The electrical conductivity structure of the Dead Sea Basin obtained from MT measurements

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Abstract

The left-lateral Dead Sea transform (DST) is a major transform fault that separates the Arabian plate in the east from the African and Sinai plates in the west. It extends from Red Sea rift in the south to the Taurus collision zone in eastern Turkey, with a total length of more than 1000 km (Fig. 1). The total displacement along the fault is estimated to about 105 km since its development ~18 Ma ago with an average slip rate of 4mm/yr (Garfunkel et al, 1981).

During its evolution, the DST formed several deep sedimentary basins. These pull-apart basins formed the Gulf of Aqaba / Eilat, the lake of Tiberius and the Dead Sea basin (DSB). The DSB is probably the largest of these structures on earth.

Geophysical, geological and geochemical studies of the San Andreas Fault system in California showed clearly that the dynamics and thereby earthquake generation processes are closely linked with (over-pressurized) fluids (Zoback, 1987; Becken et al., 2007). In addition to meteoric water and formation water, fluids may originate from as deep as the earth's mantle. At the DST, the existence of several hot springs on both sides of the fault may indicate deep-reaching fault zones that provide pathways for fluids.

The main objectives for the MT experiment are: to determine position and depth extent of the major faults within the DS basin (e.g. Ritter et al., 2003), to establish if these fault zones are associated with deep reaching fluid channels (e.g. Becken et al., 2008) and to infer the thickness of sediments within DS basin and to image the internal structures of the DS basin.

Experiment design and Data processing

In the framework of the multi-disciplinary DESIRE (Dead Sea Integrated Research) project, several geophysical methods were applied to investigate the southern part of the Dead Sea basin. Besides MT, the methods used included active reflection and refraction seismic, aero-gravity, passive seismology, and thermo-mechanical modeling.

The MT profile in Figure 1 follows roughly the seismic profiles, crossing the DST at the place where the fault separates into an eastern and western border fault (EBF and WBF), where the basin fill is at its largest and where intruded salt domes are likely three-dimensional features.

The data were collected in October and November 2006. The measurements were carried out along two profiles. The main profile is oriented N70°E, approximately perpendicular to the surface trace of the DST and has a length of ~110 km. A second, shorter profile (20 km) is oriented N20°E and runs parallel to the west coast of Al Lisan peninsula (Fig. 2). With the in-basin profile we intend to quantify the effect of the highly conductive Dead Sea brines ("ocean effect") and also to test if structural details within the sedimentary basin can be resolved.

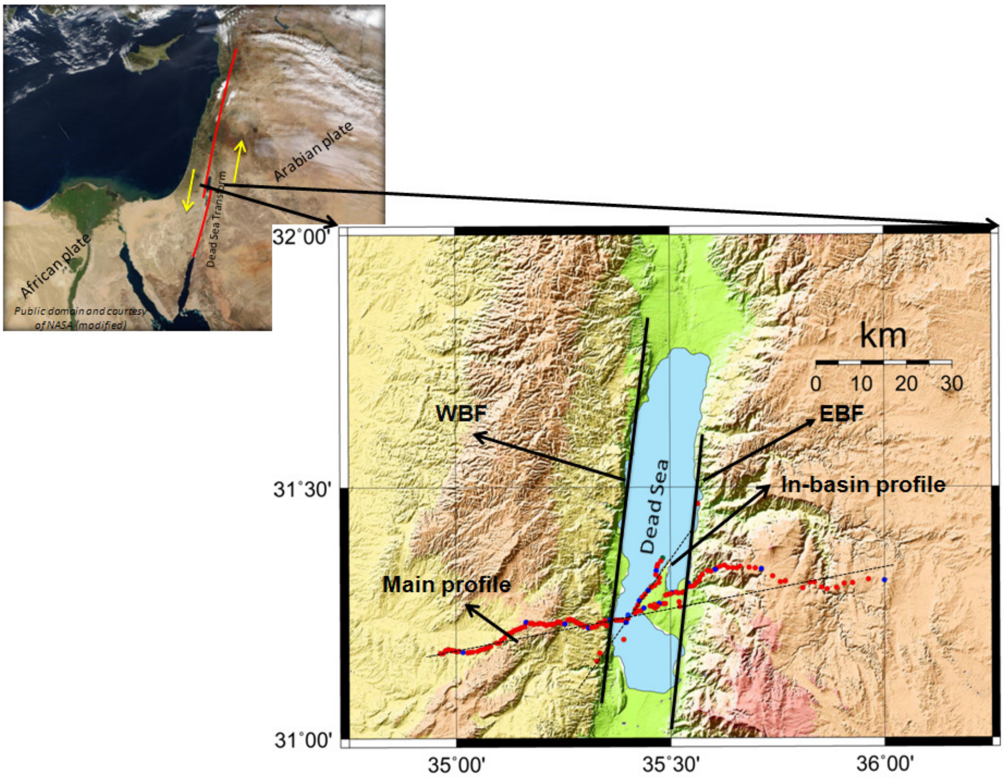

Fig. 1: Location map showing the locations of 148 MT sites. In the Dead Sea pull-apart basin the Dead Sea Transform separates into eastern (EBF) and western (WBF) fault branches

Data acquisition was accomplished with two independent teams, working at the same time in Jordan and Israel which allowed us to operate up to 30 sites recording simultaneously. This provides great flexibility to use remote reference processing with many combinations of sites.

In total, 148 MT stations were deployed along the profiles with denser site spacing within the Dead Sea basin and increased site spacing towards both ends of the profile. At each site, broad-band systems (red dots in Fig. 1, period range 0.001 s-1000 s) were used to measure time variations of the orthogonal magnetic (Bx, By, Bz) and electric (Ex, Ey) field components. Additionally, 20 sites with long-period systems (10 s – 10000 s) were distributed along both profiles (blue dots in Fig. 1).

The recorded time series were processed using the EMERALD package (Ritter et al., 1998; Weckmann et al., 2005) to compute the horizontal impedance tensor and vertical magnetic transfer functions. In addition, remote reference processing (Egbert, 1997) was useful to improve the data quality at particularly noisy sites.

The obtained impedances were analyzed to estimate the geo-electric strike direction. Based on the galvanic distortion analysis described by Becken and Burkhardt (2004) we discriminated the data into 3 subsets. Sites located to the west of the WBF and to the east of the EBF (purple and green profile segments, respectively, in Fig. 2) exhibit predominantly 2D conditions with a very stable strike direction of 10°-15° E (90° ambiguous; cf. rose diagrams in Fig 2a and c, respectively). In the central segment of the profile, i. e. between the WBF and EBF, the geo-electric strike direction exhibits greater variability (see rose diagram in Fig. 2b) consistent with the dimensionality parameters (not shown) indicating moderate 3D conditions.

But this data analysis shows very clearly that the electrical resistivity distribution is strongly correlated with the fault structure and basin architecture. The geo-electric strike direction determined for different segments along the profile is very consistent with the orientation of the DST and the DS basin (10°-15°, see rose diagrams in Fig. 2 a and c). However, data from the central part of the profile reveals a more complicated, three-dimensional nature of the internal structure of the DS basin with finite extent (Fig. 2c). Since the dominant strike direction in all parts of the profile is roughly north/south a 2D interpretation of the data is at least reasonable. The ultimate goal of data analysis is to compute 3D inversion models using the data from both the main profile and the in-basin profile.

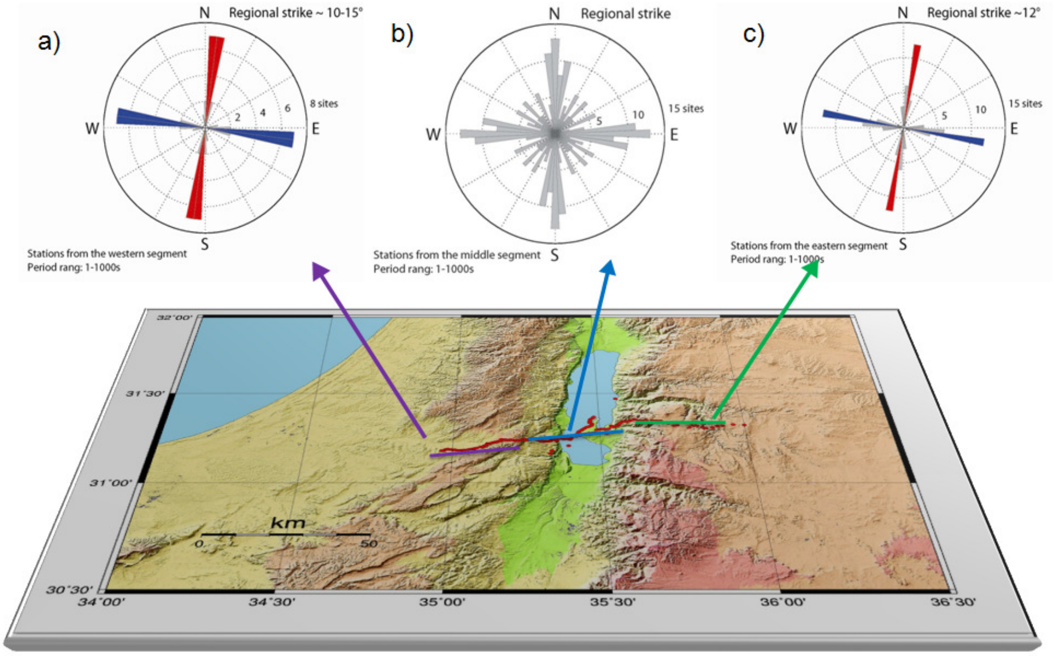

Fig. 2: Regional electrical strike direction analysis: a, b and c show rose diagrams for the western, central and eastern segments, respectively. The western and eastern segments (a and c) are consistent with the expected regional strike direction along the DS basin.

Preliminary 2D inversion results

For 2D inversion, we used the non-linear conjugate gradientalgorithm described by Rodi and Mackie (2001) to invert the data of the main profile. The data were rotated into the regional strike (12°E) estimated for the eastern and the western profile segments, and assigned to the presumed E- and H-polarizations.

For the main profile, inversions using different model parameterizations, regularizations and a priori models were examined to test the robustness of the resulting resistivity model.

The model presented in Figure 3 was obtained from joint inversion of the E- and H-polarization apparent resistivity and phases and the vertical magnetic transfer function by using stations from the central part of the main profile. However, large error floors were imposed on the E-polarization apparent resistivity to reduce the effect of static shift in the data; emphasis was on fitting the phases. Furthermore, in this preliminary inversion study we confined the period range from 1000Hz to 10s to concentrate on the structures in the upper crust.

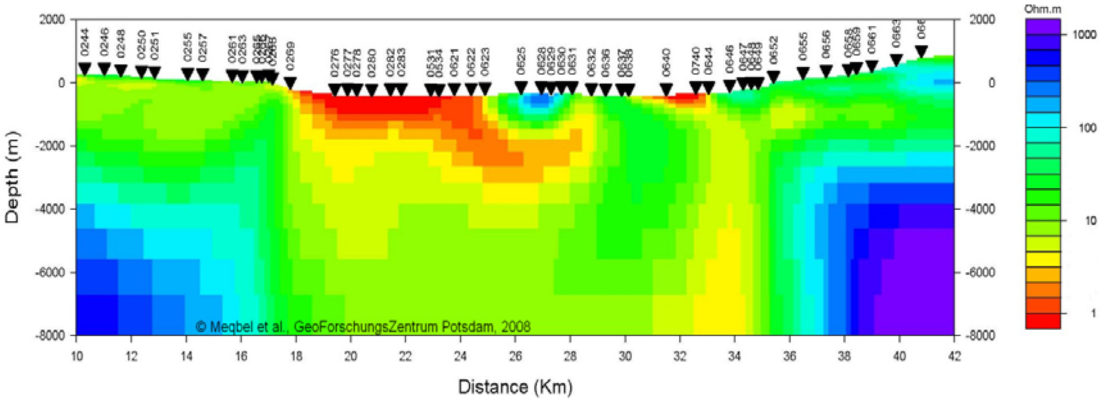

Figure 3: Resistivity model obtained for the central part of the main profile. The black triangles indicate the positions of stations. Red and yellow colours indicate zones of low electrical resistivity.

Our preliminary 2D resistivity section shows the following features (Fig. 3):

- Extremely low electrical resistivity (< 0.5 Ωm) beneath the DS (red colours) extending to approximately 3km depth. This structure could indicate that the Dead Sea brines reach depths of several kilometres.
- Within this structure and directly beneath the Al Lisan Peninsula we observe a high resistivity body (> 100 Ωm, green and blue colours) which seems to coincide with a known salt intrusion. From borehole information, a salt body (mainly halite) begins at 100m depth and extents to approximately 3000m depth (Powell, 1988).

- Very abrupt lateral changes from low to high resistivity (> 1000 Ωm, dark blue and magenta colours) at depths of 3 to 4 km coincide with the surface traces of the EB and WB faults. These boundaries indicate the width of the Dead Sea basin at depth.
- Both fault zones appear to be associated with narrow, sub-vertical zones of low resistivity which may reach mid-crustal levels.

The deep resistive structures (> 1000 Ωm) at depths of 3 (east) and 4 km (west) belong to the crystalline basement. The lower resistivity values beneath the central part of profile (Fig. 3) correspond to the sedimentary fill of the Dead Sea basin.

Outlook

Thorough resolution tests of the 2D inversion models will be important for the near future work. Furthermore, 3D modelling and inversion of the entire data set (including the in-basin profile) will help us to map the complicated electrical resistivity structure within the DS basin.

Our resistivity model will form an integral part of a joint interpretation of the many geophysical parameters obtained in the scope of the DESIRE project. Eventually, this will improve our understanding of large faults systems such as the DST.

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