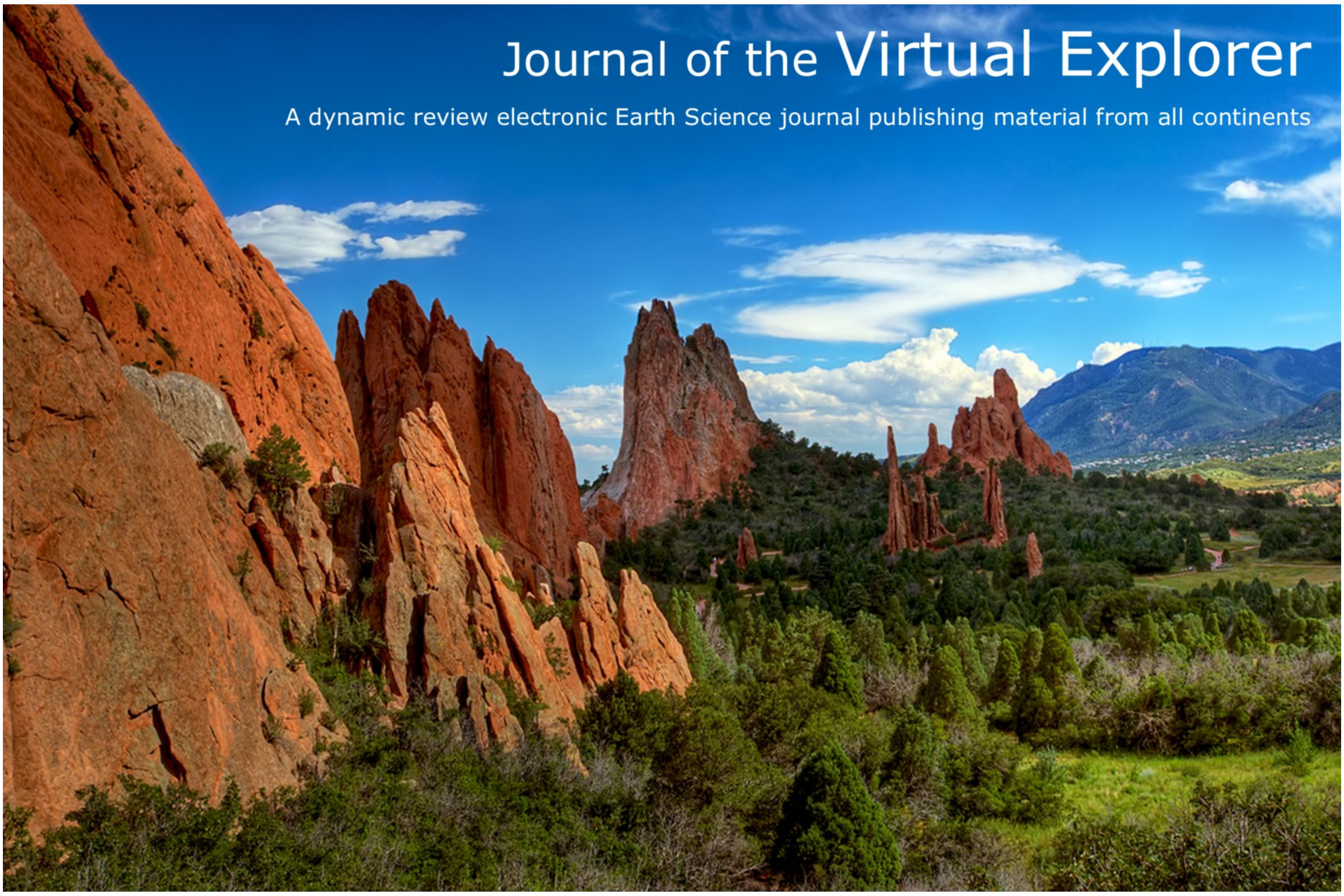


# Geological evolution of the Jordan valley

*Abdallah S. Al-Zoubi, Z.S.H. Abu-Hamatteh*

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**Abstract:** In the northwestern Arabian Plate, Dead Sea represents one of the most important geological features in the region as its geodynamic setting represents the last significant event that took place in the breaking of the Plate. Integrating the available geological and geophysical data will help to draw a sequence of evaluation of the study area. The tectonic history of Jordan may be divided into three phases: (1) the Gondwana; (2) Syrian Arc, and (3) Rift phase. A strike-slip fault type motion along the Dead Sea Rift was initiated during the Middle Miocene which developed a small component of oblique extension during the post Miocene time leading to opening of several basins along the rift. Subsidence of the rift probably commenced in the Pliocene with the deposition of the evaporite sediments in the Dead Sea basin which was accelerated during the Pleistocene.

**Citation:** Al-Zoubi, A., Abu-Hamatteh, Z. 2009. Geological evolution of the Jordan valley. In: (Eds.) Talat Ahmad, Francis Hirsch, and Punya Charusiri, *Journal of the Virtual Explorer*, volume **32**, paper 9, doi: 10.3809/jvirtex.2009.00248

## Introduction

Jordan is situated at the northwestern side of the Arabian Plate, along the eastern flank of the ancient Tethys Ocean in the western side of the Dead Sea Transform. Dead Sea Transform extends for more than 1000 km from the northern end of the Red Sea, where the crust is currently extending to the Taurus zone plate collision in Europe. Ever since the time of its formation, less than 20 my ago, the Dead Sea Transform Fault has undergone about 105 km left-lateral horizontal displacement (Freund *et al.*, 1970; Garfunkel, 1981; Hatcher *et al.*, 1981; Quennel, 1958; Girdler, 1985), leading to have Jordan situated at the transition zone between the stable part of the Arabian Plate and the unstable area of the Dead Sea Transform Fault. Lovelock (1984) suggested that the crust in the northwestern part of the Arabian Plate (beneath Jordan) has been fragmented into stable blocks separated by mobile zones. While the crystalline basement and sedimentary cover holds a block structure with faults to serve as blocks boundaries.

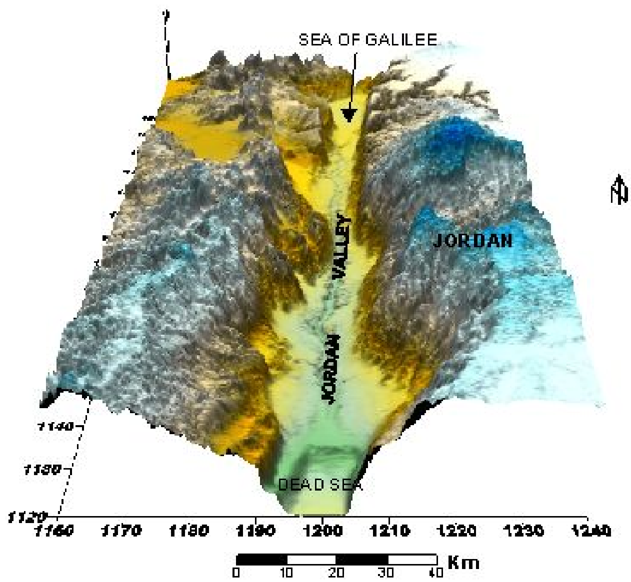
Despite of its significant geodynamic settings, the Jordan block structure and its boundaries has been subjected to limited investigation. Although several studies on the sedimentary basin of Jordan have been conducted, most of these tend to focus on the large basins such as Dead Sea, Al-Azraq, Wadi Sirhan, El Jafer and Risha Basin particularly in reference to oil exploration which were largely based on seismic investigation.

The Jordan Valley covers an area of about 700 km$^2$, extending from the Dead Sea shores in the south to Lake of Tiberia (Sea of Galilee) in the north. It is about 105 km long and up to 20 km wide. Compared to the other basins along the Dead Sea Rift such as Gulf of Aqaba, Dead Sea, Lake of Tiberia (Sea of Galilee) and Hula basins, it is the shallowest one, having only up to 300 m of Pleistocene to Miocene sediments (Fig. 1 a and b).

## Jordan valley

The Jordan Valley is a morphotectonic depression that extends from the northern shoreline of the Dead Sea to the Sea of Galilee. This depression is bordered on the eastern and western sides by faults and flexures. The Bouguer gravity data indicates that the character of the plate boundary changes to the north of the Dead Sea (ten Brink *et al.*, 1999; ten Brink, *et al.*, 2001; Al-Zoubi *et al.*, 2006). The Jordan Valley comprises several separate small basins (Jericho (Shuna) basin, Damia, Bet-Shean and Bakura).

**Figure 1a. Location map of the Jordan Valley**



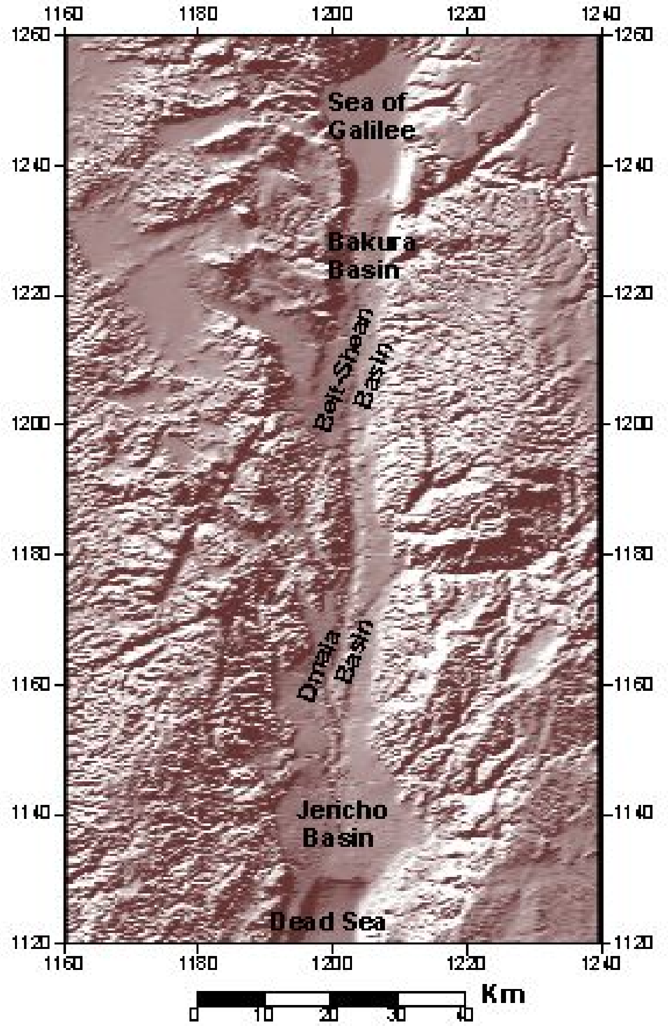

Location map of the Jordan Valley

The Jericho basin plunges westward and terminates against a west dipping strike-slip fault. A buried monocline parallel to the fault segment was found and served as independent evidence for a local compression (Rotstein *et al.*, 1991). Recently, Al-Zoubi *et al.* (2006) found the same kind of structure on the Jordan side and called it the Al-Kharar monocline. They suggested that this is a young active structure which formed as a result of compression in the Shuna area due to the motion along the transform fault. In addition, several normal active faults were also found within the valley.

The Damia basin is a shallow and complex structure with several parallel faults at the edge and within the basin. The Bouguer (ten Brink *et al.*, 2001) and the seismic data (Ben-Menahem, 1991; ten Brink *et al.*, 1999; Al-Zoubi *et al.*, 2006; ten brink *et al.*, 2006) show that the major fault is buried under a few hundred meters of sediments where the surface geology and the abrupt stream course-change indicate the recent activity in the area (Garfunkel, 1981).

The Bet-Shean basin, as a part of Mallaha structure (middle part of the Jordan Valley), was formed under transpression resulting from lateral slip combined with friction and pressure in this area (Belitzky, 2002). The transpression in this area produced counterclockwise rotation of the major fault. This rotation is combined with lateral slip on the east-west faults.

**Figure 1b. Shaded relief topography image of the Jordan Valley Basin**




Shaded relief topography image of the Jordan Valley Basin showing the sub-basins from digital terrain model (Hall, 1993). Coordinates are in Cassini Palestine grid

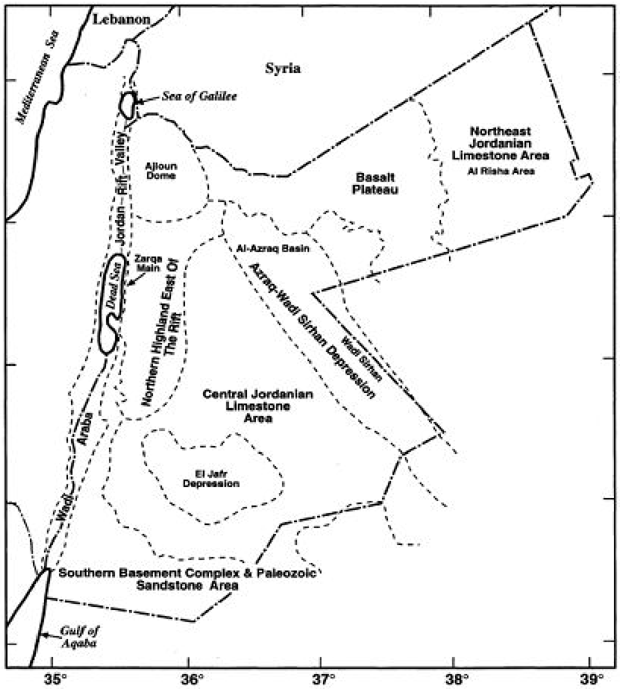
The Jordan Valley consists of flood plain of the Jordan River and the Jordan valley floor. The basin represents the Jordan Valley Rift with pronounced geologic depression recording elevation ranges from 200m to 400m below sea level. Although, several geological and geophysical studies have been performed along the Jordan Valley, but the subsurface structure of the basin is still not well understood (e.g., ten-Brink and Ben-Avraham, 1989; Frieslander *et al.*, 1995; Al-Zoubi and ten-Brink, 2001; Al-Zoubi and ten-Brink, 2002). The Jordan Valley Rift is a part of Dead Sea Rift, which is a site of large scale motion. The motion along the Dead Sea Rift was initiated in the Middle Miocene (15.5 –11.5 m.y. ago). The movements along the Dead Sea faults are of strike-slip type. In post Miocene times it changed to strike-slip with a small component of oblique extension, resulting in the opening of basins along the rift (Garfunkel, 1981). Of the 105-km total left lateral offset along the Dead Sea fault, only 30 km probably occurred in the last 5 m.y. (Joffe and Garfunkel, 1987).

Global plate tectonic models, on the other hand, indicate a faster differential motion between Africa and Arabia. Subsidence of the rift probably commenced in the Pliocene (5 m.y. ago) with the deposition of the evaporitic sediments in the Dead Sea basin. It accelerated during the Pleistocene with the deposition of several km of lacustrine, fluvial and continental sediments (Kashai and Crocker, 1987). This paper attempts to integrate the available geological and geophysical data to arrive at the sequence of evolution of the geology of Jordan.

## Geological and physiographic subdivisions

Deposits of Quaternary age in Jordan reflect continuous uplifting and retreating of the marine environment, extensive mafic volcanic and shallow intrusive activity. The volcanics occur as localized flows and plugs, and as plateau flood basalts. These are chemically primitive and appear to reflect rapid propagation of fractures into the mantle, followed by rapid extrusion (Barberi *et al.*, 1979). Based on geological, paleogeographic and stratigraphic evidence, the territory of Jordan can be sub-divided into seven major geological physiographic provinces (Fig. 2).

**Figure 2. Geologic–physiographic provinces of Jordan.**




The map shows the Wadi Araba-Dead Sea–Jordan Rift Valley, Northern Highlands East of the Rift, Southern Basement Complex and Paleozoic Sandstone Area, Azraq–Wadi Sirhan Depression, Basalt Plateau, the Northeast Jordan Limestone Area and the Central Jordan Limestone Area (after Bender, 1975)

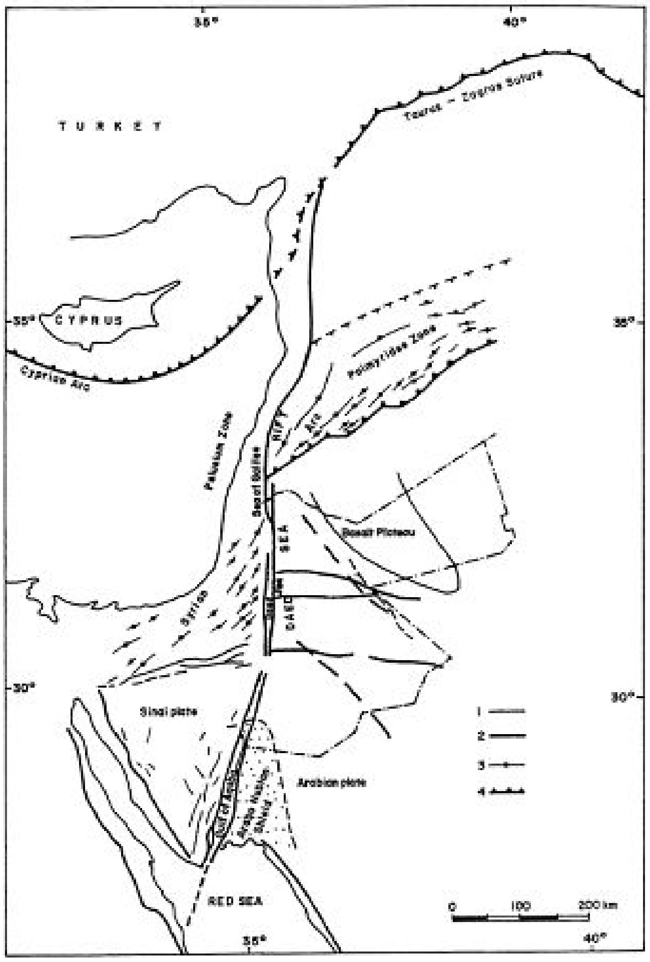
Wadi Araba-Dead Sea–Jordan Rift Valley, Northern Highlands East of the Rift, Southern Basement Complex and Paleozoic Sandstone Area, Azraq–Wadi Sirhan Depression, Basalt Plateau, the Northeast Jordan Limestone Area and the Central Jordan Limestone Area (Bender, 1975).

## Discussion

The oldest known rocks of Jordan, classified as a Pre-Cambrian Aqaba Granite Complex, outcrops in its south-western part. Since the Pre-Cambrian age the granitic shield is predominantly a land surface ringed by seas receiving sediment from the land. Generally, Jordan tectonic history is divided into three phases: the Gondwana, Syrian Arc, and Rift phases (Dewey *et al.*, 1973).

Numerous destructive earthquakes occurred during historical times in the area of study. Many of them are documented in the Bible and in the later Roman and Arabic sources. The Dead Sea fault system north of Gulf of Aqaba comprises faults with segment lengths varying from 25 to 55 km (ten-Brink *et al.*, 1999) (Fig. 3).

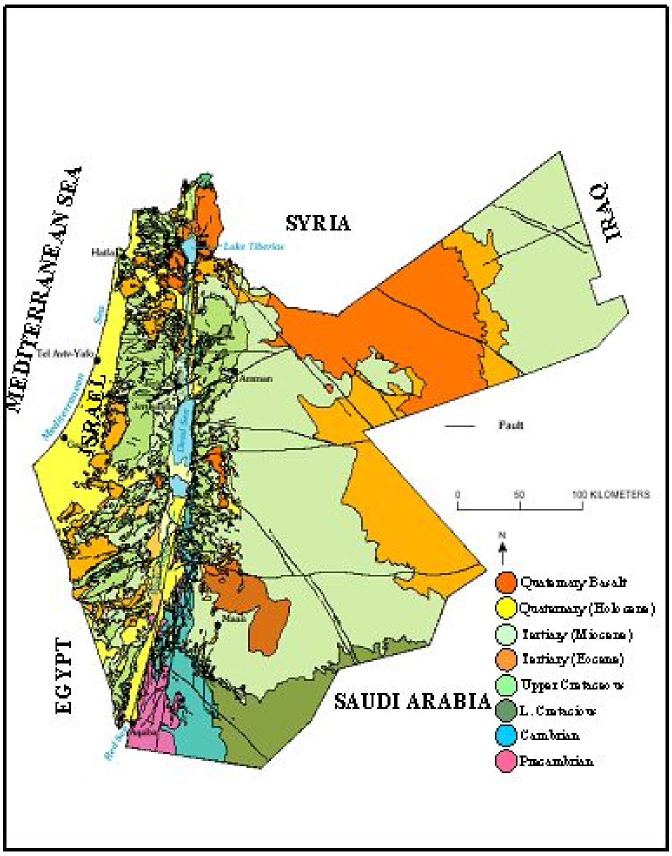
**Figure 3. Generalized tectonic setting of the Middle East**




Generalized tectonic setting of the Middle East, showing the Arabian plate, Sinai sub-plate, the Dead Sea transform (including Gulf of Aqaba, Dead Sea, and Sea of Galilee) and Palmyrides zone. (1) Faults; (2) main faults; (3) fold axes; and (4) main thrust fronts (modified after Ben-Avraham and Grasso, 1991; Bender, 1975)

More fault segments are shown buried on seismic reflection profiles, which do not offset or perturb the upper sedimentary section (e.g., ten-Brink and Ben-Avraham, 1989; Frieslander *et al.*, 1995; Al-Zoubi and ten-Brink, 2001; Al-Zoubi and ten-Brink, 2002), indicating that they are no longer active. The crustal structure of Jordan has been a matter of debate. Most of these studies in this context have focused on the Red Sea, the Dead Sea and the western side of the transform (Ben-Avraham *et al.*, 1996; Ginzburg and Ben-Avraham, 1997; Ginzburg and Folkman, 1981; Ginzburg *et al.*, 1981; ten Brink *et al.*, 1990, 1993). The deep crust and upper mantle in the eastern side of the transform have been investigated using earthquake and seismic refraction methods with limited scope (El-Isa, 1990; El-Isa *et al.*, 1987; Kovach *et al.*, 1990). The characteristics of the crustal structure of Jordan was investigated by Al-Zoubi and Ben Avraham (2002), using the potential field methods over a broad region. The oldest rocks known in the area, dated as Pre-Cambrian (more than 450 million years; Bender, 1974), outcropping in its southwestern area (Fig. 4).

**Figure 4. Regional geological map of Jordan**




Regional geological map of Jordan

The Northwestern Arabian block (Jordan) has been generally regarded as structurally featureless, except for a few well-acknowledged faults. Jordan Geological Map (modified after Bender, 1968) displayed only few sets of faults (Fig. 4) trending N-S and NW–SE and E-W striking short faults in the central part of Jordan. The significance of these faults is due to the fact that they control the mineral deposits, oil and gas within several sedimentary basins and groundwater flows. Similarly, there are other natural resources (mineral deposits, hydrocarbon and groundwater flow) scattered at various geologic sites associated with fluid conducting faults.

Since the Pre-Cambrian times, the granitic shield, which is known as Aqaba Granite Complex (AGC), continued to be main sediments source to the surrounding basins. The tectonic history of Jordan may be divided into three distinct phases: (1) the Gondwana; (2) Syrian Arc, and (3) Rift phases (Dewey *et al.*, 1973).

### *The Gondwana phase*

During the Gondwana Phase (Cambrian–Early Cretaceous), Jordan occupied a position near the northern margin of the Gondwana paleocontinent. Tectonically, the area was relatively stable and sedimentation was dominantly continental, with minor but widespread marine incursions. Lower Paleozoic rocks of Cambrian, Ordovician and Silurian age outcrop in southern part of Jordan. On the western side of the Dead Sea–Jordan Rift Valley, the presence of the upper Carboniferous and Permian rocks of the pre-rift sequence, are continental clastic to shallow marine carbonate.

### *The Syrian arc phase*

The sedimentation pattern of Gondwana phase continued into the Triassic and Early Jurassic but became increasingly more marine. The shoreline position from Triassic to Late Cretaceous remained roughly stationary across central Jordan with the sea opening in the northwest.

During the Late Cretaceous, subduction of the Neo-Tethyan oceanic lithosphere was initiated to the north. The resulting compression along the southern margin of the Neo-Tethys is indicated by locally obducted ophiolites and folding in the Syrian Arc trend. The Syrian Arc defines a sigmodial trend extending from the northern Sinai northwards into Syria (Fig. 3), following the trend of the Late Cretaceous continental margin. Extension within the Arabian plate during the Late Cretaceous (Bender, 1974; Lovelock, 1984) caused a series of northwest-trending basins such as the Al-Azraq and Wadi Sirhan Basins (Fig. 2).

Later strike-slip faulting in the Neogene modified the overall configuration and structural style of the Al-Azraq and Wadi Sirhan Basins and offset the fold geometry of the Syrian Arc trend. Transgressions from the northwest to the southeast occurred several times during the Mesozoic. In the western part of Jordan, volcanic activity is represented by dykes and sills of mafic to felsic composition, was active between Middle Jurassic and Early

Cretaceous. These intrusives are found in the Wadi Araba region cutting Mesozoic sedimentary rocks (Bender, 1974) with a prominent magnetic expression. During the Late Oligocene–Early Miocene, left lateral movement along the Dead Sea–Jordan Rift Valley was initiated. Coarse lenticular unsorted conglomerates begin to appear in the section overlying Late Cretaceous or Early Tertiary units in the eastern Wadi Araba Area showing an unconformable relationship locally. The field evidence from several localities indicates uplift and probably tectonic activity (Bender, 1974). The regional fault system consists of a series of three major west-stepping, en-echelon faults, with well defined pull-apart basins formed at each of the major offshoots (the Gulf of Aqaba, Dead Sea basin and Sea of Galilee basin: Figs. 2 and 3).

### *The rift phase*

Total strike-slip displacement along the Dead Sea Rift system is estimated at 105 km (Freund *et al.*, 1970). Matching the structural and sedimentary features offset across the fault zone, Quennell (1951) estimated that separation took place at two successive stages during the Miocene and the Late Pleistocene.

Garfunkel (1981) and Freund *et al.* (1970) have reached a similar conclusion by measuring contemporaneous motion in the adjoining Red Sea and they suggested that the second rift stage took place at 4–5 Ma ago. As the Dead Sea rift opened, more than 3.5 km of evaporites were deposited, probably during the Late Miocene to Early Pleistocene (Bender, 1974). The amount of basin fill within the Dead Sea basin exceeded than 10 km (Ginzburg and Ben-Avraham, 1997).

## Concluding remarks

An integration of geological and geophysical information from Jordan shows that the Jordan Valley had a complex geological evolution. Dominantly clastic sedimentation in the Gondwana phase gave way to dominantly marine during the deposition in the Syrian Arc phase. The initiation of the present shape of the Jordan valley can be traced to the formation of Dead Sea basin which, itself, was a consequence of a modification of strike slip motion of the Dead Sea Rift.

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