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# Comment on "New evidence of magmatic diapirs in the intermediate crust under the Dead Sea, Israel" by Nitzan Rabinowitz, Jean Steinberg, and Yossi Mart

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## 1. Introduction

The Dead Sea transform fault and the Dead Sea basin, in particular, were the subject of many geophysical studies. Any new geophysical study should improve our understanding of the seismotectonic setting of this region. The current view of the Dead Sea basin is that of a classical pull-apart basin with a passive north-south extension along a fault jog [*Kashai and Crocker*, 1987]. The extension is confined to the crust, and the upper mantle beneath the basin does not appear elevated [*ten Brink et al.*, 1993]. *Rabinowitz et al.* [1996] suggest a major change in our view of the structure of the Dead Sea basin, which bears important implications for issues such as the rifting mechanism, the development of pull-apart basins, and seismotectonics. Using travel time seismic tomography from local earthquakes, *Rabinowitz et al.* [1996] identified for the first time a series of magmatic diapirs underlying the western side of the basin and largely aligned along the north-south direction. The diapirs ascend from the lower crust up to depth of 8 km below the surface but produce no domal effect at the surface. Here we comment on the methodology presented by *Rabinowitz et al.* [1996]. We further compare their results to known geological and geophysical information from the Dead Sea. We conclude that the diapirs must be either model artifacts or misinterpreted known salt diapirs, but they are not lower crustal magmatic diapirs.

## 2. Methodology

Several aspects in the data and in the modeling as presented lead us to question the inversion results: (1) epicentral location, (2) resolution matrix, (3) model convergence, (4) lateral coverage, and (5) size and locations of diapirs.

1. While the majority of the epicenters (and the ray paths) are much shallower than 20 km, the model resolves detailed structures to depths of up to 50 km, even at the outskirts of the study area. With a characteristic length of the study area of about 100 km, it is unlikely that diving waves will travel below 30 km.

2. The ability to resolve laterally varying structure with linearized inversion is limited to the scale of the station spacing [*Thurber*, 1986]. The station spacing is 10-20 km and about 5-10 km in the northern Dead Sea basin and the southern Dead Sea basin, respectively, while the authors claim to resolve structures with a characteristic length of 5 km. Additionally, tomographic studies normally discuss at length the elements of the resolution matrix and the implication of the resolution matrix on the ability to determine various underground structures. These are not mentioned at all by the authors.

3. The initial velocity model for inversion within the basin is high relative to the low velocity of the thick basin fill. Only three iterations are performed, and the velocity changes between iterations are forced to be small (0.4 km/s) to keep the inversion stable. Under these conditions it is unclear whether the difference between data and model parameters converged to a minimum.

4. If the data are available only to blocks south of latitude 31°40'N [*Rabinowitz et al.*, 1996, Figure 3], how did the authors get results, including fine details at great depths, for many blocks north of latitude 31°40'N shown in their Figures 4 and 5?

5. The size and locations of the diapirs suggested by the foci of the observed earthquakes in their Figure 6b do not match those in their Figures 4 or 5, that is, the largest diapir in latitude 70 (km in Israel grid).

## 3. Comparison With Other Geophysical Data

The second part of our comment concerns the results of other recent geophysical studies that are in clear disagreement with those of the new tomographic study.

### 3.1. Seismic Velocity

Salt has high seismic velocity [*Dobrin*, 1952]. In the southern part of the Dead Sea, salt deposits are either exposed in Mount Sodom on the western side of the basin or located close to the surface in the Lisan on the eastern side, with a thickness of 1 km and over 4 km, respectively. According to *Rabinowitz et al.* [1996, Figure 4], cross sections AA' and BB' suggest low-velocity anomalies at midcrustal depths (deeper than 10 km) underneath the known salt deposits of the Lisan and Mount Sodom. It seems that these low-velocity bodies at midcrustal depths are pure artifacts probably compensating for the high velocity of the salt above. Furthermore, the velocity anomalies presented in AA' and BB' (their Figure 4) at depth of 10 km are inconsistent with the anomalies at the same level in their Figure 5. For example, the low anomaly of 5.6 km/s in 182.5E60N (km on the Israel grid) and the high velocity of 6.8 km/s in 192.5E60N (km on the Israel grid) in their Figure 5 that are flipped to 6.5 and 5.5 km/s, respectively, in their Figure 4.

### 3.2. Magnetic Anomaly

*Rabinowitz et al.* [1996, p. 240] proposed that the origin of the magmatic diapirs is the anomalously hot and dense lower crust. Therefore, the composition can be assumed to be gabbroic and dioritic. Gabbroic and dioritic rocks usually have high magnetic susceptibility, which is associated with a distinct



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magnetic anomaly. For example, the magnetic anomaly due to the diapir in the southern part of the southern Dead Sea basin ($X$=190 and $Y$=60 km on the Israel grid (their Figure 5)) is estimated. Assuming a relatively large thermal gradient of 40°C/km and somewhat low Curie temperature of 550°C, we approximate the diapir by a vertical cylinder [*Dobrin*, 1952] with a diameter of 7 km between the depths of 8-14 km (their Figure 4). The positive magnetic anomaly that should be observed at the surface just above the diapir is at least 50 nanoteslas, and the measurement error is less than 10 nanoteslas [*Rybakov et al.*, 1994]. The magnetic anomaly observed in the southern Dead Sea Basin is quite smooth, almost uniform, and is negative in its character, implying that any sizable anomaly due to a hypothetical buried magnetic body should be noticeable. Furthermore, the magnetic low in the southern Dead Sea basin is inconsistent with the possibility of a buried dense body and supports the extension of light, basin-fill material into depths of more than 10 km.

### 3.3. Bouguer Gravity Anomaly

Bouguer gravity anomalies in combination with known surface geology and density logs from drill holes suggest the existence of light sediments inside the basin, even at great depths (10-12 km [*ten Brink et al.*, 1993; *Rybakov et al.*, 1996]). These sediments are lighter than the mainly carbonate sequence on the western side of the Dead Sea basin and the mainly sandstone sequence on the eastern side. *Rabinowitz et al.* [1996] proposed noticeable magmatic diapirs with higher velocities than the ambient material. Assuming the latest velocity-density ratio for 10 km depth ($\Delta\rho = 4924 - 13294/V_p$ [*Christensen and Mooney*, 1995]), the expected density difference with the surrounding 6 km/s areas is 260 kg/$\mathrm{m}^3$. The expected difference with the nearby low-velocity zones [*Rabinowitz et al.*, 1996, Figure 5] is 510 kg/$\mathrm{m}^3$. We approximate the magmatic diapir in the southern part of the southern Dead Sea (for location see section 3.2) by a vertical cylinder body, assuming the dimensions proposed by *Rabinowitz et al.* [1996, p. 240] and a modest mass density difference of 260 kg/$\mathrm{m}^3$, stemming from the dense lower crust. The theoretical positive Bouguer anomaly [*Dobrin*, 1952] due to the diapir is about 20 mGals, which is definitely not observed [*ten Brink et al.*, 1993], where the measurement error is less than 1 mGal. In fact, the observed negative Bouguer anomaly, varying smoothly throughout the basin, rejects the possibility of a buried dense body and supports the extension of light basin-fill material into greater depths, in good correlation with the findings of the magnetic anomalies. Therefore sections 3.1-3.3 strongly suggest that the authors located salt domes, with high velocity and low mass density rather than dense magmatic diapirs.

### 3.4. Reflection Studies and Geological Evidence

Although seismic reflection records penetrate to a depth equal to the roof of these diapirs and drill holes penetrate down to 6 km depth [*Neev and Hall*, 1979; *Kashai and Crocker*, 1987; *ten Brink and Ben Avraham*, 1989], they do not support the existence of any of the proposed dense magmatic diapirs. The only frequently encountered diapirs are salt diapirs [*Neev and Hall*, 1979; *ten Brink and Ben Avraham*, 1989].

### 3.5. Refraction

Along the highlands surrounding the Dead Sea basin and in the Dead Sea rift, *Pn* phases refracted from the Moho, with typical velocities of 7.9-8.0 km/s, imply a Moho depth of about 27-32 km, see *Ginzburg et al.* [1979] and *El Isa et al.* [1987], who are also cited by the *Rabinowitz et al.* [1996]. *Rabinowitz et al.* [1996, Figure 4] determined, with no given reasoning, a significant deepening of the Moho under the basin extending to about 40-47 km (50%-80% increase).

In addition, *Rabinowitz et al.* [1996] did not present any other corroborating data to support the existence of hot diapirs. Nor did they put forward a plausible geodynamic regime that can give rise to diapirs originating from 15-20 km depth and reaching a depth of 8 km within the crust, a depth range that is within the seismogenic zone. Finally, the new images of the Dead Sea basin that were recalculated by N. Rabinowitz et al. (unpublished data, 1997), are significantly different from any of the images given by *Rabinowitz et al.* [1996] in their Figures 4-6 in number, size, and locations of the anomalies.

## 4. Conclusions

We argue, based on the available evidence, that the postulated velocity anomalies representing magmatic diapirs are probably artifacts, caused by mistreatment of the data and by erroneous interpretation of the results. A tomographic study, based on local earthquakes, is, nevertheless, important and should, once properly carried out, help us understand better the seismotectonic setting of the Dead Sea basin.

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