ON THE STRUCTURAL PATTERN OF THE DEAD SEA TRANSFORM AND ITS RELATED STRUCTURES IN JORDAN

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Abstract

Along the Dead Sea Transform, active left lateral strike slip faults dominate. Rhomb-shaped pull-apart basins and push-up swells of different sizes are numerous all along the Transform, from the Gulf of Aqaba to Lake Tiberias.

A framework of faults dissects the eastern margin of the Dead Sea Transform. These faults can be catagorized into four types, NNE and SSE trending synthetic faults, ESE trending antithetic faults, and SE trending normal faults. The aspect of these faults coincides with the configuration of the fractures in Riedel model.

Two general trends of fold axes are also encountered associated with the Dead Sea Transform, NNE and ENE trends, which coincide with the drag folds of Moody and Hill (1956).

1. Introduction

The Dead Sea Transform represents the boundary between the Arabian plate and Sinai plate. It connects the Red Sea spreading center in the south with the Arabia-Eurasia collision zone in the north. Based on seismicity and satellite imagery, a possible northward continuation of the transform system beneath the Mediterranean Sea south of Beirut was proposed by Girdler (1990). He suggested that the northern most termination of the Dead Sea transform located somewhere east of Cyprus where intersected with the Eurasian collision zone (Fig. 1).

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The Dead Sea Transform is a complex structural feature. It was first described as tensional graben bounded by normal faults and flexures (Picard, 1965, 1970). Other geologists (Quennel, 1958 & Freud et al., 1970 and many others) considered the Dead Sea Rift as a left lateral fault. Modern studies on the light of plate tectonics proposed the idea of transform fault (Mackenzie et al. 1970, Garfunkel, 1981).

This study is based on the analysis of aerial photographs, satellite imagery and geological maps in addition to field investigation. This contribution attempts to give an overview of the Dead Sea Transform fault and the pattern of structural elements east of it, and to find if these structures correspond to one of the models proposed for shear zones.

Two famous models are well-known in the literature of structural geology; the first one is by Moody and Hill (1956). They found that major wrench faults are accompanied by a system of second order left lateral and right lateral faults (Fig. 2), which are in turn accompanied by third-order left lateral and right lateral faults. The second model is the Riedel experiment (Riedel, 1929). This experiment showed that by simple shear failure in clay, two major directions of shears were formed: synthetic Riedal shears (R) and antithetic conjugate Riedel shears (R′) (Fig. 3). Tensional fractures (T) and other shear fractures (P) are also formed. These fractures have the same configuration in clay model, shear box test, and earthquake faults as in the case of Dasht-e-Bayaz in Iran (Tchalenko and Ambroseys, 1970).

2. General Features of the Dead Sea Transform

The Dead Sea Transform in Jordan is composed of three morphotectonic segments: Wadi Araba, Dead Sea, and Jordan Valley. They form a morphological depression which extends from the Gulf of Aqaba to lake Tiberias. The floor of this depression is covered by Quaternary sediments consisting mainly of fluviatile deposits, marl, and clay (Bender, 1968). Alluvial fans are also found at the mouths of major wadis.

The transform fault is traced in unconsolidated Quaternary sediments, where satellite images are very useful. The transform system consists of six major overlapping offset transforms with a deep rhombochasm (Girdler, 1990). Three of them are located within the Gulf of Aqaba, the others are located in Wadi Araba, Dead Sea, and lake Tiberias. (Fig. 1).
Fig. (1): The overlapping segments of the Dead Sea transform (after Girdler, 1990)
Fig. (2): Plan of wrench fault system and its associated structures (after Moody and Hill, 1956)

Fig. (3): Description of the fractures associated with a sinistral shear in Riedel experiment (after Dresen, 1990)
The Araba fault is recognized on aerial photographs and satellite images as a continuous line bordering the eastern margin of Wadi Araba. In southern Wadi Araba, the fault trace is marked by minor scarps, uplifted pressure ridges, and offset alluvial fans. The fans of Wadi Turban and Wadi Rahma are examples of these features, that indicate active faulting (Abu Taimeh, 1988). The northern termination of Wadi Araba fault is located in central Wadi Araba, where it overlaps the Er Risha fault. Khureij mountain in central Wadi Araba is an example of push-up swells due to this overlapping.

Er Risha fault which cuts Wadi Araba diagonally is traced in central and northern Wadi Araba. It causes sharp bends in the stream courses (Wadi Tasan, Wadi Abu Dubana and other Wadis south of Humrat Fidan). Push-up swells are also observed west of Humrat Fidan in the discontinuous segments of the fault (Atallah, 1986).

North of Humrat Fidan the fault is traced along the foothills of the highlands east of Wadi Araba where Dahal area compressional ridges of Upper Cretaceous rocks was formed, and is composed of tight anticlines and synclines.

A major transverse fault is recognized at the mouth of Wadi Khuncizira south of the Dead Sea. This NW-SE prominent fault scarp the southern boundary of the Dead Sea basin. Other NW-SE trending transverse normal faults were identified in the northern part of the southern Dead Sea basin (Ben Avraham et al, 1990).

Faults traced on the earth's surface in the Dead Sea area are not well manifested, except along the eastern fault scarp. Mapping of faults was deduced from deep drilling and seismic study (kashai and Croker, 1987). These maps show a complicated pattern of faults (Fig. 4), where N-S pull-apart (stretching) is described by many authors as a result of the overlapping of two major strike slip faults (Er Risha and Jordan Valley) (Quennell, 1956; Garfunkel, 1981; Gridler, 1990). Other authors prefer a more complicated picture; in addition to the overlapping of the two faults, very narrow and deep grabens have evolved (kashai & Croker, 1987).
Fig. (4): The fault pattern of the Dead Sea basins (Modified after kashai and Croker, 1987)
The transform in Jordan Valley is represented by a single left lateral strike slip fault, no Push-up swells or pull-apart basins were manifested along the fault trace. This fault commences at the Northwestern corner of the Dead Sea and cuts across the Jordan Valley obliquely and is found on the eastern side of the Valley at the Southern end of Lake Tiberias. Evidences of active movement along this fault is described by Reches and Hoexter (1981), and Grafunkel et al. (1981).

3. Structural Pattern East of the Dead Sea Transform

The three segments of the Dead Sea Transform in Jordan have different types of structural patterns along their eastern margins.

3.1 Wadi Araba:

The outcropping rocks in the area east of Wadi Araba are composed mainly of Precambrian basement rocks especially in the southern part. In central and northern Wadi Araba Paleozoic and Cenozoic sediments cover the basement rocks.

This area is characterized by intensive faulting. East of southern Wadi Araba a system of NNW trending faults cut the Precambrian basement and its Paleozoic cover. The major fault in this area is the Quweira fault (this fault was completely described by Abu Taimeh. (1988) and Barjous and Mikbel (1990). Other faults parallel to Al-Quweira fault are the Jabal Al-Muhtadi fault in the west, Wadi Rumman fault and Wadi Rum fault in the east. Other faults that belong to the previous fault systems are Gharandal and Bir khadad faults (Fig. 5).

There are NNW trending faults like Wadi Al-Yutum and Wadi Musa faults in addition to a number of short extended faults (Bender, 1968). The intersection of these two sets of faults produced rhomb-shaped pull-apart basins which are dominant east of southern Wadi Araba.

East of central Wadi Araba triangular horst was developed (Dana Horst) between two E-W faults (Fienan - Zakimat el Hasa fault in the south and Dana fault in the north). Feinan - Zakimat el Hasa fault extends from wadi Araba in the west to the eastern border in the east. It has right lateral strike slip displacement in addition to vertical displacement. The Dana fault shows only vertical displacement. Another E-W fault in northern Wadi Araba is the Wadi Al-Hasa right lateral fault.
A major normal fault, east of Wadi Araba, is the SE-NW Ras en Naqab fault which forms morphologically a prominent escarpment. NE of the escarpment Upper Cretaceous rocks are outcropping forming the flat plateau of central Jordan. SW of the escarpment Paleozoic and Precambrian rocks form a mountaineous area. Another normal fault parallel to the Ras en Naqab fault is the Disi-Mudawara fault (Fig. 5).

East of central Wadi Araba, fold belts were developed, which are better displayed and more abundant in the Upper Cretaceous carbonatic rocks. The main fold belts in this area are Petra-Shobak fold belt (Atallah, 1986 & Barjous, 1987) and Diylagha-Ail fold belt (Abu-Taimeh, 1988). The general trend of these belts is NNW (Fig. 6).

3.2 Dead Sea:

East of the Dead Sea shore lines, Cambrian, Triassic, and Cretaceous rocks are exposed. The area is characterized by a sharp escarpment in the west facing the Dead Sea. The strata east of the Dead Sea are either horizontal or show gentle dipping with little deformations except in the area east of Al-Lisan peninsula where the strata dip to the west and form the Al-karak flexure.

The area east of the Dead Sea shows sparse faulting. The major faults east of the Dead Sea are the E-W right lateral faults with basaltic extrusions (Shihan fault and Zarqa Main fault). Evidences of uplifting are also encountered in this area as thick deposits of fluviatile gravels (Atallah & Mikbel, 1983).

3.3 Jordan Valley:

The outcropping rocks in the area east of Jordan Valley are mainly of Triassic, Jurassic, Cretaceous, and Tertiary ages. The intesity of deformation in this area is less than that of eastern Wadi Araba and more than in the eastern Dead Sea.

The Northwestern corner of the Dead Sea shows intensive deformation of both faulting and folding (Sahawneh, 1991). In this area, the western extension of two major fold belts of north Jordan are found. These folds are the Amman-Hallabat fold and the Wadi Shuweib fold (Mikbel & Zacher, 1981, 1986).

The area adjacent to the Valley floor is characterized by short-extended step faults, narrow tilted blocks, and flexures.
Fig (5): Fault pattern east of the Dead Sea transform
Fig. (6): Fold belts east of the Dead Sea transform
A major E-W right lateral fault in north Jordan east of the transform is the Zarqa fault. North of this fault a number of fold belts were encountered: The Ajlun anticlinal dome (Burden, 1959), The Halawa-Al Husan, and Ibben-Hausha fold belts (Atallah & Mikbel (in press)).

4. Volcanic activity east of the Dead sea transform

Along the Dead Sea Transform itself few small volcanic plugs are present, but at its eastern margin basaltic rocks are abundant. They mainly erupted along faults and fissures. The E-W antithetic faults are associated with volcanism as Zakimat el Hasa fault. Along the normal tensional faults, basaltic eruptions are abundant along karak-Feiha fault. The plateau basalts of Hauran (NE Jordan) erupted along SE-NW trending fissures.

5. Discussion

Figure (5) shows the major faults east of the Dead Sea Transform. There are four major trends of faults as shown in Fig. (7):

1. Left lateral (synthetic) strike slip faults, they make an angle of 18° anticlockwise with the transform, as Al-Quweira, Rumman, Gharandal, Bir khdad, and Jabal Al-Muhdati faults.

2. Right lateral (antithetic) strike slip faults; they make an angle of 85° anticlockwise with the transform. Examples of these faults are Zarqa River, Zarqa Main, Shihaan, and Feinan-Zakimat El Husa.

By comparing the above mentioned fault system with the two models of Moody and Hill (1956) (Fig. 2) and Reidel (1929) (Fig. 3), we conclude that the above mentioned faults correspond to a great extent with the shear and tensional fractures of Riedel model. The faults of the first type correspond with Riedel shears (R), while the faults of the second type correspond with the conjugate Reidel (R').

The angles between the Dead Sea Transform and its accompanied faults are greater than the corresponding angles in Riedel experiment (Fig. 3 and 7). In the experiment the angle between both (R) and (P) fractures and the major shear is 12° - 15°, while the Dead Sea faults have angles of 18°. The angle between R' and the major shear in the experiment was found to be 75° - 78°, but the corresponding angle in the case of the Dead Sea Transform is 85°. The tensional faults in Jordan coincide exactly with the tensional fractures (T) in the experiment.
Fig. (7): The relationship between the Dead Sea transform and its associated faults.

3. Tensional faults making an angle of 45° anticlockwise with the transform as the faults of Ras en Naqab, Mudawara-Disi, and karak-Feiha.

4. A small number of short extended left lateral faults strike NNE which make an angle of 18° clockwise with the Dead Sea Transform. Examples of these faults are: Hilwa Fault and Wadi el Yutm fault.

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The difference between the directions of the actually measured angles of the associated fault system of the Dead Sea Transform and the experimental results of
Riedel can be attributed to the probable rejuvenation of older faults and the heterogeneity of the rocks in the area. Fault rotations can also explain this difference (Atallah, 1988).

If we compare the associated faults of the Dead Sea Transform with the second order left lateral and right lateral faults of Moody and Hill (1956) (Fig. 2), we will find that the angles between these faults and the first order wrench fault (the major shear) are different from those between the Dead Sea Transform and its accompanied faults. Tensional faults are not recorded in the model of Moody and Hill (1956).

The fold axes in east Jordan (Fig. 8) make an angle of 15° (Petra-Shobak fold belt and Diyalgha-Ail fold belt) and 60° (the other fold belts in Fig. (6)) with the transform. These trends coincide with the drag folds of Moody and Hill (1956).

Figure (9) shows rose diagrams of the major trends of all faults east of the transform as mapped by Bender (1986b). They show four major trends:
1. A NNE trend which corresponds with the Reidel shears.
2. A NNW trend which corresponds with the P fractures.
3. A SE trend corresponds with the tensional fractures.
4. A trend of ESE direction corresponds with the conjugate Riedels.

![Diagram](image)

**Fig. (8):** The relationship between the Dead Sea transform and the associated fold belts.
Fig. (9): Major trends of fault east of the Dead Sea Transform as mapped by Bender (1968)
6. Conclusions

The fault pattern east of the Dead Sea transform coincides with the fractures in Riedel model. The E-W right lateral faults coincide with the conjugate Riedel shears, the SSE left lateral faults coincide with the Riedel shears, the SE normal faults coincide with the tensional fractures, and the NNE left lateral faults coincide with (P) fractures.

The NNE and ENE fold axes east of the transform coincide with the drag folds of Moody and Hill (1956).
References


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