The Dead Sea Fault and its Effect on Civilization

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Abstract

The Dead Sea fault (DSF) is the most impressive tectonic feature in the Middle East. It is a plate boundary, which transfers sea floor spreading in the Red Sea to the Taurus collision zone in Turkey. The DSF has influenced many aspects of this region, including seismicity and ground water availability. It may have even affected the course of human evolution.

Numerous geophysical and geological studies of the Dead Sea fault provide insight into its structure and evolution. Crustal structure studies have shown that the crust at the fault zone is slightly thinner than that of the regions west and east of it. A transition zone between the lower crust and the Moho under the fault was mapped.

The region has a remarkable paleoseismic record going back to about 70 ka years. Several earthquakes, such as the one that occurred in the Dead Sea region on 31 BC, may have even influenced the course of history of this region. The confusion and fear inflicted by the earthquake paved the way for the expansion of Herod's kingdom. Places such as Jericho, the oldest city in the world, which are located within the valley formed by the fault, were affected immensely by seismic activity.

The DSF is an important part of the corridor through which hominids set off out of Africa. Remains of the earliest hominids are found in several sites along the Dead Sea fault, including Erk-el-Ahmar, Ubediya and Gesher Benot Ya'aqov. It is interesting to note that acceleration in the vertical motion along the Dead Sea fault, which produced its present physiography, began slightly before man had started his way out of Africa northwards.

1. Introduction

The Dead Sea fault (DSF) is the most impressive tectonic feature in the Middle East (Fig. 1). It is a left lateral transform plate boundary, separating the Arabian plate and the Sinai sub-plate. The transform has been active since the Miocene (Garfunkel, 1981; Garfunkel and Ben-Avraham, 1996) with movement continuing today. Motion is transferred along the fault from the opening of the Red Sea in the south, to the Taurus-Zagros collision zone in Turkey and Iran to the north. It is one of the most seismically active regions in the Middle East.

The region has a remarkable historical and geological record of seismicity going back to about 70 ka. Several historical earthquakes have caused extensive damage in the area. Places such as Jericho, the oldest city in the world, or Bet She'an (Fig. 2), one of the largest cities in the region in Roman time, were greatly affected by seismic activity.

Crustal structure studies have shown that the crust directly under the fault valley is somewhat different from that on the sides. These differences in crustal structure may have controlled the evolution of physiography in the region. Since the Miocene the margins of the transform were uplifted in several stages and the rift floor subsided, creating the present-day physiography. A large part of the transform is situated below sea level. The lowest place along the transform (and on Earth) is the Dead Sea basin (Ben-Avraham, 2001).

The physiography of the Dead Sea fault is a result of vertical motion, which caused subsidence of the floor of the rift and uplift of its shoulders. Acceleration in the vertical motion began shortly before man started his way out of Africa. Remains of the most ancient hominids outside Africa are found along the DSF, which actually formed a corridor through which hominids set off out of Africa. The geological evolution of the DSF and the active tectonic processes occurring along its length, thus, may have affected the course of human history.

2. Crustal Structure

"In his hand are the deep places of the earth: and the strength of the hills is his also. The sea is his and he made it: and his hands formed the dry land" Psalm 95:4-5

Seismic refraction studies along the DSF indicate that the crust directly under the fault valley is thinner than that on both sides. It is 33 km thick at

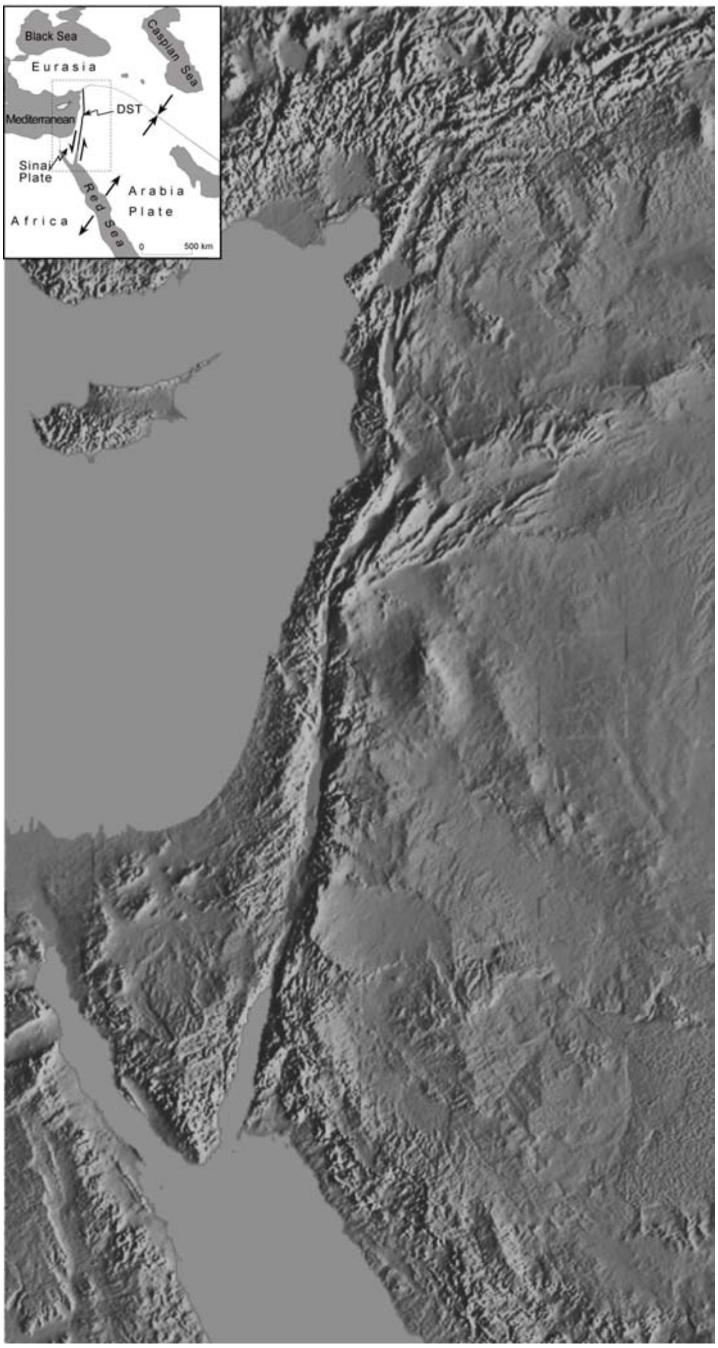

Fig. 1. Digital Terrain Model (DTM) of the Middle East. Inset: tectonic setting

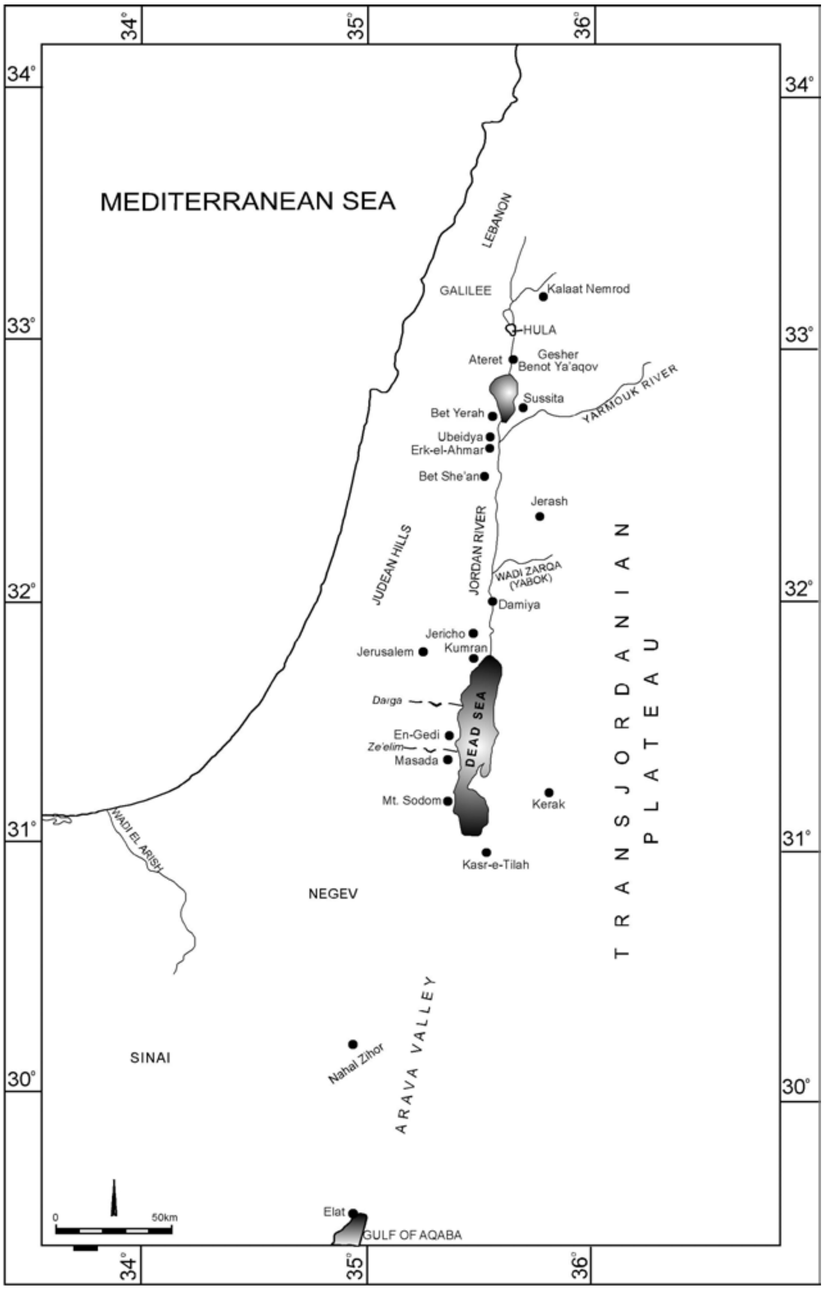

Fig. 2. Sites along the Dead Sea fault mentioned in the text (modified after Horowitz, 2001)

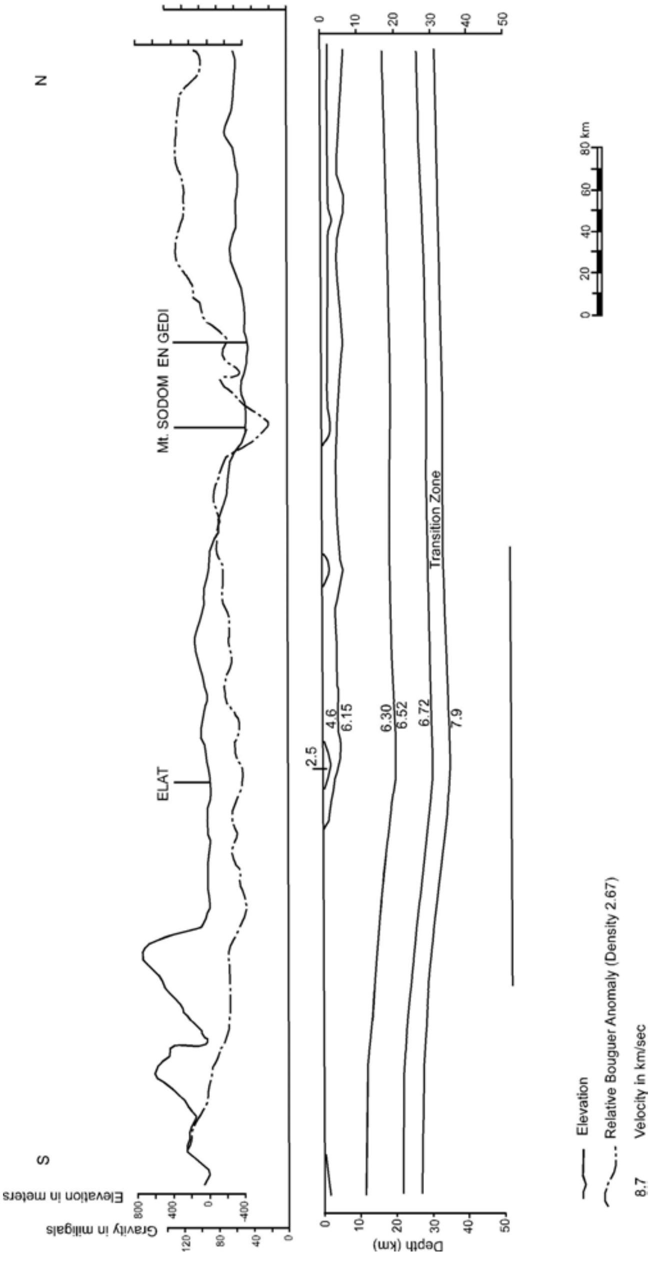

Fig. 2 A composite section along the Dead Sea Fault from the Sea of Galilee to the Red Sea showing the calculated crustal model and the relative Bouguer anomaly (after Ginzburg, 1981). The locations of Elat, Mt. Sodom, and En Gedi are shown in Fig. 2

the Dead Sea basin and shows a slight thickening towards Elat. From Elat south the crust thins gradually from a thickness of 35 km to a thickness of 27 km, 160 km south of Elat (Ginzburg et al., 1979). A discontinuity between the upper and lower crust was also observed (Fig. 3). The seismic refraction data also show a 5 km thick velocity transition zone within the lower crust above the crust-mantle boundary. In other areas adjacent to the fault the crust-mantle boundary is manifested as a sharp velocity discontinuity. However, many questions still remain as to the detailed crustal structure along the DSF (DESERT group, 2000).

The Dead Sea basin itself provides evidence for dramatic activity during the Plio-Pleistocene. Crustal studies indicate that a thick sedimentary fill characterizes the two basins of the Dead Sea graben. Depth to basement is about 6 km in the northern basin and more than 12 km in the southern basin (Fig. 4) (Ginzburg and Ben-Avraham, 1997). Local earthquake data indicate the presence of lower crustal seismicity under the transform. In the Dead Sea basin, hypocenters are located almost as deep as the Moho discontinuity (Aldersons, in preparation).

The changes in crustal thickness across the transform implies that it is a relatively narrow zone of deformation, which penetrates the entire crust (ten Brink et al., 1990). This unique crustal structure allowed the dramatic uplift of the transform margins and subsidence of the floor of the fault since the Miocene until present.

3. Evolution of Physiography

"Every valley shall be exalted, and every mountain and hill shall be made low; and the crooked shall be made straight, and the rough places plain" Isaiah 40:4.

The prominent morphotectonic expression of the DSF (Fig. 1) is characterized by the deepest continental depressions in the world, flanked by up to ~3-km-high margins (Fig. 1). In general, the eastern shoulder rises gently towards the west, reaching its highest elevations near the transform and drops abruptly into the median valley. The elevation of the eastern shoulder is usually higher than that of the western shoulder, reflecting broad regional uplift along the rift (Wdowinski and Zilberman, 1997).

Present-day physiography of the DSF formed as a result of continental breakup processes took place since the beginning of the Miocene throughout the Present. In the Plio-Pleistocene, a major tectonic phase uplifted the margins. During this period the Arava rift valley subsided and the Negev was uplifted and tilted (Avni, 1998). The accelerated uplift at the end of

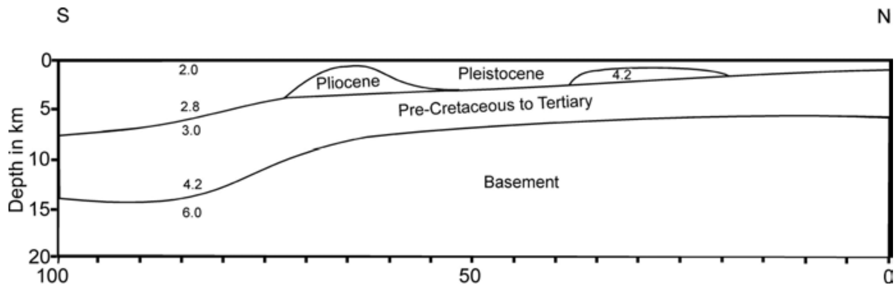

Fig. 3 Velocity-depth section along Dead Sea from north of the northern basin, to the southern basin. The 2.0 km/s velocity represents the Pleistocene fill of the basin. The 4.2 km/s velocity is associated with Pliocene evaporates. The 6.0 km/s velocity represents the top of the crystalline basement, while the overlying 3.0-3.8 km/s is associated with the Tertiary to pre-Cretaceous sediments (after Ginzburg, 1997)

the Pliocene and the Pleistocene affected river drainage patterns in the Negev and a massive rise in topography. Consequently large fresh water lakes developed in the southern Negev (such as Nahal Zihor, Avni, 1998; Ginat, 1996) and within the Arava valley, indicating a more humid environment (Avni, 1998). At the same time 200 m arching occurred in the Galilee (40-60 km wavelengths) dated at 1.8 Ma using basalt clasts constraint (Matmon et al., 1999).

Subsidence of the Dead Sea graben began in the early Miocene. Thick sequence of Pliocene and probably also Late Miocene evaporites, with Pleistocene sediments represent acceleration of subsidence rate (Fig. 5) (ten Brink and Ben-Avraham, 1989). Sedimentological evidence also supports a low topographic relief during the Pliocene, but a high relief during the Pleistocene (Sa'ar, 1985). A detailed study of subsidence rate in the southern Dead Sea basin was carried out by Larsen et al. (2002). It has been suggested (Ginzburg and Ben-Avraham, 1997) that during subsidence, normal faults between the northern and southern basins (Ben-Avraham, 1997) induced large vertical displacements, which in turn may have caused a greater deepening of the southern Dead Sea basin.

The tectonic processes that have modified the crustal structure along the Dead Sea fault are responsible for the creation of a morphological valley where a unique microclimate could develop. These ideal conditions would create a friendly environment, which would allow the migration of flora and fauna (and even man) from Africa northwards, within a wider corridor, often referred to as the Levantine Corridor (Bar-Yosef and Belfer-Cohen, 2001).

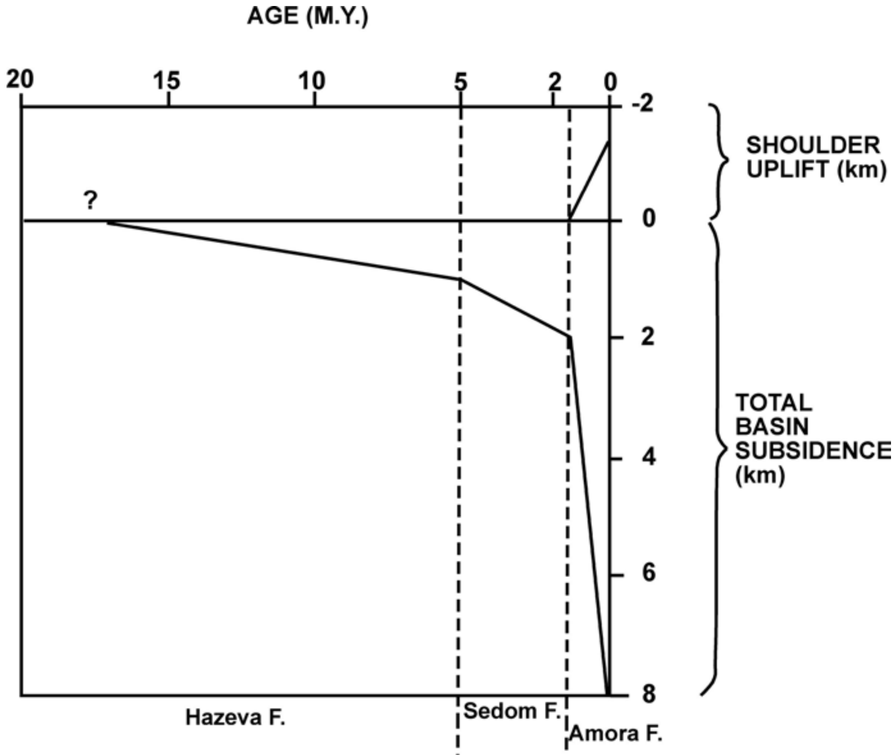

Fig. 4 Estimates for total subsidence of the Dead Sea basin with time based on stratigraphic interpretation of seismic lines. Approximation for the total up-lift is based on the current elevation of Late Cretaceous layers east of the Dead Sea basin (after ten Brink, 1989)

4. Ancient Hominids out of Africa

The common approach in the study of ancient hominids and their culture, relates to the early archaeological evidence from eastern Africa, about 4-5 Ma, as the cradle of humankind (e.g. Bar-Yosef and Belfer-Cohen, 2001). The earliest evidence for human activity was found in Kenya, Ethiopia and Tanzania. Amongst these findings were remnants of stone tools related to the Acheulian (tool-making culture in which large nodules of flint were shaped to create hand axes), remnants of animals and even remains of hominids. These sites are dated as Plio-Pleistocene (>2 Ma). Hominid remains outside Africa delineate the routes of their spreading to the rest of the world (Fig. 6).

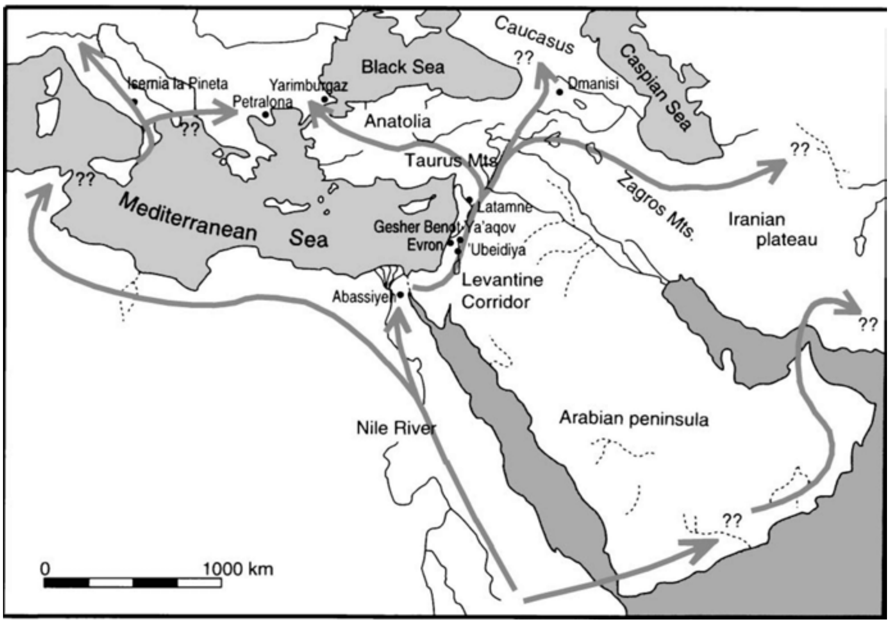

Fig. 5 Archeological evidence indicate at least three waves of early hominid migration out of Africa, but there were probably more. Map shows the sug-gested routes (after Bar-Yosef and Belfer-Cohen, 2001)

Human migration from Africa northwards is part of a wider phenomenon of migration of fauna and flora, which occurred along with the relief accentuation of the Dead Sea fault margins. A likely explanation for the relatively high number of tropical organisms, especially Ethiopian, along the Dead Sea fault is by migration, as today a vast desert separates them from their relatives in Africa and Asia (Tchernov, 1986). The DSF is a preferred migration route for billions of birds between Africa and Europe. It is one of the three major bird migration routes along with Gibraltar, and Sicily (Leshem, 1986), which are also known to be paths of hominid migration.

The morphology of the DSF created conditions in which fresh water bodies existed since the Pliocene. The lakes created friendly environments, richly varied in fauna and flora, for migrating hominids (Horowitz, 2001) along the fault. The Levantine Corridor, which extends from the Mediterranean coast on the west to the Jordanian plateau on the east, channeled hominids, technologies and materials from Africa to Asia and visa versa (Bar-Yosef, 1987). We argue that the DSF created a favorable zone within this corridor.

Archeological evidence of early hominid migration out of Africa show at least three pulses (Bar-Yosef and Belfer-Cohen, 2001). The earliest site in which human related flint artifacts were found is the Erk-el-Ahmar, about 10 km south of the Sea of Galilee (Fig. 1). Combined paleontologic and paleomagnetic dating of Erk-el-Ahmar yielded 1.7-2.0 Ma (Braun et al., 1991; Horowitz, 1979, 1989; Ron and Levi, 2001). The next pulses are observed at Ubediya, 1.4 Ma (Bar-Yosef and Goren-Inbar, 1993); and Gesher Benot-Ya'aqov, 0.78 Ma (Goren-Inbar et al., 2000).

In contrast to the sporadic findings in Erk-el-Ahmar, a series of sites were found in Ubediya (3 km southwest of the Sea of Galilee and 255 m below MSL), which represented numerous returns to the same location, close to a lake. According to Bar-Yosef and Belfer-Cohen (2001), the Ubediya site provides the best data set for the Levant. More than 60 archeological horizons were excavated in Ubediya, relating to different sedimentation sequences. The Acheulian artifact assemblage of Ubediya is very similar to the one in Upper Bed II of Olduvai Gorge (~1.4 Ma: Goren-Inbar, 2000). The bio-stratigraphic dating is based on the remains of over 100 species of mammals, birds and reptiles (Tchernov, 1999).

The mid-Acheulian site near Gesher Benot-Ya'aqov, on the banks of the Jordan River ~15 km north of the Sea of Galilee, dated to 0.78 Ma (paleomagnetic reversal and oxygen isotope stage 19), presents technological innovations, which appear for the first time outside of Africa (Goren-Inbar et al., 2000). The site is rich in flora and fauna remains. The Gesher Benot-Ya'aqov lithic assemblage, which is unique compared to contemporary sites in Eurasia, shows the development of complex human cognitive abilities in the tool industry.

5. Seismicity along the Dead Sea Fault

"For thus saith the Lord of hosts; yet once, it is a little while, and I will shake the heavens, and the earth, and the sea, and the dry land" Haggai, 2:6.

The Dead Sea Fault is seismically active (Fig. 7). Man and earthquakes have coexisted along the DSF since early hominids migrated to this region some 2 Ma ago. Three sources provide information on past earthquakes: Instrumental data that have been amassed since the early 20th century, historical and archeological data that cover the last few millennia, and paleoseismic geological data that span tens of thousands of years. Paleoseismic studies along the DSF were initiated by Gerson and his colleagues in the

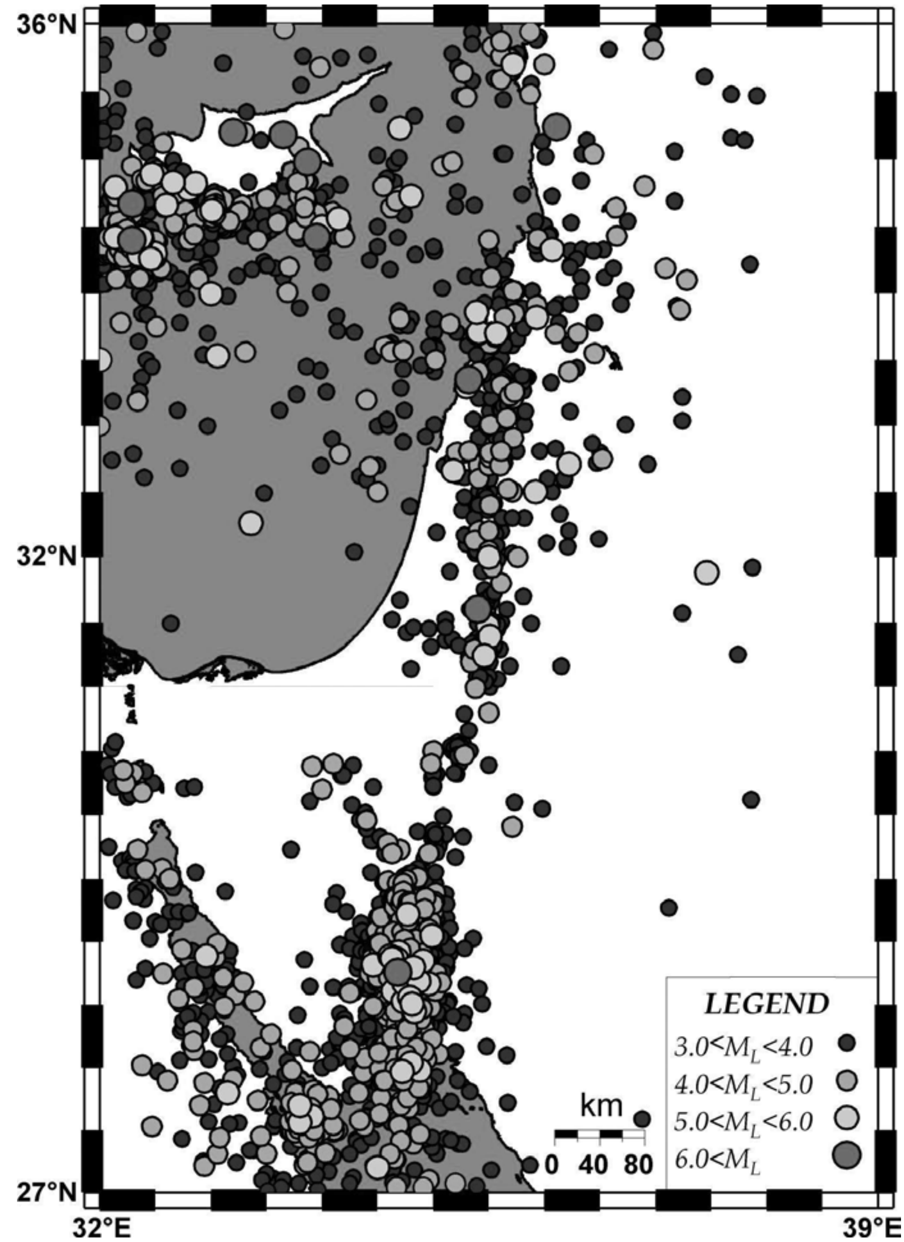

Fig. 6. Epicenters distribution map of earthquakes with ML>3 in the eastern Mediterranean between 1900-2000 (Geophysical Institute of Israel, 2002)

southern Arava (Gerson et al., 1993) and by Reches and Hoexter (1981) near Jericho. Subsequent studies have augmented our knowledge on the seismic activity of the DSF, although many questions still await further research.

The study of seismicity along the DSF benefits from several advantages. The tectonic framework is relatively simple with a single major plate boundary - the DSF. Arid climate entails excellent exposures. Sedimentary basins preserve sediments that potentially record tectonic events. In addition, the area has been inhabited throughout history. Written accounts on various phenomena, in particular earthquakes, are relatively abundant.

5.1 Paleoseismic Record

Broken and mixed lacustrine seasonal laminae in the Dead Sea basin ("mixed layers", Fig. 8) were interpreted as seismites - layers that exhibit earthquake-triggered deformation. Undisturbed laminated layers between these mixed layers represent interseismic intervals (Marco and Agnon, 1995). The mixed layers in the Late Pleistocene lacustrine Lisan Formation and its subsequent Dead Sea sediments comprise an almost continuous 70 ka paleoseismic record in the Dead Sea basin (Ken-Tor et al., 2001; Marco et al., 1996). Ken-Tor et al. (2001) show a remarkable agreement between mixed-layer ages and historical earthquakes in the last 2 millennia in the Dead Sea basin (Fig. 9), strengthening the interpretation of the mixed layer as seismites. Enzel et al. (2000) recovered evidence of combined faulting and shaking effects in the Darga alluvial fan, northern Dead Sea. Paleoseismic on-fault studies revealed slip histories on marginal normal faults of the southern Arava (Amit et al., 2002), the Dead Sea (Marco and Agnon, 2002), and the Hula basin (Zilberman et al., 2000). Strike-slip movements have been measured and dated on the Jordan Gorge Fault, north of the Sea of Galilee, where 2.2 m and 0.5 m sinistral slip occurred in the earthquakes of 1202 and 1759 respectively. A 15 m displacement of a 5 ka stream channel gives a minimum average displacement rate of 3 mm/a (Marco and Agnon, 2003). Klinger et al. (2000a) and Niemi et al. (2001) dated offset channel deposits in alluvial fans in the northern Arava. They conclude an average Late Quaternary slip rate of about 4-5 mm/a (Table 1). For comparison, it is an order of magnitude smaller than across the San Andreas system.

Fig. 7. Broken and mixed lacustrine seasonal laminae in the Dead Sea basin (“mixed layers”), which are interpreted as seismites - layers that exhibit earthquake-triggered deformation. Undisturbed laminated layers between these mixed layers represent interseismic intervals

Table 1. Slip rate estimates of the Dead Sea Fault

Period	Rate [mm/a]	Data	Reference
Post Miocene	6 [0.283°/ma]	Plate kinematics	Joffe and Garfunkel, 1987
Plio-Pleistocene	7-10	Geological	Garfunkel et al., 1981
Plio-Pleistocene	20	Geological	Steinitz and Bartov, 1986
Plio-Pleistocene	5.4-6.1	Geological	Heimann, 1990
Plio-Pleistocene	3-7	Drainage systems, Arava Fault	Ginat et al., 1998
Pleistocene	2-6, prefer 4	Alluvial fans, N. Arava	Klinger et al., 2000a; Klinger et al., 2000b
Pleistocene	4.7±1.3	Alluvial fans, Arava	Niemi et al., 2001
Late Pleistocene	6.4±0.4	Seismicity	El-Isa and Mustafa, 1986
Late Pleistocene-Recent	10	Geological	Freund et al., 1968
12 ka	4.5-4.8	Geological, alluvial fans, N. Arava	Zhang et al., 1999
Holocene	9	Geological	Reches et al., 1987
Holocene	0.7	Geological	Gardosh et al., 1990
Last 5000 a	3	Stream channel, Jordan Gorge	Marco et al., 2000
Last 4500 a	2.2	Seismicity	Ben-Menahem, 1981
Last 1000 a	0.8-1.7	Historical	Garfunkel et al., 1981
Last 800 a	<2.5	Archaeological	Marco et al., 1997

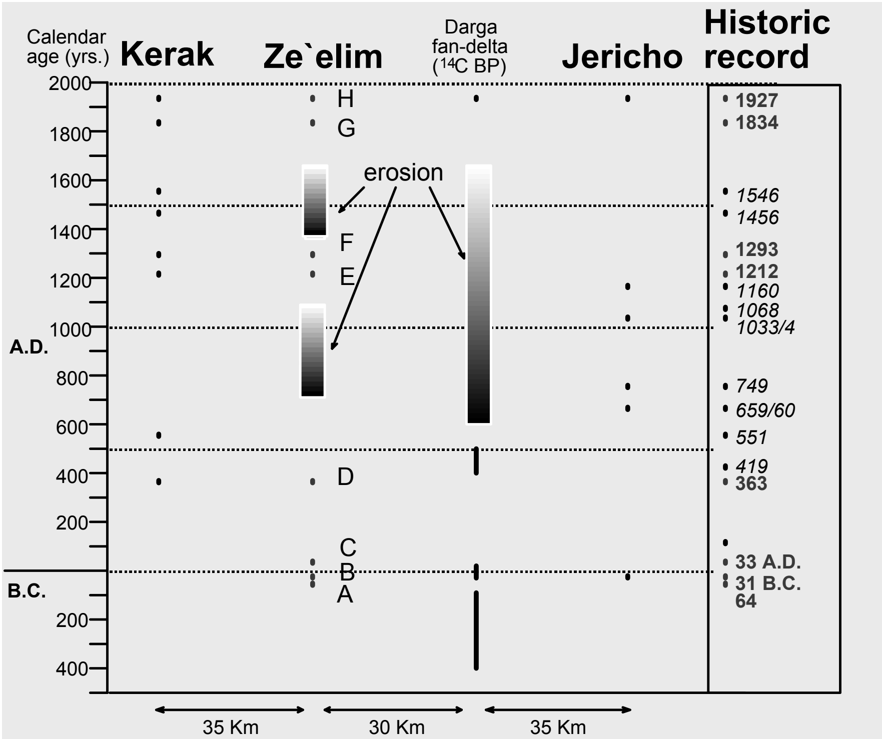

Fig. 8 Correlation between mixed-layer ages and historical earthquakes in the last 2 millennia in the DS basin at four locations (after Ken-Tor et al., 2001). C14 – ages of mixed layers A-H in Ze'elim are correlated with the historic record of earthquakes in the area (right column dates in bold were measured in Ze'elim). The earthquakes reported either from Karak (35 km to the southeast) and/or from Jericho (some 60 km north of Ze'elim)

5.2 Historical and Archeological Earthquake Record

As described above, the Dead Sea Fault is part of the hominid migration route out of Africa. Some of the settlements have been affected by earthquakes and the observed damage together with historical accounts, provide a unique record of past seismic activity in the region (e.g. Amiran et al., 1994).

Two forms of written texts of natural catastrophes can be found: biblical stories where uncertainty is high, such as the destruction of Jericho (Joshua

Jerash 749 AD

Sussita 749 AD

Kal’at Nemrod 1759

Jericho 1927

Fig. 9. Ruins of Jerash, Kalaat Nemrod, Jericho and Sussita, which were damaged by earthquakes during the last 2000 years (see Figure 2 for locations).

6) and contemporary detailed accounts, such as Josephus Flavius’ vivid description of the 31BC earthquake. Archeology can usually corroborate history although interpreting damage to ancient structures is not trivial. Damage related to earthquake shaking is recognized in numerous ruins, including Jerash, Jericoh, Sussita, and Kalaat Nemrod (Fig. 10). Finding evidence for historical earthquake ruptures is extremely rare. Recently, the first such evidence from the DSF has been recovered from the Crusader fortress of Vadum Iacob (now called Ateret near Gesher Benot Ya’aqov – Fig. 2) (Ellenblum et al., 1998; Marco et al., 1997b). The fortress, which was built on the active trace of the fault, was torn apart twice, first by the earthquake of 1202 and again by the earthquake of 1759. Both events are in agreement with the paleoseismic observations mentioned above. A water reservoir at the Roman-Early Byzantine site Kasr-e-Tilah in the northern Arava was also offset by the fault (Klinger et al., 2000b).

5.3 Instrumental Record

The seismological division of the Geophysical Institute of Israel operates some 100 monitoring systems of the modern Israel Seismic Network. The accrued data reveal several important characteristics.

most active area has been the Gulf of Elat, where thousands of small earthquakes cluster during periods of several months to a few years in different regions of the gulf. The activity culminated in the 22 Nov. 1995 Mw7.1 earthquake (Baer et al., 1999; Klinger et al., 1999).

Focal plane solutions of other events confirm the primary sinistral motion predicted by local geology and plate tectonic considerations. Local complications in the form of stepovers are manifested by normal faulting. Reverse fault solutions are rare (Salamon et al., 1996; van-Eck and Hofstetter, 1989, 1990). The earthquakes largely obey the Gutenberg-Richter magnitude-frequency distribution with typical *b* values of 0.85-0.9 (Shapira and Shamir, 1994).

5.4 Patterns of Seismicity

By combining several disciplines including history, archaeology, and seismology, several spatio-temporal patterns begin to emerge from the data. Clustering, periodicity, and triggering have been reported in several studies. In accordance with theoretical and experimental results (e.g., Lyakhovsky, 2001), a temporal pattern in a century time window resembles that of the 10 ka window. The longest continuous off-fault record (68-18 ka) from the lacustrine Lisan Formation shows that strong (M>6) earthquakes cluster during periods of ~10 ka, with more quiet periods between the clusters. During the long cluster periods earthquakes appear in secondary clusters (Marco et al., 1996). A pattern of clustering is also evident in the record of the last two millennia in the Dead Sea (Ken-Tor et al., 2001) and in the M>4 record of the 20^{th} century (Marco and Agnon, 2001)

Bearing in mind the large uncertainties associated with the interpretation of historical accounts, it seems that a unique quasi-periodic recurrence of four large earthquakes occurred in the Jordan Valley between the Dead Sea and the Sea of Galilee from 31 BC through AD 363, 749, and 1034. This sequence was followed by the two smaller earthquakes of 1546 and 1927 with a similar recurrence interval (Marco and Agnon, 2001). The quasi-periodic pattern appears to last only for a short period on the order of a few centuries, and is not observed elsewhere along the DSF. An alarming note is the absence of strong (M>6.5) earthquakes in the last eight centuries between Lebanon and the Dead Sea, since most of the DSF sustained rupture during the 1034 earthquake in the Jordan Valley and the 1202 earthquake north of the Sea of Galilee.

5.5 Example: Jericho

"Jericho is the latch of the Land of Israel. If Jericho was taken the whole country would instantly be conquered" Rabbi Samuel Bar-Nahmani (AD 426-500), Midrash Rabba.

Settlements along the Dead Sea Fault have been repeatedly affected by earthquakes. An example can be found in the ancient city of Jericho. Tectonics has played an important role in the cultural record of Jericho. On one hand, its unique position close to an active strand of the Dead Sea transform, gives rise to a source of fresh water – the Spring of Elisha, which probably ascends through channels along fractured rocks east of the main fault (Neev and Emery, 1995). The abundance of fresh water in such an arid area, has led Jericho to play an important role in history – that of the oldest continuously settled city in the world. The first human settlement was by Mesolithic people of the Natufian age, 12,500-10,000 years ago who were probably associated with the first Mesolithic group further along the transform – at the Mount Carmel caves (Kenyon, 1960). Jericho is one of the first places where evidence of man as a member of a settled community and a food producer rather than a food gatherer, exists (Pre-Pottery Neolithic A - Kenyon, 1960). In addition, the settlement at Jericho is around two thousand years older than the earliest known villages elsewhere. The spring has also allowed inhabitants of the city to resist siege, by providing a constant supply of vital water, thereby limiting the need for abandonment due to destruction or capture. On the other hand, what man could not accomplish, nature could.

The proximity to an active fault meant that Jericho has been faced with multiple destructions due to earthquakes. Damage to the city's outer walls, is well documented (Kenyon, 1960) and the city itself has been destroyed and rebuilt at least 17 times. This view is supported by paleoseismological data (Reches and Hoexter, 1981). Radiocarbon dating has shown that defensive walls existed around Jericho as far back as 7000 BC (Kenyon, 1960). The most famous account of destruction by earthquake is of course, the biblical tale.

Ancient Jericho was the meeting place of several important trade routes and thus a strategically important place to control. The biblical importance of the city cannot be overlooked. Jericho, the first town encountered in the Promised Land after the exodus from Egypt, was the gateway to Israel. The narrative reports that the waters of the Jordan River stopped flowing and allowed the Israelites to pass (Joshua 3:13-16). Earthquakes are known to have caused landslides, which dam the river and interrupt its flow for several hours or even days. Reports of such events exist from 1160, 1267 (16 hours), 1546, 1834, 1906 and 1927 (21 hours) (Amiran et al., 1994; Ben-Menahem, 1981). The destruction of the walls of the city and the damming of the river, as described in Joshua 6:1-16, is generally agreed by most archeologists to be the result of an earthquake, possibly on the Jericho Fault (Neev and Emery, 1995).

In 31 BC, during the 7th year of King Herod's reign, a strong earthquake hit the region. The historian Josephus Flavius records: "*…and there was an earthquake in Judea, such as had not occurred before, which killed many cattle throughout the country. And about thirty thousand persons also perished in the ruins of their houses, but the army, which lived in the open, was not at all harmed by this calamity*". The Arabs, believing that Judea was in ruins due to the earthquake, intended to invade it. However, King Herod managed to lead his army across the Jordan River and defeated the Arabs. Consequently, as a result of the earthquake his kingdom was enlarged.

6. Discussion

Active tectonic processes along the DSF have fashioned an environment that has influenced the course of human history as the critical bridge between the continents of Africa, Europe and Asia, creating a corridor of friendlier environments through which hominids migrated. The region has played an important role in Near Eastern prehistory and archeology. The historical and archeological associations of this area are extensive. Here is where the oldest sites of hominids outside Africa, Erk-el-Ahmar and Ubediya are located, as well as Jericho, the oldest city in the world.

The uplift that created the unique physiography of the DSF is controlled by the crustal structure and the tectonic processes in this region. The crust was formed during the processes that shaped the Arabian-Nubian shield in the Precambrian and later modified by the formation of the DSF plate boundary. The precise location of the DSF was suggested to be on a rejuvenation of an old Precambrian weakness zone (Girdler, 1991). Garfunkel and Ben-Avraham (2001) showed that the mechanical properties of the Precambrian basement may have affected the various styles of deformation along the DSF margins, but the general trace of the fault is totally different from the old structures. It is therefore highly unlikely that the DSF is a rejuvenated Precambrian structure.

Earthquakes that are associated with the Dead Sea Fault plate boundary and also reflect the crustal structure because they occur where the crust fails due to regional stresses. Lyakhovsky et al. (1997) relate the failure to growth patterns of distributed damage in the lithosphere. Once a fault zone is created, the occurrence of earthquakes is influenced by the geometry of the fault zone, which evolves in time from complex to simple geometry (Stirling et al., 1995) and by the velocity of the plate movements. Hence the occurrence of earthquakes is governed by the detailed combination of crustal structure and regional motions of the tectonic plates. The theoretical work by Lyakhovsky et al. (2001) suggests that the relatively slow plate velocity along the Dead Sea Fault is compatible with long-term clustering.

The immediate effects of damaging earthquakes on society are known and familiar to modern people. Unfortunately earthquake-inflicted human tragedies and economic losses are huge. It is less clear how earthquakes affected society in the past and whether they significantly changed the course of history. For example the 31 BC earthquake in the Dead Sea region caused confusion and fear, which paved the way for the expansion of Herod's kingdom. Episodic time-space clustering of earthquakes such as during the eastern Mediterranean 'seismic crisis' at the end of the Bronze Age (around 1200 BC) and in the 4th century AD (Nur, 2000). The seismicity of the north Anatolian fault during the 20th century is another example of a cluster of strong earthquakes. Society benefits as well as is harmed by the same geological processes. Studying the ways in which earthquake affected societies may help us cope with such catastrophies that will certainly occur again.

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