Tectonic Evolution of the North-Eastern Corner of the Dead Sea, Jordan

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Abstract

Field investigation and aerial photographs interpretation of the northeastern corner of the Dead Sea showed that the area is highly deformed. In this area two major fold belts are present, the Amman-Halabat fold belt in the south, and Wadi Shu'ieb structure in the north. The folding preceded the formation of the Dead Sea Transform. In some places the folding is represented by monoclines. These folds are part of the Syrian Arc system.

A series of antithetic, right-lateral strike slip faults trending mainly 95°, are correspondent to Riedel shears. Synthetic, left-lateral strike slip faults trending mainly 155° are correspondent to the conjugate Riedel shears. A group of normal faults strike mainly 125°. The configuration of these faults is correspondent to other regional structures in the Arabian Plate.

A major uplifting phase was responsible for the accumulation of Pliocene-Pleistocene clastic sediments. The major compressive stress in the study area is NW-SE, but NE-SW local stresses are suggested to explain the formation of NW-SE trending reverse faults and folds.

Introduction

The Dead Sea Transform (DST) is the most prominent geological and geomorphological feature in the Middle East. It separates the Arabian plate in the east from the Sinai-Palestine plate in the west. Many authors discussed the formation of the transform (rift) since the last century (Lartet, 1869, Blanckenhorn, 1886. Dubertret, 1932; Quennell, 1958, 1985; Picard, 1965, 1987; Freund, 1965; Bender, 1968; Garfunkel, 1981; Bahat and Rabinovitch, 1983,...etc.).

The formation of the Dead Sea Transform (rift) is connected to the opening of the Red Sea, which occurred in two stages at the same time with the horizontal movement along the Dead Sea transform fault (Girdler and Style, 1974). The Dead Sea Transform was preceded by the formation of the Syrian Arc, an S-shape fold.
belt extending from Sinai to Palmyra. The Syrian Arc was discussed by many authors (Krenkel, 1924; McBride et al. 1990; Mart, 1991; Barazanji, et al., 1993 and Shahar, 1994). Many secondary structures were formed associated with the DST in Jordan; right-lateral antithetic strike slip faults, left-lateral synthetic faults, normal faults and some folds (Atallah, 1992a; 1992b).

The aim of this work is to study the effect of the Syrian Arc and the DST on the area northwest of the Dead Sea in an attempt to better understand the evolution of the southern Jordan Valley segment of the DST. Aerial photographs at scale 1:10,000 were analysed by mirror stereoscope to delineate the geological structures and the boundaries between the different rock units. Extensive fieldwork was undertaken to measure the different structural elements and to verify the unclear features on the aerial photographs. Different geological and structural maps were produced. Geological cross sections were drawn across the major structures. Structural elements were plotted on rose diagrams and stereographic projection diagrams.

Geological setting

The study area is located at the northeastern corner of the Dead Sea; it extends from Mount Nebo in the southeast to Wadi Shu'ieb in the north (Fig. 1). It covers part of the Jordan Valley floor and part of the highlands east of the DST. The rift floor in this area is relatively wide. The west-facing slope of these highlands in the study area is less steep than the eastern margin of the DST to the north and south. The rift in this area trends due north. The area includes the western extension of two fold belts east of the rift; the Amman - Hallabat structure and the Wadi Shu'ieb structure (Mikbel and Zacher, 1986). Most of the fold belts east of the rift were described as either normal faults or as flexures (Bender, 1968), but in the light of the more detailed studies most of these structures were found to be fold structures of compressional origin (Mikbel and Zacher, 1981, 1986; Sahawneh, 1991).

The main rock sequences cropping out in the study area are:

1. Triassic rocks: They are the oldest rocks cropping out in the study area. They are mainly exposed in the southwestern corner of the study area. They are of Middle Triassic age (Bandel and Khoury, 1981) and composed mainly of dolomite, marl, shale, limestone, and sandstone. These rocks are cut by acidic sills and dikes. The main trend of the dikes is 135° (Bandel and Khoury, 1981) (Fig. 2).

2. Lower Cretaceous, Kurnub Sandstone: This unit outcrops mainly in the southeastern part of the study area as a belt along the western slopes of the highlands and along the deep valleys unconformably overlying the Triassic rocks. It is composed mainly of friable white sandstone in the lower part and varicolored sandstone in the upper part. Clay lenses and plant fossils are also present.

3. Upper Cretaceous rocks: These rocks cover most of the study area, mainly the eastern and the northern parts. The age of these rocks ranges from Cenomanian
to Maestrichtian. They are composed of a wide variety of rock types: limestone, marl, dolomite, chalk, chert, and phosphate.

4. Quaternary rocks and unconsolidated deposits of Quaternary age cover unconformably the underlying Mesozoic rocks. They are mainly exposed on the Jordan Valley floor. The Upper Pliocene-Early Pleistocene Shaghur unit comprises thick-bedded conglomerates with a hard calcareous, sandy, and siliceous matrix. The rocks were deposited in fluvial and lacustrine environments (Bender, 1968). The Upper Pleistocene Lisan Formation outcrops in the Jordan Valley. This formation is composed of laminated aragonite, gypsum and calcite and was deposited in brackish lake environment.

**Structural Geology**

The following major structural elements are found in the study area (some of them are described for the first time):

1. **Folds:**
   
   The following fold belts were observed and described in the area (Figs 1,3):

   1. Siyala Fold Belt: It extends from Jelda village in the north, to Wadi El Hiri in the south, passing through Wadi Siyala. The folded rocks are the Triassic beds and the overlying Pliocene-Pleistocene Shaghur Formation. The dip of the folded beds ranges from 20° to 60°, and the beds show three trends of fold axes: N18-26E, N75E, and N10W. Fig. (4) shows a cross-section of this fold belt, and Fig. (5) shows a stereographic projection of some of the individual folds in it.

   2. Siyagha Fold Belt: It can be seen between Mount Nebo and Siyagha and represents the western extension of the Amman-Hallabat fold belt (Mikbel and Zacher, 1986) (Fig. 3). It is composed of en echelon parallel to sub parallel anticlines and synclines in the Upper Cretaceous carbonate beds. The general trend of the consisting fold axes is NNE-SSW (N14E, N34E, and N38E). Some of the folds are overturned. Fig. (6) shows a cross section of the folds and Fig. (7) shows a stereographic projection of the individual folds.

   3. Hisban fold belt: These three short-extended parallel folds are located along Wadi Hisban. The dip angle of the Triassic folded beds ranges between 10° to 28°. The Hisban monocline was formed at the western margin of this fold (Fig. 8). The steeper limb of the monocline faces to the west with dips up to 70°

   4. Wadi Shu’ieb structure: This structure was considered as compressional fold by Mikbel and Zacher (1981) for the previously described Salt flexure (Bender, 1968). It extends from the eastern margin of the Jordan Rift to the Zerqa River outside of the study area in a NNE-SSW trend. It is considered to be one of the prominent fold belts east of the rift. The detailed mapping enabled the authors to subdivide the fold zone into three fold belts based on the concentration of the folds:
1. El Kafrien Fold Belt: This structure is located in the middle part of the study area (Fig. 3), east of the village of El Kafrien. The structure was considered to be a NNW facing monocline (Bender, 1968, McDonald, 1965). The structure is composed of a N45E trending syncline and a N54E trending anticline in addition to minor anticlines and synclines (Fig. 9). The dip angles of the folded beds range between 30° and 70°. The folds were cut by the El Kafrien reverse fault, which is parallel to the fold belt (Fig. 10).

2. Jureia Fold Belt: It is located at the southern end of Wadi Shu‘ieb, east of Shunat Nimrin. It is composed of a bundle of anticlines and synclines (some of them are recumbent). They are faulted by NE-SW trending reverse faults (Fig. 11). The fold axes have the following trends: N62E, N28E, and N54E (Fig. 12). Lower and Upper Cretaceous strata are involved in the deformation, where the dip angle range between 40° to 80° and overturned.

3. Shu‘ieb fold belt. It is composed of a bundle of en echelon, tight anticlines and synclines, some of them are overturned (Fig. 13). Most of the fold axes strike ENE-WSW (Fig. 14); three of them strike N54E, one strikes N72E, one strikes N40E, and one anticline strikes N10W. The dip angles of the folded layers range between 20° to overturned.

2. Faults:

The northeastern corner of the Dead Sea is highly faulted. Strike slip, normal and reverse faults are observed with varying lengths and displacements (Fig. 15).

2.1. Strike slip faults:

Most of the strike slip faults in the study area strike NW-SE, but few of them strike NE-SW (Fig. 16.a). The major strike slip faults are shown in Fig. 15:

1. El Hilwa Fault: It might represent a branch of the Dead Sea Transform, bordering the eastern side of the Dead Sea pull-apart basin. It has a general NNE-SSW trend and shows left-lateral displacement.

2. Ain Musa Fault. It can be traced for more than 6 km. The strike of this fault ranges from 120° to 135°, it has right lateral sense of movement, as indicated from the dragging of the layers across the fault plane.

3. El Atab Fault. It strikes N70E, extending more than 4 km from Wadi El Kafrien to Wadi El Atab. It shows sinistral sense of movement.

4. Shu‘ieb Fault. It is a NE-SW striking fault, parallel to Wadi Shu‘ieb. The dislocation of some faults and folds along Shu‘ieb road indicates that this fault has a sinistral sense of movement (Fig. 11).

2.2. Normal faults:

The major trend of the normal faults in the study area is 145° (Fig. 16.b). The major two normal faults are.

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1. En Nar Fault: It is located in the northeastern corner of the study area, and strikes N25W. Down throw is to the southwest.

2. Nimrin Fault: It is located in the northwestern corner of the study area and strikes SE-NW with a curved trace. It juxtaposes Upper Cretaceous strata on the northeast against Quaternary sediments on the southwest.

2.3. Reverse faults:

The major trend of the reverse faults is N35E (Fig. 16.c). The main reverse faults in the area are the following (see Fig. 15 for location).

1. El Hiri - Hisban Fault: These two faults extend more than 7 km from Wadi El-Hiri in the south to the Amman - Dead Sea road in the north. The southeastern block is downthrown relative to the northwestern block. This fault is horizontally displaced by Ain Musa dextral strike slip fault. The horizontal offset is about 2 km, therefore it is divided into two fault segments; El Hiri fault in the south and Hisban fault in the north.

2. El Kafrien - El Amir Fault: This fault extends from Wadi El Kafrien in the southwest to Wadi El Amir in the northeast, striking NE-SW. The northwestern block is upthrown. This fault is offset by 350 m by a sinistral strike slip fault as shown in Fig. (15). The intersection of these two faults produced a complex structural pattern. El Kafrien fold was displaced longitudinally by the strike-slip fault, which is parallel to the fold axes.

Interpretation of the structural elements

1. Folds:

The main trend of the fold axes in the study area is N25E (Fig. 16.d). Other minor trends are also encountered especially the ENE-WSW trend represented by N54E, N62E and N75E, and the NW-SE trend represented by the N10W fold axes. The fold axes mainly plunge to the NE. The axial planes of the folds generally dip to the SE.

These folds represent part of the Syrian Arc System (SAS) as suggested by Bandel and Mikbel (1985) and Abed (1989). These authors have strong evidences that there was syn sedimentary uplift in Tell Es Sur area (which is part of the Amman - Hallabat fold belt, trending ENE-WSW). Other evidences for the Syrian Arc movement in Jordan are also found in Ajlun-Irbid area (Mohammad, 1985; Abed, 1994). Eyal and Reches (1983) suggested that the Syrian Arc formed during the period from Late Cretaceous to Miocene.

There are two main trends of fold belts in Jordan; the first is NNE-SSW and the other is ENE-WSW (Atallah, 1992b). The latter is most probably part of the Syrian Arc System and possibly represents a continuation of SAS segment of the Naqab fold-belt after shifting the Arabian plate 100 km southwards. The first fold trend could be formed as a result of SE compression responsible for the rift formation.
This trend coincides with Riedel model (Tchalenko, 1970). It was also found that the folds close to the rift have NNE trend, therefore the NNE-SSW folds in the study area are more probably formed during the early stages of the shear movement, but some of the ENE-WSW trending folds are part of the refolded SAS.

2. Faults:

The study area is highly faulted. The fault sets have definite orientations relative to the Rift. The major features of the fault sets are.

1. Strike-slip faults: More than 90 strike slip faults were identified in the area. The major trends of these faults are 95° and 155°. The first trend consists mainly of right lateral strike-slip faults, and the second trend consists mainly of left lateral strike-slip faults. The two trends of strike-slip faults form a conjugate set with an angle of 60° between them.

2. Normal faults: Approximately 190 faults of normal type were recognized in the area. The throw of these faults varies from few centimeters to more than 300 m. The main strike of the fault planes is 125°. This trend of normal faults is parallel to other regional tensional structures in Jordan such as the Wadi Sirhan Fault and the Karak-Feiha Fault zone.

3. Reverse faults: Approximately 100 reverse faults were identified in the area; they have a general strike of N35E, and are generally associated with the fold structures. They probably represent reactivation along NE-SW trending faults formed in Late Jurassic time, prior to deposition of Kurnub Sandstone (Powell and Moh'd, 1993).

The fault configuration in the study area relative to the DST has a more or less simple pattern. The normal faults have a major trend of N125°; this trend bisects the acute angle between the right lateral faults and the left lateral faults (they strike N95° and N155°). The right lateral faults correspond with the antithetic shears in Riedel model (Tchalenko, 1970), while the left lateral faults correspond with the synthetic shears in the same model, and the normal faults coincide with the tensional fractures. A number of regional major right lateral antithetic strike-slip faults have the same trend. These faults include the Swaqa Fault, Zerqa Ma'in Fault, Al Hasa Fault, and Saiawan Fault. An example of left lateral strike-slip faults is the Al Quweira fault in south Jordan (Atallah, 1992b).

Course of tectonic movements

The oldest exposed rocks in the study area are the Triassic strata. They show intensive diking, trending N135°. Triassic rocks in southern Naqab have been also affected by diking phase at the end of the Triassic period. From the trend of the dikes it can be concluded that the study area was subjected to a NE-SW tensional stresses (i.e. Perpendicular to the trend of the dikes). Jurassic rocks are absent in the study area, because the area was uplifted and the Jurassic shoreline is located further to the north. During the Early Cretaceous the area was uplifted and the Kurnub
sandstone was deposited. During the time interval from Late Cretaceous to Miocene, the area was affected by the formation of the Syrian Arc fold system, represented by the ENE-WSW trending folds. Preceding the first phase of left-lateral shear movement along the Dead Sea Transform, which may have begun before the Middle Miocene (Garfinkel, 1997) a system of antithetic and synthetic strike slip faults were initiated in addition to some tensive normal faults. The pre-existing folds were refolded and more NNE-SSW folds were formed. Much evidence indicates uplift of the rift shoulders before and during the major strike-slip displacement along the DST, this evidence includes the uplifted highlands east and west of the DST, and the thick deposits of clastic sediments in other parts of the rift such as the Dana (syntectonic) Conglomerate of Early to Late Miocene age (Garfinkel, 1997). The second phase of horizontal movement along the DST was accompanied with uplift of the eastern shoulder of the rift, which caused the deposition of the Shaghur Formation during the Early Pliocene-Pleistocene. During this phase of movement, further displacement along the pre-existing synthetic, antithetic, and normal faults took place. Folding was continued as indicated from the folding of the Shaghor formation in some places.

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التطور التكتوني لزاوية الشمالية الشرقية للبحر الميت

جوليا سراوته و محمد عطانه

**منتهى**

قد بنيت الدراسة الميدانية وتحليل الصور الجوية لزاوية الشمالية الشرقية للبحر الميت، أن المنطقة قد شهدت نشاط في هذه المنطقة يوجد نطاقين من الطبقات الأول هو نطاق عمان الخالات في الجنوب والثاني نطاق وادي شعب في الشمال. لقد سبقت عملية الطبقات تتكون صدوع البحر الميت التحويلي. في بعض الأماكن تتوصف الطبقات على شكل تراكيب أحادية. في جزء من الكوست السوري.

تم تقسيم الصدوع في منطقة الدراسة إلى المجموعات التالية: مجموعة الصدوع اليدوية المضربية البيئية التي تأتي 90 وهي تشكل تشظيات ريد القائمة. مجموعة من الصدوع التالفة المضربية البالية والتي تأتي 150 وتشمل تشظيات متراصة ريد. واخريما مجموعة من الصدوع القدرة والتي تأتي 125. توزع هذه الصدوع بتراكيب التراكيب القدائية في الصورة العربية. حركة الرياح الرئيسية كانت مسؤولة عن تراكم رسوبات الريفيين - البيروسيسیت المرتفعات. قوة الضغط الرئيسية في منطقة الدراسة بإتجاه شمال غرب - جنوب شرق ولكن تم افتراض فوري محلية بإتجاه شمال غرب - جنوب غرب.
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Fig. (1): Geological map of the area northeast of the Dead Sea

Fig. (2): Rose diagram of dikes in Triassic rocks.
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Fig. (3): Fold pattern in the area northeast of the Dead Sea

Fig. (4): Geological cross section of Wadi Siyala (A-A' in Fig. 3).
Fig. (5): Stereographic projection diagram of some folds in Siyala fold belt

Fig. (6): Geological cross section of Wadi El Muhtarqa/Ain Musa (B-B in Fig.3).
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Fig. (7): Stereographic projection diagram of some individual folds in Siyagha fold belt.

Fig. (8): Hisban monocline and related structural elements.
1- Horizontal-subhorizontal beds
2- Steep broken flank, covered by soil
3- Steep flank, bedding planes dip 70 to the NW.
4- Radial joint.
5- Conjugate shear planes with displacement in the crest.
6- Minor folding in the incompetent beds.
7- Gentle monocline.
Fig. (9): Stereographic projection diagram of some folds in El Kafrien fold belt.

Fig. (10): Geological cross section of Wadi El Kafrien (C-C' in Fig. 3).
Fig. (11): Geological cross section of Wadi Jureia (D-D' in Fig. 3).
Fig. (12): Stereographic projection diagram of some folds in Jureia fold belt.

Fig. (13): Geological cross section of Wadi Shu'ieb (E-E' in Fig. 3).
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Fig. (14): Stereographic projection diagram of some folds in Shu'ieb fold belt-

Fig. (15): Fault pattern in the area northeast of the Dead Sea.
Fig. (16): Rose diagrams for the major trends of
a: strike slip faults. Total measurements = 90.
b: normal faults. Total measurements = 99
   c: reverse faults. Total measurements = 100.
   d: fold axes. Total measurements = 92