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The Dead Sea – a unique global site

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The Dead Sea area is unique in the sense that it is a natural laboratory in which key topics in several scientific disciplines can be studied in situ. Processes that take place during continental break-up, geochemistry and dynamics of the hypersaline Dead Sea water, paleoclimate and paleoseismic records in sediments and the survival mechanisms of halophilic micro-organisms are among the topics being studied there. Active tectonic processes control all aspects of the Dead Sea and have created an environment that has also influenced the course of human history.

The Dead Sea is situated within a unique region, which has interest for many scientific disciplines – above all for Earth sciences.[1] At about 413 m below mean sea level, the Dead Sea is the lowest point on the face of the Earth. It is located at the centre of the Dead Sea rift, a large feature that extends over 1000 km from the southern tip of the Sinai Peninsula to the Taurus mountain in Turkey (Figure 1), and is the most prominent tectonic feature in the Middle East. The Dead Sea rift is bordered by a number of countries including Saudi Arabia, Egypt, Jordan, Israel, the Palestinian Authority, Lebanon, Syria and Turkey. In terms of plate tectonics, the Dead Sea rift is a transform plate boundary that separates Arabia from Africa and Sinai and connects the incipient mid-ocean ridge of the Red Sea to the collision belt of the Taurus Mountains in Turkey.

The Dead Sea rift is unique in the sense that it is a natural geodynamic laboratory in which the tectonic processes that take place during continental break-up can be studied in situ.[2] Research in this area has shed light on processes through which large features on the earth's crust, such as the Rhine Graben in Europe or the Baikal Rift in Siberia, have been created.[3] This is because the structure of the Dead Sea rift is relatively simple. In addition, research in this area helps in understanding the geological evolution of the entire region.

The Dead Sea basin is divided into two sub-basins (Figure 2): the southern subareal sub-basin occupied by commercial evaporation ponds and the northern sub-basin occupied by a $\sim$300 m deep lake.[4] The sub-bottom structure of the basin is composed of a deep depression. Seismic refraction data indicate that the depth to the basement in the southern part of the basin is more than 10 km.[5] It is overlaid by a large sequence of sediments that reach the surface. Taking into account the height of the Judea Mountains on the west and the Moab

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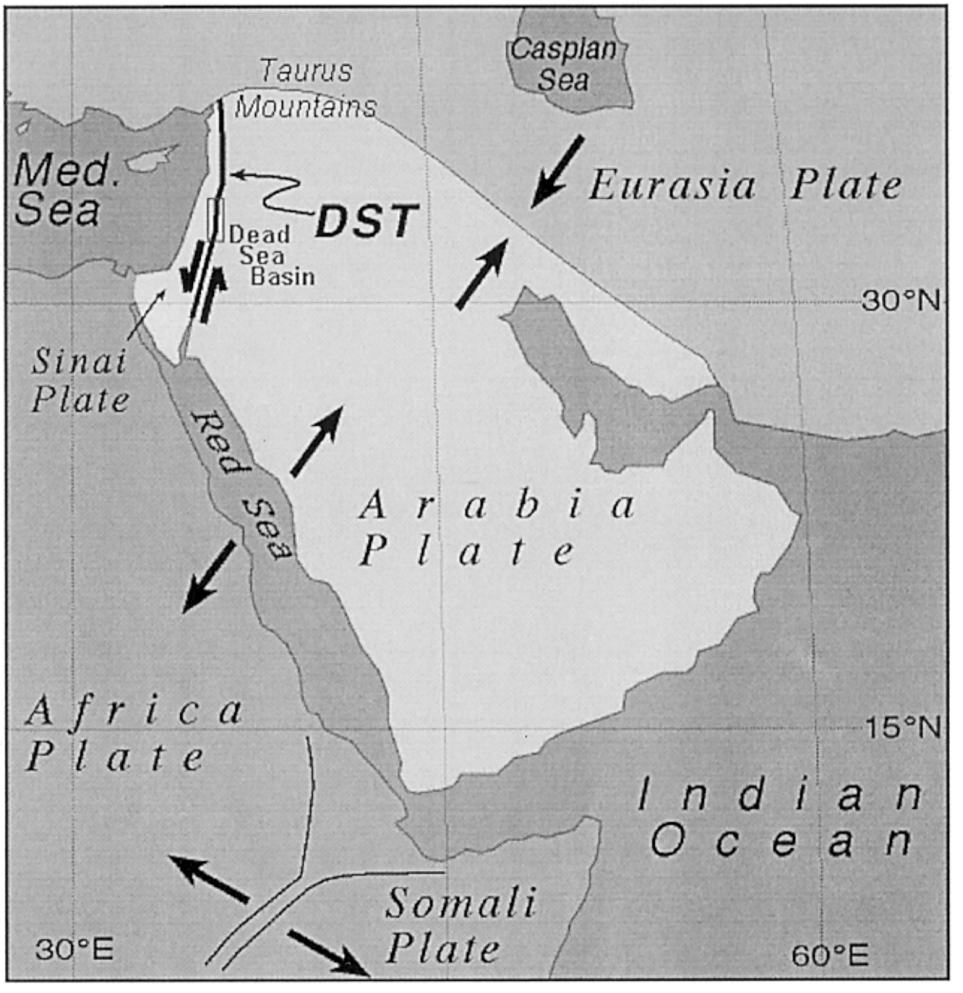


Figure 1. Lithospheric plates in the Middle East. The Dead Sea rift is a plate boundary, extending from the Red Sea to the Taurus Mountains in Turkey.

Mountains on the east and the erosion that took place in this region, the Dead Sea basin is one of the deepest 'cracks' in the Earth's crust – over 13 km.

The shape of the Dead Sea basin is controlled by fault activity. Deformation takes place mainly on transverse and longitudinal faults and the intervening sediments are relatively undeformed. The longitudinal faults are strands of the Dead Sea transform and the latitudinal faults divide the basin into segments, 20–30 km long.[6] Fault motion in the basin itself and along the entire Dead Sea transform plate boundary has been a major source of earthquakes in the Holy Land and the entire Middle East during Biblical and more recent times.[7] Sediments in the Dead Sea basin provide much evidence for paleoseismicity in this region. The largest earthquake in the Levant in the 20th century was the 1927 Jericho earthquake, which caused extensive damage.

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Today, the motion of both sides of the Dead Sea rift is measured with Global Positioning System (GPS) satellites. It was found that the current relative motion of both sides of the rift is about 4 mm a year. The eastern side, the Arabian plate, is moving northward relative to the western side, the Sinai plate. Since the beginning of this motion, less than 20 million years ago, 105 km of displacement has taken place between both sides of the Dead Sea rift.[8]

The sediments that have accumulated in the rift valley include evaporites, carbonates and terrigenous material. The fill of the Dead Sea basin is composed of three main units.[9] The lower one is a broken rock (clastic) unit (the Hazeva Formation) of Early to Late Miocene age and consists predominantly of sandstone and conglomerates of river and lake origin. The middle one is an evaporitic unit (the Sedom Formation), probably of Late Miocene and Pliocene age, which consists predominantly of rocksalt of lagoonal origin. The ingression of the Sedom lagoon from the Mediterranean Sea into the Jordan Valley has caused the deposition of this thick sequence of salts. This evaporitic series forms several domes of rocksalt; one of which, Mount Sodom, is exposed (Figure 3). The upper one is a unit of clastic, of Pliocene to Recent age, which consists of coarse to fine clastics of river and lake origin. This sequence was deposited in several lakes that were developed in tectonic depressions along the Dead Sea basin–Jordan Valley after the disconnection of the Sedom lagoon from the open sea.

The series of lakes in the Dead Sea region disappeared and reappeared over a long period due to climatic and geological changes in the area. The last of these lakes, known as Lake Lisan, stretched from the northern Arava Valley to the Sea of Galilee. About 15 000 years ago it dried up, leaving behind what is known now as the Dead Sea. Climatic changes have caused considerable fluctuations in the level of the lake's water. Sediments, which were deposited in the Dead Sea and previous lakes, record the climatic conditions that prevailed in the region during the Pleistocene–Holocene time.[10] These sediments are quite sensitive to the water level during the time of deposition.

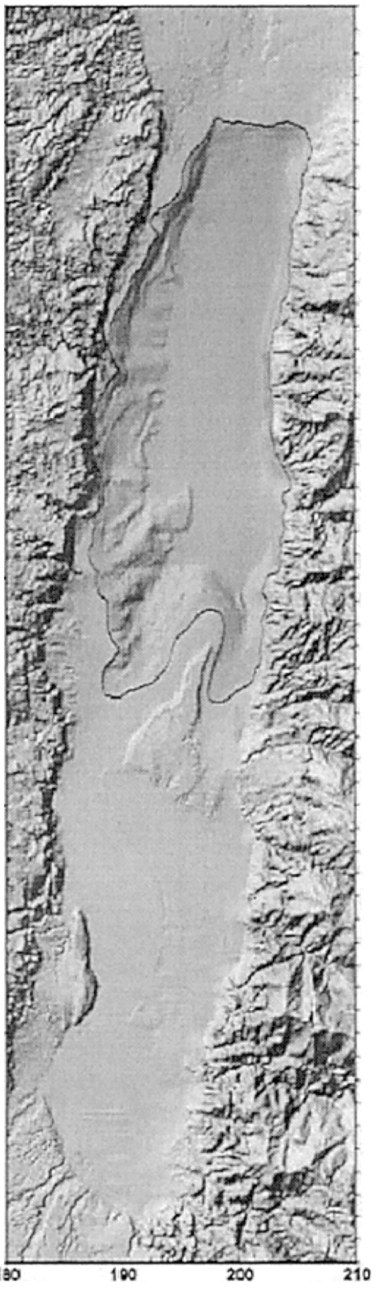


Figure 2. Relief map of the Dead Sea basin.[17] The basin is divided into two sub-basins. The northern one is covered by a lake with a depth of around 300 m and the southern one is exposed.

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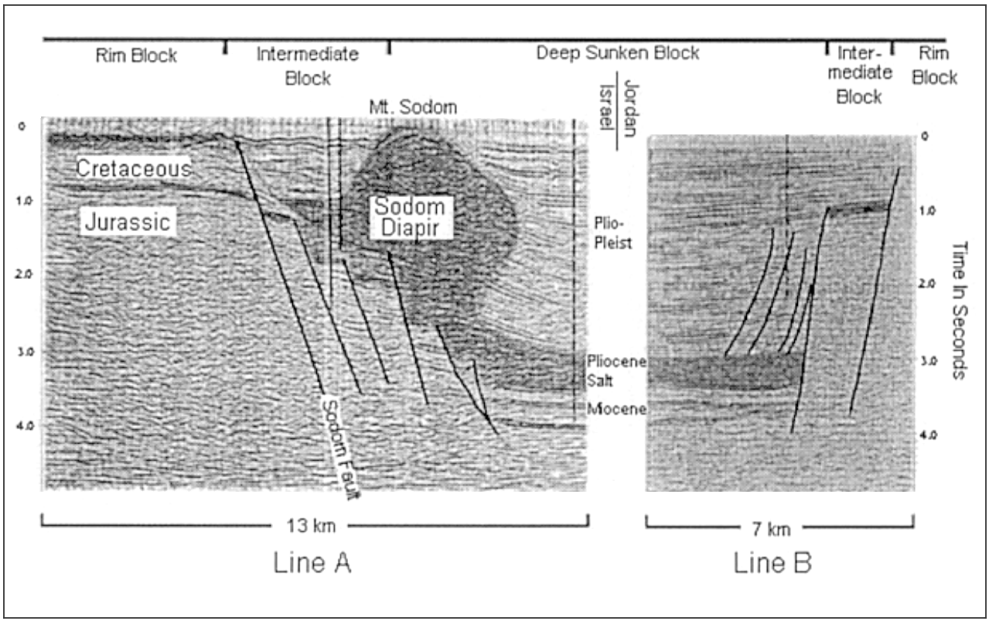


Figure 3. Seismic sections across the Dead Sea.[18] The western side was obtained by Israeli scientists and the eastern side by Jordanian scientists. The marked sequences are salt layers whose movement created Mount Sodom. The Dead Sea basin is delimited by active faults, which are the cause of local earthquakes. The depth of sedimentary fill in the Dead Sea basin reaches more than 10 km. Each second along the depth scale is equal to about 2 km.

The Dead Sea has a large drainage basin, about 40 500 sq km. The Jordan River is the conduit that supplies the majority of the inflow to the Dead Sea. However, fresh recharge from the snow-covered mountains in the northern catchment area is a valuable commodity that is not allowed to be wasted in the brine of the Dead Sea. Canals have been constructed to divert water from the Sea of Galilee (Israel National Water Carrier), and a dam across the Yarmouk River, which flows into the Jordan River, channels water into the Jordan Valley canal in the Hashemite Kingdom of Jordan. As a result, the Jordan River now carries only a trickle of water. Except for the flow of a few wadies from the east, the drainage around the Dead Sea only delivers water to the basin during flashfloods. During the period in which hydrographic records have been recorded (1929–present) the level of the Dead Sea has fallen more than 20 m. This drop has caused enormous changes in the lake's morphology, physical hydrography and geochemistry. Whether by tectonic, climatic, hydrologic or anthropogenic forces, the Dead Sea and its environment is in a state of dynamic change.

Freshwater flowing into the Dead Sea floats and dilutes the surface water creating a thermohaline stratification of the water column. However, the reduction of the amount of freshwater has led to considerable changes. The year 1979 is a noteworthy turning point in the history of the Dead Sea water.[11] It marks the time when this long-term stratification, which lasted several centuries, was destroyed in a complete overturn that brought oxygenated waters to the fossil deep water. Soon afterwards rocksalt started to be deposited.[12] At present, salt

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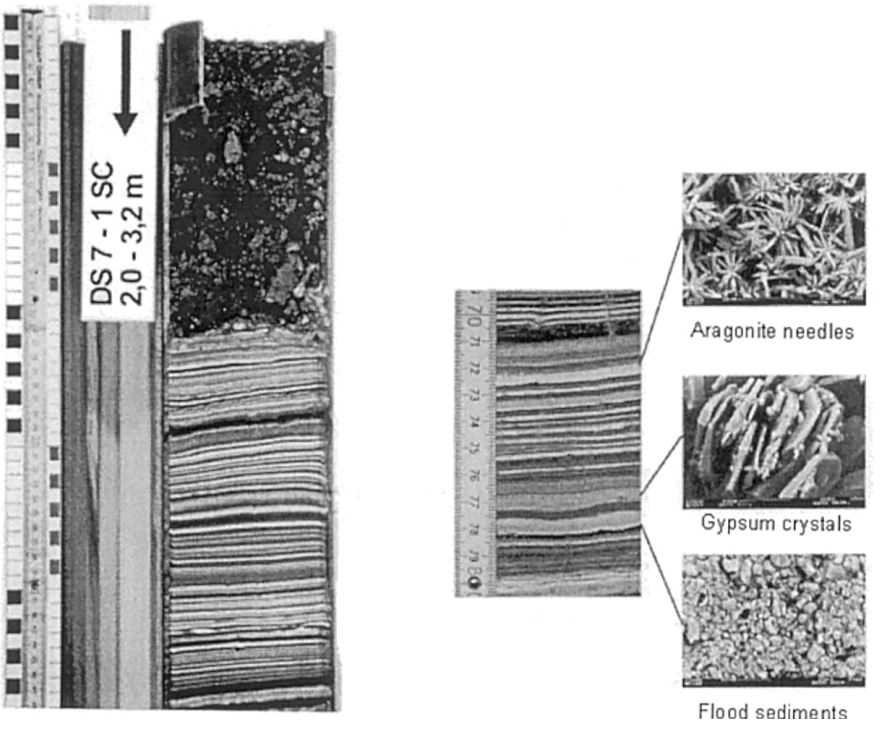


Figure 4. Left: Part of a core taken from the floor of the Dead Sea at a depth of 250 m near Ein Geddi. The bottom part is made up of layers of marl composed of annual sediment deposits of evaporitic minerals, calcite, aragonite and gypsum during summer periods, and clay and flood sediments during winter. The upper section shows a sequence of salt deposited during a time of low water levels (lower than 400 m below mean sea level) and indicates a dry period. The transition between marl and salt took place about 1500 years ago. Right: An electron microscopic section of the same core showing the composition of the layers.[19]

is deposited at a rate of about 50 mm/year. The water level of the Dead Sea is currently dropping at a rate of about 80 cm/year.

The sedimentary sequences recovered in cores from the deep basin of the Dead Sea suggest that significant lake level fluctuations took place in the past in response to climatic changes. Interbedded marl and rocksalt deposits in the Dead Sea cores (Figure 4) suggest alternating periods when the water mass was stratified and unstratified.[13] Supported by pollen grain data, marl layers indicate a less arid climate with a low evaporation/runoff ratio, whereas the salt layers reflect an arid climate with a high evaporation/runoff ratio. This relationship has been artificially simulated with the diversion of the freshwater inflow from the Jordan River and the resultant lowering of the Dead Sea level. The negative water balance and the resultant increased salinity led, as mentioned above, to the complete mixing of the water column and supersaturation with respect to salts. The present deposition of rocksalt has effectively simulated a drier climatic period due to the shrinking area of the lake and changes in its geochemistry. Radiocarbon age dating on the cores suggests that Dead Sea stratification

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developed about 365 years ago, during the wetter/cooler climatic conditions of the 'Little Ice Age'. Prior to this, a thick rocksalt layer suggests a dry period with a low water level, which lasted about 900 years.

The extreme negative elevation, in combination with the tectonically elevated mountains that flank the basin, promotes a very arid environment marked by low precipitation and high evaporation. Water that enters the Dead Sea has no outlet in this actively subsiding basin. These conditions control the physical, chemical and biological properties of the inland lake. The hypersaline Dead Sea water is dense with more than 30% dissolved solids,[14] the highest salinity of any lake on Earth. The dissolved material includes high concentrations of potassium and magnesium salts as well as bromine, which are commercially exploited. These salts appear at present to constitute Israel and Jordan's most extensive natural resource.

Almost nothing can survive in this water except highly specialized halophilic green algae and red archaeobacteria, which are of great scientific interest. The Dead Sea water composition differs from other saline lakes in its high concentration of magnesium and calcium. As a result, unique highly specialized endogenous communities of micro-organisms survive in the hypersaline, Mg-enriched brines of the Dead Sea. The population is dominated by green algae (*Dunaliella parva*) as the only primary producer in the upper water layers whose organic matter feeds the red bacterial life.[15] In the last few years, the populations of surface algae and redbacteria could not be detected and were thought to be dormant due to increasing salt concentration caused by the lack of freshwater supply to the lake. However, recent diving in the Dead Sea (using a manned submersible) detected the presence of halophilic bacteria along the escarpment of the Jericho fault (Figure 5), which is the most active longitudinal fault in the Dead Sea basin. In this area, it is possible that less-saline water is flowing along the fault zone into the lake. Such seepage of fresher water would decrease the local salinity and may provide an explanation for the abundance of red halobacteria along areas in close proximity to the fault by creating a friendlier environment for them to thrive in.

Due to the low elevation of the Dead Sea region much of the sun's ultraviolet radiation is filtered by the deeper atmosphere. This effect, along with properties of the lake water, is claimed to be effective in the treatment of psoriasis and other skin diseases.

Active tectonic processes that control all aspects of the Dead Sea have created an environment that has influenced the course of human history as the critical land bridge between the continents of Africa, Europe and Asia. The shores of the Dead Sea are part of the Fertile Crescent and the region has played an important role in Near Eastern prehistory and archeology.[16] The historical and archaeological associations of this area are extensive; to name but few, it is in this region that Jericho, the oldest city in the world is located, the Dead Sea scrolls were found and Sodom and Gommorah once existed. Many historians and archaeologists believe that the region has much to yield in regard to biblical understanding.

The region is thus of considerable scientific, economic and historical interest, with many important and interesting problems to study. The tectonic activity in this region affects a wide variety of phenomena, such as the ground water regime, earthquakes and the formation of life. The Dead Sea also offers the largest continuous record (almost 100 000 years) of environmental fluctuations in the world. Through the study of the laminated marl (exposed and collected by coring) it is possible to discover, with an unprecedented degree of precision, past climatic variability as well as prehistoric earthquakes. The investigation of these and other

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Figure 5. Photograph of the Jericho fault plain taken from a submarine at a depth of 150 m below Dead Sea level. The sharp interface between the sea floor and the vertical cliff caused by faulting is clearly visible and points to recent faulting activity.

topics is interdisciplinary in nature and requires coordination between scientists from several fields. It is for this reason that the Minerva Dead Sea Research Center was founded as a focal point for regional scientific collaboration and as an example of peaceful cooperation between the region's neighbours.

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