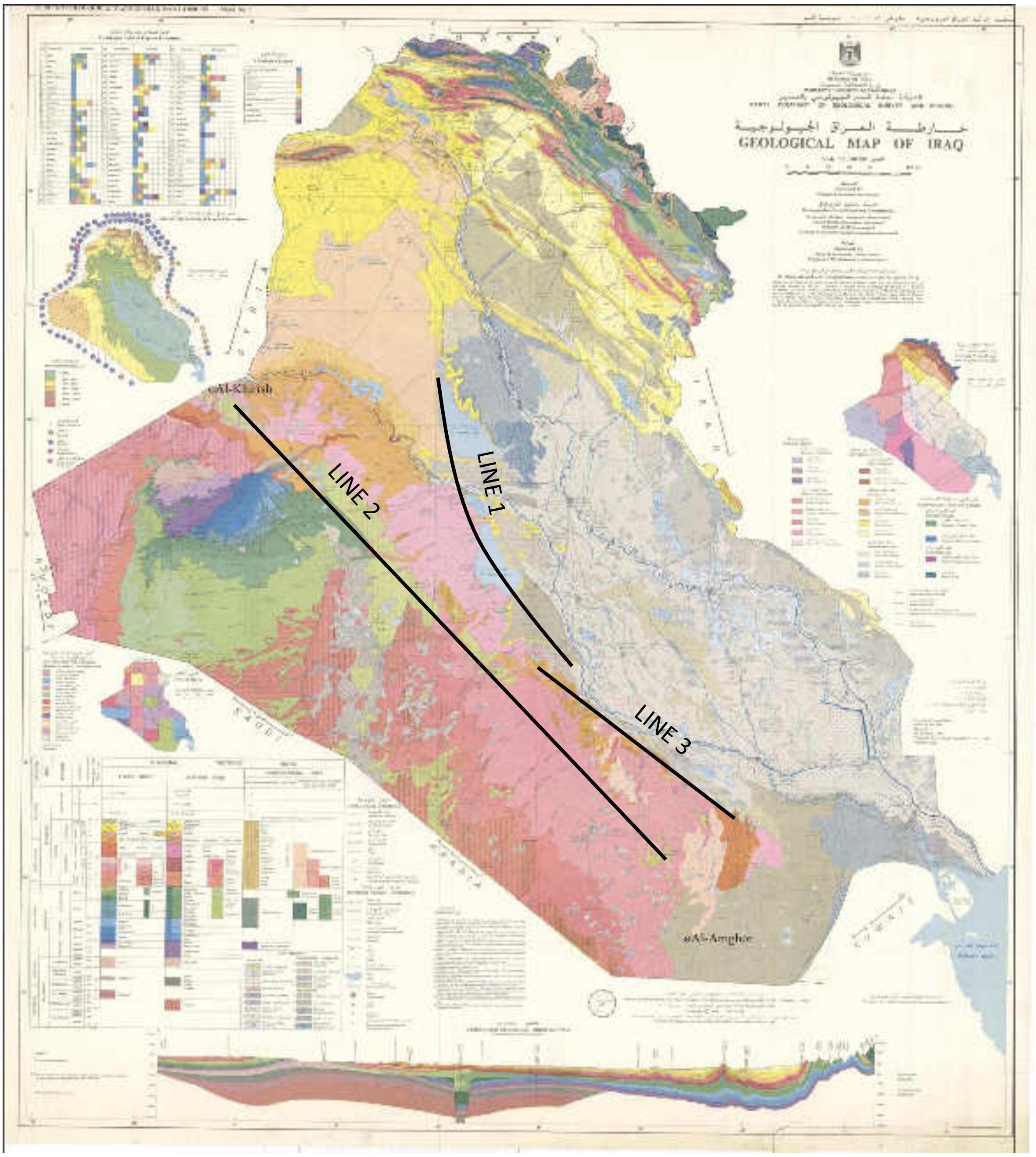

Figure (4-3) Three lines of extensional features drawn at the geological map of Iraq after Sissakian, 2000.

The tilt began in Miocene (Al-Bidaiwi, 2012). Rapid subsidence takes place in Mesopotamian basin during Mid-Late Miocene (Jassim and Goff 2006). On the other hand the separation of the Arabian Plate from the African Plate occurs during Miocene and move toward northeast. The tilt of the Mesopotamia sequence and the rotation of Arabia made the study area under stressed. The extension reactivates some of the normal faults. The simple thickening No. 6 near the earth surface in seismic reflection profile LT-30, the thickening No. 4 in seismic profile RH-19 and the thickening No. 5 in seismic profile LR-22 may be developed due to the extension.

4-3-7 Quaternary neotectonics

There are no remarkable evidences for tectonic activities during quaternary time. The geomorphological landforms are modest neotectonic indications. They may be developed during Pleistocene due to last phase of extension in response to the tilt of Mesopotamian sequence. Deflection the axes of each of Al-Thirthar and Al-Razzazah Lakes took place due to the sinistral strike slip movement of the Amij-Samarra and Sirwan transversal fault system respectively in this time.

4-4 Genesis of the Lakes

The configuration of some of the extensional structures; normal faults, graben and horst from southwest to northeast is presented in all seismic reflection profiles except the seismic profile WTM-28. The geometry, dynamic and kinematic of these extensional structures are similar in all seismic profiles. The extensional structures are regional features extend from the north of Al-

Thirthar Depression to the Abu-Jir Fault System south of Al-Razzazah Depression.

The extensional structures in seismic reflection profile WTM-26 are reactivated during Mesozoic and Cenozoic. They may reach to earth surface. The extensional structures in the seismic profile LT-30 are also reactivated during Mesozoic and Cenozoic.

The extensional structures in both seismic profile RH-19 and LR-22 are near the Abu-Jir Fault System and convergent with it south of Al-Razzazah Depression. They are influenced strongly by Abu-Jir activities. The extensional structures reach to the earth surface especially in profile RH-19.

The extensional structures in the seismic profile LH-18 under Al-Habbaniya depression are far from effects of Abu-Jir Fault System. They are restricted within Paleozoic and Early Mesozoic sequence without any indication of reactivation. The effect of the extensional structures to the formation of Al-Habbaniya Depression is limited, therefore the lake remain small.

The seismic reflection profile RH-19 that is located between Al-Habbaniya and Al-Razzazah Depressions contain uplift due to strike slip movement. The uplift makes relatively elevated area; therefore the area of this profile remains high relatively to Al-Habbaniya and Al-Razzazah Depressions.

The structural setting and tectonic history play important role to develop the three lakes especially Al-Thirthar and Al-Razzazah Depressions. The extend and longitudinal shape of the three lakes are also controlled by the extensional structures. The shapes of Al-Thirthar and Al-Razzazah Lakes are influenced by Amij-Samarra and Sirwan transversal fault system respectively, that deflects the axis of each lake eastward as a result of sinistral strike slip movement of the transversal fault system (Figure 1-10). (Jassim and Goff, 2006) mentioned that some faults of this system underwent sinistral strike slip fault movement in Quaternary time.

The karstification of soluble rocks, limestone and gypsum, such as Al-Fatha Jeribe, Euphrates, Anah and other formations that play important role to develop the three depressions after fixing their locations by tectonic setting.

The normal faults beneath the lakes are developed in Late Triassic, several phases of extensions occurred during Mesozoic and Cenozoic. The phases of extensions reactivated some of the normal faults. (McClay, 2000) mentioned once faults have formed they are generally weaker than the surrounding rocks and may activated by stress field which are not optimally oriented.

The formation of the normal faults and their reactivations developed vertical fractures (Figure 4-4). The phases of extensions make the faults and their fractures have often been considered to be effective conduits for water flow. Abu-Jir Fault System 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 sulphide (Al-Sa'di, 2010). The sequence in the area of Abu-Jir Fault is like the sequence of the study area. The dissolved hydrogen solution made the water as acidic solution. It becomes active in processes of dissolution by vertically move water. Water surface and dissolution by horizontally moving water also contribute in processes of karsitification. At least two of pluvial periods during Holocene are distinguished by (Al-Toash, 1996).

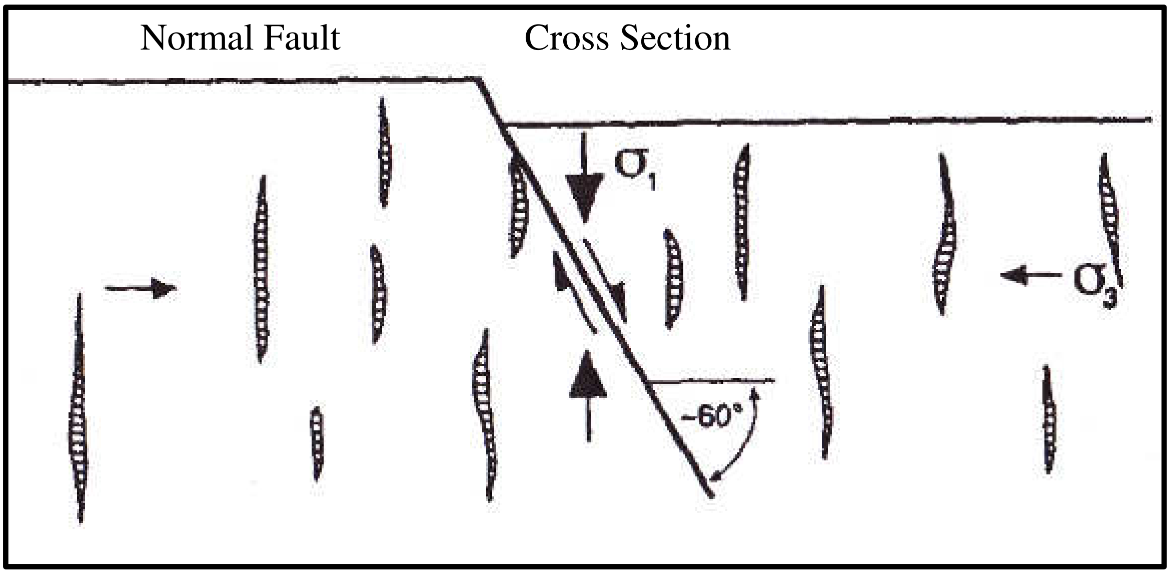

Figure (4-4) Vertical fractures are developed by high angle normal fault (After McClay, 2000).

Processes that produce closed depression features must operate within constraints imposed by the geological setting. Included among these constraints are; Thickness of carbonate rocks, depth to water table, large scale structure, the fracture system and lithological characteristic of the carbonate rocks (White and White, 2006). All of above parameters are available in area of the three lakes. There are thick layers of carbonate rock in the sequence from Shuaiba Formation to Euphrates Formation. Carbonate and evaporate as soluble rocks are also presented in exposed Al-Fatha Formation.

Finally, the extension that produced by the tilt of the Mesopotamia sequence made collapse in the soluble and non-soluble near-surface rocks which develop the depressions.

4-5 The Age of the Depressions.

The Dibdibba Depression is filled by Dibdibba Formation (Pliocene-Pleistocene) and surrounded by outcrops of Injana Formation (Late Miocene). Therefore the age of the Dibdibba Depression, eventually the age of Al-Thirthar, Al-Habbaniya and Al-Razzazah Depressions, is Pliocene-Pleistocene.

The deflection of the axis of Al-Thirthar Lake from north-south to the N35°W-S35°E, also the deflection of the axis of Al-Razzazah Lake took place due to sinistral strike slip movement, that occurred during Quaternary time after development the lakes. Pliocene-Pleistocene is the typical age for the three depressions.

This age is older than that assumed by (Sissakian, 2011). He estimated the age of the development of Al-Thirthar Depression is most probably Holocene, and may be during the 17th century, because Al-Thirthar Depression did not exist during Yaqoot Al-Hamawi (1226), Abin Al-Haq (1338) and in the map of Al-Idrisi (1664). Geologically, he determined the age based on the presence of gypcrete layer covering the plateau in the eastern side of the depression and along the eastern cliffs of the depression. The age of the gypecrte is Pleistocene-Holocene; therefore the depression must be developed after the formation of the gypcrete.

Chapter Five

CONCLUSIONS AND RECOMMENDATIONS

5-1 Conclusions

1. There are three groups of lineaments. The first group is trending east-west perpendicular to the extensional structures beneath the three depressions. The second group is trending N60°E-S60°W perpendicular to the most of the normal faults in the extensional zone. The third group is trending N30°W parallel to the most of the normal faults in Extensional Zone.

2. There are dense lineament features in area surround the depressions. Some of them are parallel to the depressions and the others are perpendicular to them. The intersection of the lineaments divided the area into small fragments which contribute to develop the depressions.

3. The extensional structures coincided with all normal faults in Unstable Shelf, which are developed by the rifting of northeast passive margin of the Arabian Plate during Mesozoic. They become pre-existing faults which are reactivated during younger phases of extensions or strike slip movements.

4. The extension structures are named by this study. They are called Lake Fault system. It is an arcuate fault system convex westward. It extends from north of Al-Thirthar Lake to the south of Al-Razzazah Lake. It comprises grabens, horsts and normal faults.

5. The Lake Fault System is formed during Late Triassic. Some faults of the system are reactivated upward.

6. There are at least three stages of extensions, they are developed when the area behaves as passive continental margin. They are Late Triassic-Early Jurassic, Late Jurassic and Cretaceous-Miocene stages.

7. The study area suffered from two types of stresses. The first one is the extension due to the development of the northeast passive continental margin of the Arabian Plate as well as the extension in response to the tilt of the Mesopotamia sequence during Miocene time. The flexure axis of the tilted sequence develops west of the Abu-Jir Fault System. The study area was influenced by the flexure. The second type of the stress is strike slip movement which was formed as a result of the rotation of the Arabia due to the opening of the Red Sea and the Gulf of Aden and separated the Arabian Plate from African Plate during Miocene time.

8. There are no distinct tectonic activities during Quaternary time except the last phase of the extension. It developed the three depressions during Pliocene-Pleistocene. Another stress is represented by the reactivation of some faults of the transversal fault system. Sinistral strike slip movement of the Amij-Samarra and Sirwan transversal fault system are deflecting the axis of Al-Thirthar and Al-Razzazah Depressions respectively after the development of the depressions. The axis of Al-Thirthar Lake deflects from north-south to N35°W-S35°E whereas the axis of Al-Razzazah Lake deflects from north-south to N45°W-S45°E.

9. Reactivated faults of the Lake fault system reach to the earth surface or near-surface rocks. They control the extent and the shape of the depression.

10. The three depressions are developed by several processes. The important one is the Lake Fault System. It made thinning in the earth crust of the study area along the strike of the fault system. Vertical dissolution by dissolved hydrogen sulfate-bearing ground water through the planes of the Lake Fault System and the fracture system, vertical and conjugate; the fault system and the fractures translate the ground water from lower aquifer to the upper formations. The horizontal dissolution by ground and surface water also contributed in the development of the depressions.

11. The four depressions, Al-Thirthar, Al-Habbaniya, Al-Razzazah and Dibddiba depressions (located south of Al-Razzazah Depression) are the same geological feature, but there is no reactivation in the faults beneath Al-Habbaniya depression and the uplift in area between Al-Habbaniya and Al-Razzazah Depressions prevented the four depressions to develop as one feature.

12. The age of the depressions is Pliocene-Pleistocene due to the age of the Dibddba Formation (Pliocene-Pleistocene) that filled the Dibddiba Depression. The Amij-Samarra and Sirwan transversal fault system are deflecting the axis of Al-Thirthar and Al-Razzazah Lakes respectively after the development of the depressions. The last phase of the reactivation of the Transverse Fault System took place during Quaternary therefore the typical age of the depressions is Pliocene-Pleistocene.

5-2 Recommendations

1. Studying the north and south terminates of the Lake Fault system in area north of Al-Thirthar Lake and south of Al-Razzazah Lake.

2. Studying the major fault of Abu-Jir Fault System in the southwest part of the seismic section WTM-26 by using other seismic sections along Al-Thirthar valley that may coincide with earlier tectonic divisions of Iraq territory.

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أن التراكيب الاستطالية المتواجدة تحت المنخفضات والتي سميت بفوالق البحيرات تمتد تقريبا باتجاه شمال-جنوب مع انحراف باتجاه الشرق. شملت تراكيب (grabens, horsts and normal faults). هذه التراكيب الاستطالية هي المسؤلة أو المتحكمة بنشوء و امتداد المنخفضات الاربعة.

أن المنخفضات الاربعة يمكن اعتبارها مظهر جيولوجي واحد يمتد من التقاء فوالق البحيرات مع فالق ابو جير جنوب منخفض الدبدبة قرب مدينة النجف جنوبا الى وادي الثرثار شمالا. أن عدم ظهور المنخفضات الاربعة كمنخفض واحد هو عدم تنشيط الفوالق الاعتيادية الموجودة تحت منخفض الحبانية و كذلك وجود نهوض بين بحيرتي الحبانية و الرزازة ناتج عن الحركة المضربية لصدع مضربي.

أن التنشيط الذي حصل لبعض فوالق البحيرات وصعودها الى الاعلى لعب دورا كبيرا في نشوء المنخفضات بالاضافة الى الدور الذي لعبته في رفع المياه الجوفية المحملة بغاز كبريتيد الهيدروجين ونقلها من التكاوين السفلى الى التكاوين العليا وشدة تأثيرها على الصخور القابلة للذوبان مثل الجبسم و الحجر الجيري. كل هذا عمل على حدوث تخسفات وانزلاقات ساعدها في ذلك المراحل الاخيرة من الاجهادات الشدية و كذلك الحركة الافقية للمياه الجوفية.

أن امتلاء منخفض الدبدبة برواسب تكوين الدبدبة (بلايوسين-بلايستوسين) وكذلك حصول انحراف في محور كل من منخفضي الثرثار و الرزازة في بداية العصر الرباعي يعكس ان عمر المنخفضات الاربعة هو (بلايوسين – بلايستوسين).

المستخلص

تقع منخفضات الثرثار والحبانية والرزازة وسط العراق الى الغرب من نهر دجلة. عمر الصخور المنكشفة تتراوح بين المايوسين الأسفل والهولوسين وتمثل تكوبن الفرات (المايوسين الأسفل) ونكوين الفتحة (المايوسين الأوسط) وتكوين انجانه (المايوسين الأعلى) وتكوين الدبدبة (بلايوسين – بلايستوسين) وترسبات العصر الرباعي. تمثل المنخفضات الثلاثة الحافة الغربية لنطاق ما بين النهرين على الحدود مع نطاق السلمان.

أن المقاطع الزلزالية الانعكاسية المأخوذة باتجاه شمال شرق-جنوب غرب و العمودية على المظاهر التركيبية المتواجدة في منطقة الدراسة تظهر أن الحوض الرسوبي تحت المنخفضات قد تعرض الى عدة مراحل من الاستطالات (extensions) نتيجة لتعرض الحافة الشمالية الشرقية الخاملة للصفيحة العربية الى اجهادات شدية. هذه الاجهادات بدأت ضمن منطقة الدراسة في نهاية الترايا‌سي ثم تلتها عدة دفعات من الاجهادات الشدية استمرت الى المايوسين. بعد ذلك تعرض الحوض الرسوبي الى حركة مضربية بدى تأثيرها على بعض المقاطع الزلزالية.

هناك مرحلة جديدة من الاجهادات الشدية حصلت ضمن المايوسين الأسفل واستمرت الى العصر الرباعي. هذه الاجهادات حدثت بسبب هبوط او ميل التعاقب الطباقي لحوض ما بين النهرين نتجة لتصادم الصفيحة العربية مع الصفيحة الايرانية. هذا الانحناء ولد اجهادات شدية على طول محور الانحناء حيث امتداد المنخفضات الثلاثة. هذه الاجهادات عملت على تنشيط بعض الفوالق الاعتيادية وصل تأثيرها بالقرب من سطح الارض وتركت بعض المظاهر الجيولوجية السطحية التي تعكس تواجدها. واهم هذه المظاهر هي المنخفضات الثلاثة مع وجود منخفض رابع هو منخفض الدبدبة الواقع جنوب منخفض الرزازة وعلى امتداد المنخفضات الثلاثة.

عكست دراسة التكتونية الحديثة (نيوتكتونك) والتي تمت باستخدام بيانات التحسس النائي أن المنطقة ذات نشاط تكتوني ضعيف خلال العصر الرباعي باستثناء ظاهرتين، الاولى هي تطور المنخفضات الاربعة بفعل التنشيط الذي حصل على الفوالق الاعتيادية في بداية العصر الرباعي والثانية تغير اتجاه محور كل من بحيرتي الثرثار و الرزازة من شمال-جنوب الى شمال 35° غرب-جنوب 35° شرق بالنسبة لبحيرة الثرثار واكثر من ذلك بالنسبة لبحيرة الرزازة بفعل الحركة المضربية اليسارية للفوالق المستعرضة والتي نشطت في بداية العصر الرباعي.

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