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Magnetic and Gravity Investigations of the Dead Sea Rift and Adjacent Areas in Northern Israel

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Abstract. Magnetic and gravity data covering a wide strip across the rift, with dimensions suitable for crustal and upper mantle investigations are presented and analysed. They suggest that the thickness of the crust remains almost unchanged across the rift and that the upper mantle is also normal. On the other hand, the rift probably delineates the boundary of an upper crustal lithological transition zone, characterized by an increasing mafic component from east to west.

Local magnetic anomalies within the rift zone are believed to be related to basalt flows instead of the commonly interpreted intrusions. Based on this suggestion, fault patterns are delineated. They support the sinistral strike-slip hypothesis for the origin of the Dead Sea Rift.

Key words: Dead sea rift – Magnetic anomalies – Gravity anomalies – Crust – Upper Mantle.

Introduction

The structure of the Dead Sea Rift has been intensively investigated for almost one hundred years. However, in the field of geophysical crustal and upper mantle investigations, little has been published based on continuous data measurements across the rift (Knopoff and Belshe 1967).

This is the first study to present an analysis of gravity and magnetic data which cover a wide strip across a segment of the Dead Sea Rift. The dimensions of the strip are sufficient to allow interpretation of deep crustal and upper mantle characteristics as well as analyses of near surface features.

The investigated portion of the rift extends from Lake Kinneret (Sea of Galilee) to the town of Kiryat Shemona (Fig. 1). It forms an elongate valley, five to eleven kilometers wide, and is bounded by mountainous terrain – the Golan Heights in the east and the Galilee mountains in the west.

The geology in the northern rift valley has been described in detail by Picard (1965), Horowitz (1973), Michaelson (1973), Neev (1979), and Schulman (1962, 1978), and can be briefly summarized as follows: until Late Eocene or Early Oligocene times, the depositional environment in the area presently occupied by the valley was marine and similar to neighboring areas. However, since the Miocene and up to recent times, several phases of faulting and block tectonics which were associated with the creation of the rift resulted in the formation of inland lakes covering different parts of the area. These followed rapid accumulation of thick sequences of clastic deposits with minor chalks within deep grabens. In addition, two major phases of basalt eruption covered the area. The earlier one occurred in Miocene times and is represented in neighboring areas by a thickness of up to 600 m of the 'Lower Basalt' (Schulman 1962). The second phase, namely the 'Cover Basalt', followed intensive faulting activity during Late Pliocene and Early Pleistocene times (Freund et al. 1965). It covers the entire Golan Heights and parts of eastern Galilee. This 'Cover Basalt' is also found in the rift valley where major flows have descended from the mountains.

According to the structure and morphology, three zones are clearly distinguished in the valley. They are, from south to north (Fig. 1).:

(a) Lake Kinneret (Sea of Galilee) depression with the lake surface at 210 m below sea level.

(b) The Korazim block, a structural high rising to 500 m above sea level and covered by up to 200 m of the 'Cover Basalt,' and

(c) The Hula basin, a topographic and structural depression filled with a thick accumulation (more than 700 m) of clastic sediments.

The elevated areas on both sides of the rift differ considerably in their structure. In the east, the Golan Heights form an uplifted syncline covered by hundreds of meters of basalts (Michaelson 1973; Mor 1973). In the west, the Galilee Mountains exhibit a complex structure composed of transverse faults (i.e., normal to the rift valley), tilted blocks and faulted anticlines. Outcrops are composed mainly of carbonate rocks ranging in age from Early Cretaceous to Early Tertiary (Picard 1943; Picard and Golani 1965).

The Data

The magnetic data consist of previous aeromagnetic surveys (Domzalski 1967; Folkman 1971; Folkman and Yuval 1976) flown at an altitude of 1,000 m above sea level with a line spacing of 2 km. The gravity data were compiled from previous surveys and investigations (Amitai 1962; Yuval 1966; Ginzburg 1960, 1968) with additional recent measurements. The Bouguer anomalies refer to mean sea level datum.

The aeromagnetic map (Fig. 1) clearly demonstrates considerable differences in the magnetic field across the rift. As one goes from east to west, three zones, each characterized by distinctive anomalies, can be distinguished. Over the Golan Heights, elongated short wavelength high amplitude anomalies are arranged in a sublinear pattern trending NE (Folkman 1978). Near the eastern boundary faults of the rift valley, this pattern changes

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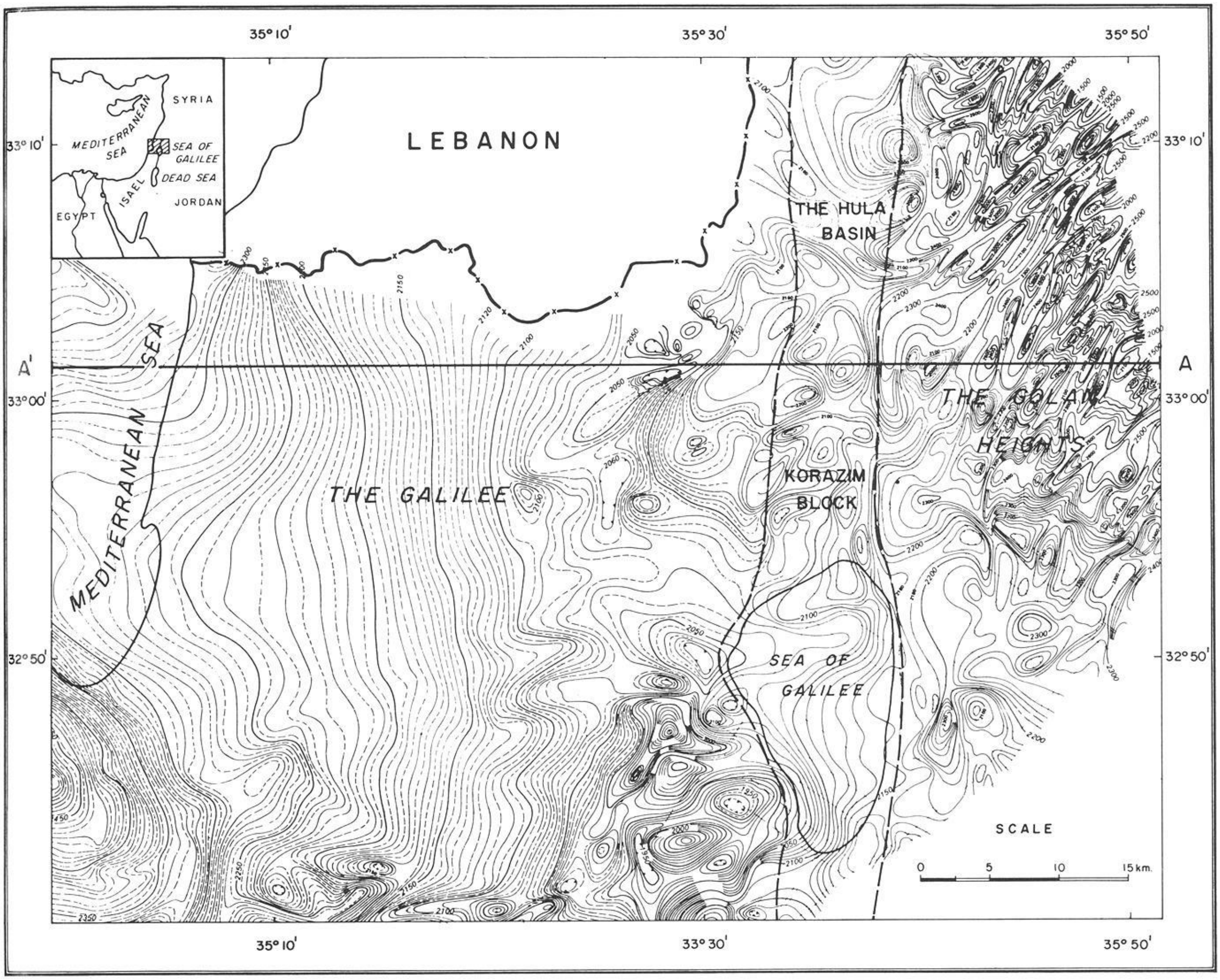

Fig. 1. Aeromagnetic map, after Folkman and Yuval, 1976 Flight altitude – 1,000 m above M.S.L. *Dashed lines* delineate the rift zone

abruptly into N-S trending contours which clearly delineate the eastern boundary fault system. Further to the west, the anomaly pattern changes again into well defined local anomalies of various orientations covering the rift valley and eastern Galilee. The western boundary faults of the rift are undetectable on the magnetic map.

The third zone having a characteristic magnetic field extends over the central and western Galilee, the coastal plain, and the continental shelf. Here, rarely affected by the complicated geological structure, the magnetic field increases continuously westward.

The detailed compiled Bouguer anomaly map is not authorized for publication. However, the main gravity patterns are demonstrated on a generalized map (Fig. 2) which shows that a good correlation usually exists with the main magnetic patterns. Again, the same three zones have typical and yet different characteristic patterns of Bouguer anomalies. Over the Golan Heights, an axis of a Bouguer low trending NE is located in the south with a rising gradient towards Mount Hermon in the north. Within the rift valley, two distinct negative anomalies cover the Hula basin and the eastern portion of Lake Kinneret. Apart from these anomalies, the disturbance caused by the rift is almost unnoticeable.

Further to the west, over the Galilee, the Bouguer anomaly map becomes very similar to the magnetic map. The gradient rises westwards with a dominant pattern of N-S trending contours that cannot be correlated with the known major structural features. Only over the coastal plain and the continental shelf can local anomalies be separated from the regional field and be correlated with structural features.

Interpreted Crustal Structure

The gravity and magnetic fields over the Galilee, which as described above, are not correlatable with local structures, resemble that of a regional component with only minor superimposed local effects. It may, therefore, be justified to assume causative structures which lie deeper in the crystalline crust or upper mantle. However, the magnetic field excludes a mantle solution because the Curie point is most probably reached near the Moho, under local conditions of a normal thermal gradient (Ben Avraham et al. 1978; Eckstein 1976) and a crustal thickness of approximately 30 Km (Ginzburg et al. 1979).

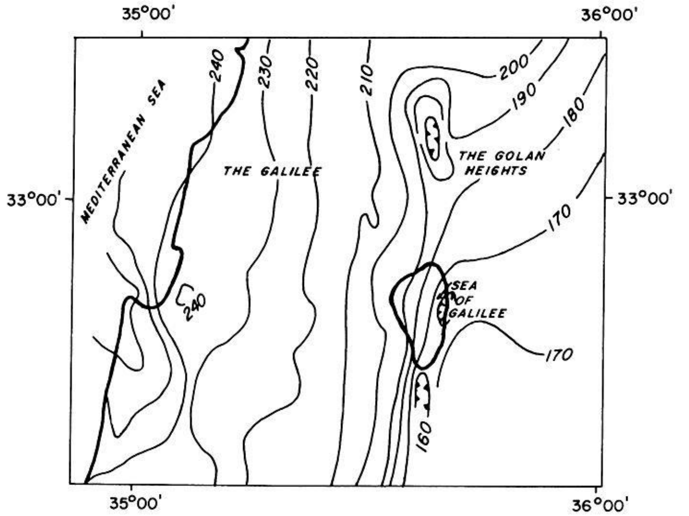

Fig. 2. Generalized relative Bouguer anomaly map. Contour interval 10 milligals

The pattern of the magnetic contours, as demonstrated in Fig. 1, allows a two dimensional interpretation along E-W oriented profiles across the entire area. The short wavelength high amplitude anomalies in the east are obviously caused by near surface basalts. They are superimposed on the main regional component and may be filtered out by choosing the best fitted zero curve. The interpretation of this curve yields a crustal model with N-S trending discontinuities across which lateral variations in rock magnetization occur (Fig. 3). The increasing magnetization westwards probably indicates an increase in the mafic content of the rock type. Thus, according to this interpretation, the rift and its eastern side are underlain by a crust which is different in composition from the crust underlying the western side of the rift.

This hypothesis is supported by the interpretation of the Bouguer gravity anomaly which is again based on two dimensional modeling along the same profile (Fig. 4). The Bouguer anomaly profile shows a steep gradient over the Galilee which becomes more moderate over the Mediterranean coastal plain and continental shelf, where low density marls fill a large sedimentary basin of Neogene age (Gvirtzman 1969). The gravity effect of the basin has been calculated and stripped off the anomaly, thus causing a continuation of the steep gradient also over the coastal plain and the continental shelf, as demonstrated in Fig. 4.

The resultant regional component of the Bouguer anomaly may be explained on the basis of the following three models:

(a) Lateral density variations in the upper mantle, which form an anomalous low density lens under the rift zone

(b) thinning of the crust towards the Mediterranean Sea

(c) lateral lithological variations in the crystalline crust across N-S trending discontinuities, with the density increasing westwards.

The first explanation is unacceptable because the Bouguer anomaly map of Syria (Bureau Gravimetrique International 1971; Tiberghien 1974) shows that the Bouguer values in the east continue to decrease towards a regional low over southeastern Syria. This means that if an anomalous low density lens exists in the upper mantle, then its axis should be sought after under southeastern Syria, while over the coastal plain of northern Israel, only minor gravity effects would be noticed.

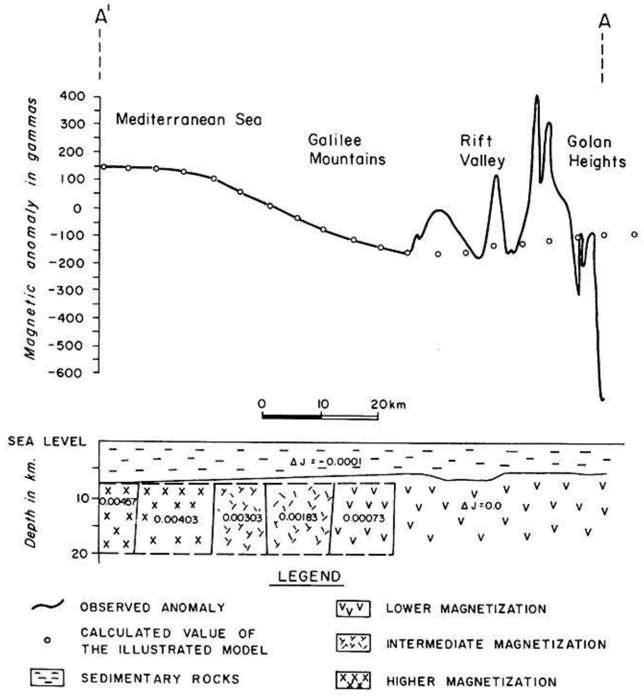

Fig. 3. A possible model interpretation of magnetic profile *A–A'* across northern Israel. Δj denotes the assumed magnetization contrast in e.m.u.

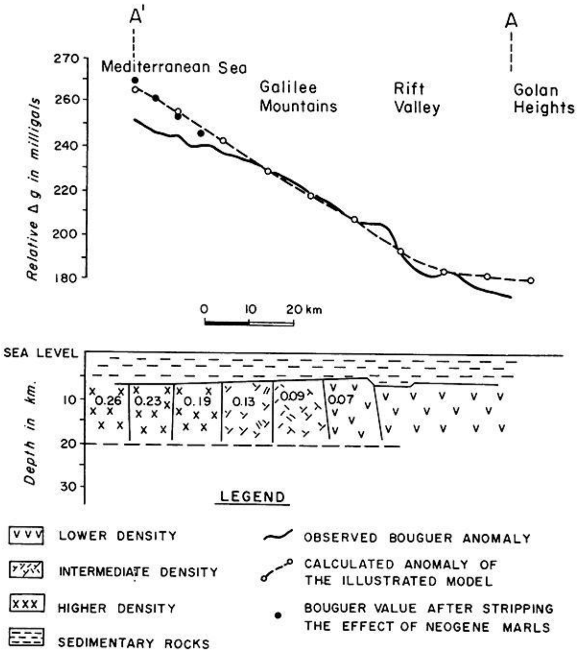

Fig. 4. A possible model interpretation of magnetic profile *A–A'*; $\Delta\rho$ is the assumed density contrast in g/cm^3 units

The second explanation is probably the most acceptable one for central and southern Israel (Folkman 1976; Ginzburg et al. 1979). However, across northern Israel the magnetic anomaly cannot be explained by crustal thinning and, therefore, the third possibility is more attractive; it presents an interpretation model, shown

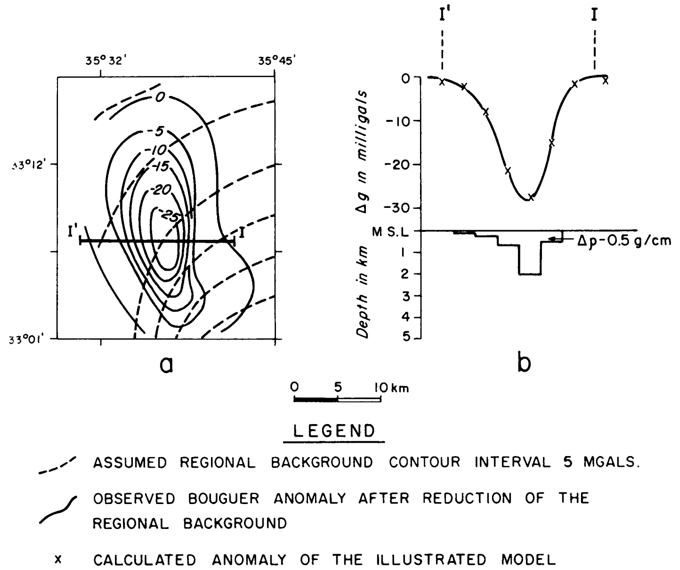

Fig. 5a and b. Gravity interpretation of the Hula basin. **a** Relative Bouguer anomaly over the basin. *Dashed contours* are the assumed regional component with a 5 mgal. interval. **b** Model interpretation of a profile across the basin after subtraction of the assumed regional background. Crosses denote the calculated anomaly of the illustrated model

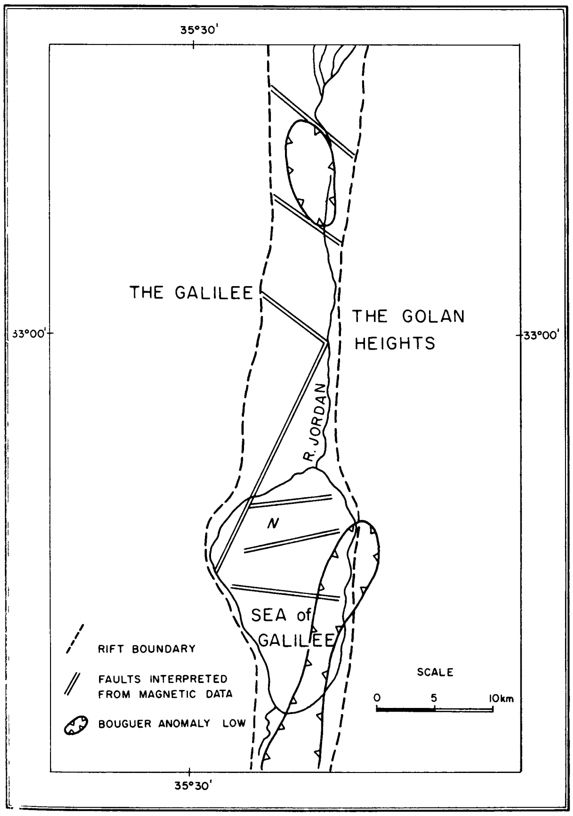

Fig. 6. Interpreted transverse and oblique fault patterns in the rift zone. *N* denotes a block interpreted to be free of basalt cover

in Fig. 4, which is almost identical with the one derived from the magnetic data.

It can be concluded, therefore, that the magnetic and gravity data suggest variations in the lithological composition of the crust across the northern segment of the Dead Sea Rift. Under the rift and its eastern side, magnetization and density of the rock type are relatively lower, whereas under the region west of the rift, the magnetization and density increase towards the continental shelf, probably indicating an increase in the proportion of mafic minerals in the rock type.

Local Anomalies in the Rift Valley

Gravity

Two distinct negative anomalies are located over the Hula basin and the southern and eastern portions of Lake Kinneret (Fig. 2). They clearly define deep depressions filled with thick accumulations of low density sediments and separated by a structural high.

Assuming a density contrast of -0.5 g/cm^3 between the dense limestone and dolomite of Cretaceous age and the soft clastic fill, the depth to the bottom of the depressions has been calculated by an inversion technique (Bott 1960), after removal of the assumed regional component of the Bouguer anomaly as shown in Fig. 5. A depth of 2,000 m was calculated to the Cretaceous carbonate rocks in the deepest part of the Hula basin and also under the Jordan River, just south of Lake Kinneret. The inversion models also indicate normal step fault boundaries east and west of the interpreted depressions.

Magnetics

Unlike the Gulf of Elat (Allan 1970; Allan and Morelli 1970) and the southern portion of the Dead Sea Rift (Folkman and Yuval 1976; Neev and Hall 1976) whose typical magnetic field is smooth, the northern area is characterized by short wavelength, well defined local anomalies, some of which probably indicate reversely magnetized basalts (Fig. 1). Those anomalies which delineate causative bodies of a three dimensional type, could well be interpreted as being caused by igneous intrusions, the existence of which has been speculated (Picard 1953; Vroman 1958).

However, the same anomalies can be more simply explained by bodies of extrusive material formed during several periods of basalt eruption, particularly in Late Pliocene and Early Pleistocene times. In this area, the most expected causative bodies may belong to the following three groups:

(a) local accumulation of basalts in a pre-existing topographic relief,

(b) vertical displacement across a faulted sheet of basalt, and

(c) successive crystallization of normal and reversed magnetized flows.

In those places where basalts crop out, the magnetic anomalies usually correlate reasonably with the outcrops. It seems, therefore, justified to suggest an interpretative approach based on extrusive material only. In this case the existence of dykes is obviously not supported by any direct evidence. On the other hand, magnetic anomalies can be used for the delineation of major faults and the estimation of vertical movements of blocks before and after the main periods of basalt eruption.

Let us first consider the Hula basin in the north (Fig. 6). Here, the deep depression based on the gravity interpretation is bounded in the north and south by a pattern of NW-SE trending elongated magnetic anomalies which most probably delineate 'step models' or faults in a sheet of basalts, provided that one assumes dominant normal magnetization.

A fault pattern of this kind has been previously suggested by Freund et al. (1970) to account for the interpreted rhomb-shaped graben of the Hula. However, its existence has never been supported by direct observations because of the thick cover of young sediments. Thus the combined magnetic and gravity study is the first to detect and delineate the major rhomb-shaped faults of the Hula graben which have a downthrow of up to 2,000 m.

A transverse fault pattern has probably also dominated the tectonic history of the Lake Kinneret depression. Here, the magnetic field is very smooth in contrast to the surrounding areas either because the causative basalts are deeply burried under the lake, or because most of the area occupied by the lake formed an elevated ridge during the periods of eruption and therefore was not covered by basalts.

The dominant magnetic features which have also been detected on a follow-up ground survey (Ben Avrahan, personal communication) comprise a transverse low separating two distinct highs across the lake (Fig. 1). Again assuming dominant normal magnetization, a straightforward solution would relate this pattern to a block structure divided by transverse faults as shown on Fig. 6. The positive anomalies represent blocks which are covered by basalts, whereas the negative anomaly is interpreted as being caused by the absence of a basalt cover. If this is the case, then the positive anomaly near the northern coast of the lake probably describes an accumulation of basalts which descended from the north and were dammed by a barrier formed by an elevated transverse block. Consequently, the positive anomaly occupying the central portion of the lake probably describes a block tilted to the east with a maximum thickness of basalts covering the lower eastern side.

The magnetic evidence strongly supports Neev's (1979) suggested structural solution in which the northern portion of the lake is shown to have been an elevated continental block until 13,000 years ago. Moreover, the magnetic study clearly delineates the faulted boundaries of the block and may thus help to detect brine springs which contaminate the lake. These springs are known from onshore observations to ascend along fault planes.

The western and higher portion of the tilted block, suggested as occupying the central portion of the lake, may be a part of the NNE trending anticlinal ridge postulated by Michaelson (1973) to be buried under the western margins of the lake.

Structural Implications

The magnetic and gravity anomalies clearly indicate that unlike some other portions of the East African Rift system, which are associated with a regional thinning of the lithosphere and an extreme thinning beneath the rift floor (Girdler 1978), the northern segment of the Dead Sea Rift is probably underlain by a normal crust and upper mantle.

Unlike the Red Sea magnetic anomalies which are generally accepted to indicate sea floor spreading, here an explanation based on basalt flows is more convincing, hence the Red Sea structural model is not considered applicable for the Dead Sea rift even in the northern segment where well defined local magnetic anomalies are shown.

Some crustal thinning under the rift between the Dead Sea and the Gulf of Elat was suggested by Ginzburg et al. (1979) based on explosion seismology. Further investigations of the same seismic data (Perathoner et al. 1979; Ginzburg et al. in press) have indicated vertical lithological variations near the base of the crust under the rift, and a normal lower crust under the western side of the rift. Unfortunately, the seismic experiments did not cover the eastern side of the rift and, therefore, the possibility still remains that the crustal type under the rift also extends to the eastern side. This implies that the rift zone is adjacent to some kind of a lateral lithological transition in the crust. This lateral transition zone is strongly supported by the magnetic and gravity anomalies over the northern segment of the Dead Sea rift and adjacent areas. Under the rift and its eastern side, the crust is interpreted to be characterized by low magnetization and relatively low density. West of the rift, however, these properties gradually increase, probably indicating an increase in the mafic content of the crustal rock type. A similar model has been previously suggested by Knopoff and Belsche (1967) for the portion of the rift between the Dead Sea and Lake Kinneret.

Although the investigated portion of the rift does not coincide with the interpreted boundary of the crustal lithological transition, its vicinity supports the classic view of movements along a complicated transform fault system (Quennell 1958, 1965; Freund et al., 1970; Freund and Garfunkel 1976). This view is also supported by the detection of transverse and oblique fault patterns which divide the rift floor into a complicated block structure.

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