The tectonic geomorphology and the archeoseismicity of the Dead Sea transform in Jordan Valley

Abstract

Remote sensing and field studies of the Jordan Valley area from the Dead Sea in the south to the Lake Tiberias in the north shows different morphotectonic features indicating the active nature of the Jordan Valley Fault, which is a segment of the Dead Sea Transform. These features include different scale pressure ridges and sag depressions, stream offsets, linear valley courses along the transform, and fault scarps. In man made and natural trenches, the transform shows negative and positive flower structures associated with transtensions and transpressions respectively. In addition to active sinistral strike slip movement along the transform, the boundary faults show active vertical movement as indicated from fault scarps in the recent sediments. From the offset of Post Pleistocene streams, the calculated slip rate is 7.9±1.7 mm/yr in the past 13 Ka. The different deformational styles of the Quaternary sediments and the angular unconformity between the different units indicate six phases of tectonic movements ranging from the Pre-Pleistocene uplifting phase to the Holocene historical and instrumental earthquakes.

1. Introduction

The Dead Sea transform (DST) forms the boundary between the Arabian plate in the east and the Palestine- Sinai plate in the west. It connects the Red Sea divergent plate boundary, where sea floor spreading takes place, with the Taurus collision zone in the north. In Jordan, the Dead Sea transform consists of three morphotectonic segments, the Wadi Araba in the south, the Dead sea in the middle, and the Jordan Valley in the north(Fig..). The formation of the Dead Sea transform (Rift) started in the Early Miocene (Quennell, 1959). The left lateral displacement along the transformed is measured to be 107 km (Quennell, 1959). The seismic, historical, and archeological record of the Dead Sea region show that large earthquakes are known to have occurred along the DST (Poirier and Taher, 1980; Abou Karaki, 1987; Ben Menahem, 1991; Ambrayses et al, 1994). Slip rate calculations for the DST vary. Estimated geologic slip rate of 6-10 mm/yr is based on accumulated offset of 107 km of pre-Miocene rocks east and west of the transform (Zak and Freund, 1966; Freund et al, 1970). Based on aerial photograph analysis and earthquake catalogue information, Garfunkel et al. (1981) suggested that present day slip rate has been slower (1.5-3.5 mm/yr) when compared with the Pli-Pleistocene rates. Recent work on offset alluvial fan surfaces and

drainages along the northern Wadi Araba fault indicated a slip rate of 4.7 mm/yr (Niemi et al., 2001) and 4 mm/yr (Klinger et al., 2000).
The aim of this study is to map in detail the Jordan Valley fault (JVF), its subsidiary fractures, and morphotectonic features. Jordan Valley fault extends from the northwestern corner of the Dead Sea to the southeastern corner of the Lake Tiberias, crossing Jordan Valley diagonally. This study is based on field investigation, aerial photographic analysis, and TM Landsat interpretation. The fault trace can be observed very clearly in parts of the study area, in other areas the fault is covered by thick soil and farming. In man made and natural trenches cross sections of the transform can be described.

2. Geologic Setting

Jordan Valley is a morphotectonic depression, extends from the Dead Sea in the south to the Lake Tiberias in the north. It is about 104 km long and 7-25 km wide. The whole valley locates below sea level, its elevation ranges between 200 m below mean sea level in the Lake Tiberias to less than 412 m below sea level in the Dead Sea. The outcropping rocks in the Jordan Valley are mostly of Quaternary age (Fig.); The oldest is the Shaghur Formation of Late Pliocene to Early Pleistocene (Bender, 1968). These sediments outcrop at the northeastern corner of the Dead Sea, they consist of sandstone, conglomerate, limestone, and travertine. Ghor Al Katar Formation, of Early Middle Pleistocene (Bender, 1968), outcrops in the Dhahrat Al Qrein pressure ridge, it consists of conglomerate, sandstone, marl, and marly clay. The Lisan Formation covers a considerable area of the Jordan Valley. They were deposited in a lake extended from Lake Tiberias to the south of the present Dead Sea during the Upper Pleistocene (60 – 15 ka B. P. (Kaufman et al, 1992)). The sediments of this lake are mostly evaporites , they consist of laminated and varve- like gypsum, aragonite and calcite in addition to clay and sand layers (Abed and Yaghan, 2000). The Lisan Formation is overlain in some localities by the Damya Formation of Uppermost Pleistocene (Abed, 1985). It consists of 14 m calcareous siltstone and silty limestone.
Other recent sediments in the Jordan Valley are the alluvial fans at the eastern rim of the Valley floor, wadi deposits of the major streams crossing the valley floor. Soil and other recent sediments cover most of the Jordan Valley. The Jordan River flood plain sediments are concentrated close to the river course. The only basalt extrusion in the area is located in the Dhahrat Al Qrein pressure ridge.

3. Previous Work

Few studies concerning the neotectonic and active tectonic of the Jordan Valley fault (JVF) were done. The fault was mapped by Quennel (1956) and Bender (1968) in their 1:250 000 maps as an inferred fault trace. The

Jordan Valley fault was also mapped by McDonald and Partner (1965) in their 1:25 000hydrological maps. Part of the JVF was recently mapped as part of the Jordanian Natural Resources Authority mapping project (Abdelhamid, et al; Mohd and Muneizel, 1998). In these maps the location of the fault is mostly inferred. Garfunkel, et al (1981) studied the active faults along the whole length of the Dead Sea transform from the Gulf of Aqaba to Lebanon. Reches and Hoxter (1981) investigated the paleoseismic activity of the JVF, west of Jordan River near Jericho, by excavating trenches across the fault trace. Gardosh et al. (1990) dug trenches across the JVF along the western and northwestern margin of the Dead Sea, a minimum slip rate of 0.7 mm/y in the last 4 000 years was calculated in this study. Seismic reflection data of the JVF in Jericho area showed that the fault zone is about 1 km wide consisting of intensive deformation. The fault zone dips to the west having both reverse and left lateral components (Rotstein et al, 1991). Belitzky and Mimran (1996) studied the Dhahrat Al Qurein hill and explained it as an active salt dome. Ellenblum et al. (1998) through historical, archeological and geological investigation studied the deformation of a crusader castle in upper Jordan Valley and attributed the offset of its wall to the 1202 earthquake. Galli (1999) studied the recent movement along the Dead Sea transform from the Gulf of Aqaba to the Lake Tiberias including the Jordan Valley segment. Al Taj et al (2004) studied the orientation of fractures associated with the Jordan Valley fault (JVF)

4. Active faults of The Jordan Valley

Three types of active faults are recognized in the area of the Jordan Valley. First: The boundary normal faults of the rift margin, which show active uplift. Second: The transform fault itself, where active sinistral movement dominates and its morphotectonic features. Third: Other subsidiary faults of the transform, which have distinct orientation and sense of displacement.

In the area of Al Kafrein in the southern Jordan Valley (Fig.), a group of boundary faults trending NNE, NE, N, and NNW forming the border of the rift giving it a triangular shape. The NNE and the NE faults have sinistral movement and they could be a splay of the DST. Other subsidiary faults are shown on the map of Fig (..). In this area most of the JVF trace locates west of the Jordan River. It crosses the Jordan River at Zor Um Nakhla as a result of dextral offset by Nimrien dextral fault (Fig..). In a trench this fault forms a 1 m of brecciated zone with normal separation between the Lisan and Damya formations (photo 4.1 in the thesis).

In the area of Al Karamah (Fig…), the JVF zone forms the major feature of the area. In addition to the JVF, a group of parallel faults and subsidiary faults forms the fault zone. The JVF strikes N-S to N10^{0}E. It is clear in the Lisan beds. In some places the some streams follow the fault trace causing a clear linear stream course (Fig…). In some places fault step forms sag ponds and pressure ridge (Fig..). A group of parallel P shears are formed. The boundary normal faults in this area are clear striking NW-SE to NNW-SSE separating the bed rocks from the rift floor sediments. Indication of active uplift is the vertical offset of the recent alluvial fans. Man made trenches show a detailed deformation of the transform; the high steep Lisan and Damya beds, the presence of squeezed beds, and the formation of positive flower structures are example of high and recent deformation (photo Fig.4.7a). In one location the Lisan beds are folded and dragged (Photo fig. 4.7 b)

In the area of Dahrat Al Qurein (Fig..), the JVF shows a complex fault pattern. South of Dahrat Al Qurein three intersected fault zones trending NNW, NNE, and N-S, the first zone is Riedel Shears, the second is P shears and the third is the JVF zone. South of Dhahrat Al Qurein, the JVF bends to the right forming the Dhahrat Al Quren pressure ridge, which is the major transpression in the Jordan Valley. Dhahrat Al Qrein is 4 km N-S long and 2 km E-W wide. It is an elongated asymmetric ramp-anticline uplifted about 42 m relative to the surrounding area. In the center of this structure the single basalt in the Jordan Valley extruded. North of Dhahrat Al Qrein pressure ridge, the JVF steps to the left forming the Kibed sag pond. It is 570 m long and 240 m wide. The floor of this pond is 6 m below the top of the erosional surface of the Damya Formation. In this area, the JVF shows some morphotectonic features. A fault scarp of maximum 10 m height is observed 1 km north of Dhahrat Al Qurein. Many stream offsets were also observed north of Kibed sag pond, one of them is 12 m in a stream incised in the Damya Formation.

In Damya area, The JVF continues northward as a 12 km continuous zone striking N5E. 4 km south of the Zarqa River a 210 m long and 120 m wide sag pond was formed. The banks of the river itself are shifted sinisterly by about 80 m. South of Damya Village, Al Faraa active sinsistral fault branches out of the JVF, it strikes N30W west of the Transform in the western bank of Jordan representing a Riedel shear fracture. Field evidences shows that the Faraa fault is older than the JVF and it is sinistrally displaced by the JVF. Another active sinsitral fault branching from the JVF is the Zarqa River fault. It strikes N25E and represents a P shear. East of Damya Village a fault parallel to the JVF can be traced; it shows normal separation with downthrow to the west. Other small scale similar faults are traced west Muadi Village (Fig…). Boundary faults in this area are a continuation of those in the previous areas, where a group of N-S normal step faults separate the Mesozoic beds from the rift floor sediments. In cross sections the PDZ is recognized by normal and reverse separation faults in the Lisan beds uncomfortably overlain by the Damya beds (photo Fig. 4.12 or 4.20 or both)

In the area of Dair Alla, the JVF trace is close to the Jordan River. It is difficult in some places to follow the fault trace, because it passes into areas covered by the dense vegetation of the flood plain of the river. Indications of the fault trace are deformation of the Lisan Beds as tilting of strata, cracks, and minor folding. Left lateral deflection of Wadi Kufranja and the alignment of springs are other indications of the fault trace. Boundary faults are represented by N-S and NNW-SSE normal faults with some preserved fault scarps. Evidence of rupture due to historical earthquakes are found in the man-made Tall Deir Alla (Photo Fig. 4.26)

Tall Al Qarn area is characterized by a complex fault pattern, where several faults are interacted (Fig.)**.** In the southern part of the area, the transform consists of a bundle of faults. Stream offset across these faults reaches 100 m. further to the north; these faults form the Tall Al Qarn pressure ridge. This ridge is 2 km long and 1.5 km wide. North of the ridge the DST consists of en echelone fault strands separated about 150 m from each other. Within the pressure ridge of Tall Al Qarn a clear angular unconformity separating the highly dipping conglometare of the Ghor Al Kattar formation from the overlying horizontal Lisan beds (Photo Fig. 4.31). West of Wadi Al-Rayyan the fault steps to the left forming the wadi Ar Rayyan depression. This oval shape sag pond is 2 km long and 1 km wide. North of this depression the fault is represented by a single fault trace. North of Tall Al Qarn two dextral transverse fault were detected on satellite images and aerial photographs west of the transform (Fig..). They strike NW-SE. The horizontal offset across these faults reaches 1.5 km, the course of the Jordan River was deflected due to these faults. Boundary faults in this area consist of parallel faults of different generations and sharp scarps. They strike NNE-SSW in the southern part, NNW-SSE in the central part and again NNE-SSW in the northern part.

Tall Al Arbaeen area is characterized by thick soil cover and dense farms. Although, the extension of the JVF and the boundary fault can be recognized. The JVF can be traces as a linear fault trace, where some springs were located. The sense of sinistral movement can be detected from the bend of the streams. The fault steps to the right in two locations forming Tall Al Arbaeen pressure ridge in one of them. The Tall is 800 m dimeter circle and less than 20 m high. The formation of tall Al Arbaeen is similar to the formation of Tall Al Qarn. The boundary faults in this area have a general N-S trend. The eastern faults separate the Cenozoic rocks from the recent sediments, while the western faults cut the recent alluvial fans. These faults are cut in some places by NE-SW and NW-SE younger faults. Fault scarps can be recognizes along the trace of some faults.

The JVF in North Shuna area is covered by thick soil and dense farms. The fault trace can be delineated based on previous geophysical data and field investigation. Left lateral deflection of some stream courses, different level benches of soil and farm surfaces, and cracks in King Abdullah water canal all are indications of active sinistral movement of the JVF in this area. Small scale negative flower structure is observed in the in the recent gravel (Photo Fig. 4.39). The JVF leaves the Jordanian territories by forming a prominent sinistral deflection of Yarmouk River, where it continues to the north passing through the southeastern coast of Lake Tiberias forming a pull apart basin. The boundary faults in this area are mostly parallel N-S normal faults with clear fault scarps in some cases.

5. Discussion

The active strike slip fault of the Jordan valley (JVF), which is part of the Dead Sea Transform (DST) was mapped in detail. The outcropping sediments in the study area are mainly the Late Pleistocene soft Lisan evaporates and other Quaternary and recent sediments and soil. The active faults in the area can be divided into three main categories; the boundary faults, where uplift is the main process, the transform faults, where the main activity is the left lateral movement and finally the transverse faults crossing the Jordan Valley. Many morphotectonic features were described along the trace of the JVF, these elements include fault scarps, linear valleys, offset and beheaded streams, linear alignment of springs, sag ponds, pressure ridges. The fault planes are exposed along man made and natural excavations; positive and negative flower structures are observed across sag depressions and pressure ridges of different scales. In some locations highly deformed and crushed zones indicate intensive and recent deformations. Unconformities between different stratigraphic units with different deformation styles indicate different phases of deformation

The post-Lisan streams show different amounts of offset. The stream course offset of Wadi Ar Russief is about 125 m., the calculated slip rate in the past 13 Ka is 9.5 mm/yr. The offset of the Zarqa River is measured to be 84 m and the calculated slip rate is 6.5 mm/yr. The average slip rate as calculate from the above mentioned case is 7.9±1.7 mm/yr in the past 13 Ka. This figure is consistent with the average slip rate along the JVF fault derived from plate reconstruction and the regional kinematic models (Garfunkel, 1981; Tapponnier, 1992).

The tectonic history of the Jordan Valley as indicated from the Quaternary sediments can be summarized in the following phases. The first phase of uplift is prior to the deposition of the Early Pleistocene clastic Shaghur Formation. Shagur Formation overlies unconformably all older Mesosoic rocks. The second phase occurred at the end of early Pleistocene. This phase affected the Shagur Formation represented by N-S faults and westward dipping strata. The overlying Ghor el Katar sediments are not highly disturbed as the underlying Shagur Formationa. The third phase of tectonic movement was intensive during the Middle Pleistocene before the deposition of the Lisan sediments. The Ghor el Katar sediments are highly deformed relative to the overlying Lisan sediments. The Lisan sediments overly all older formation with a visible angular unconformity. The fourth phase can be interpreted from a minor block faulting affected the Lisan Formation, which can be dated to post Late Pleistocene. The Damya Formation, which is the youngest formation in the study area, was subjected to the fifth phase of deformation. In some places it overlies the disturbed Lisan Formation with angular unconformity. The sixth phase of activity is still active in the present time as indicated from the historical and instrumental earthquakes. Among the major earthquakes occurred in the Jordan Valley are the events of AD 33, 634, 748, 853, 1034, 1287, 1546, 1759, 1834 and 1927.