Magnetotelluric images completed with gravity, magnetics and seismics from SW-Hungary

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SUMMARY

In the contact zone of three tectonic units (Pannonian Basin, Eastern Alps and Dinarides), in a complicated – basin and range – geological situation magnetotelluric deep soundings were carried out along a 140 km long profile with a site distance of 2 km. The MT sites followed the Hungarian part of the CELEBRATION-007 (CEL-7) deep refraction profile, and the MT spacing was the same as the seismic one.

In the paper various magnetotelluric images completed with gravity, magnetics and seismics are provided. A joint interpretation of magnetotelluric, gravity, magnetic and deep seismic results provide a quite comprehensive interpretation about the deep geological structures in SW-Hungary, but different magnetotelluric approaches may lead to different conclusions. E.g., if the subsurface is not perfectly two-dimensional, the reality of results of automatic TE+TM mode joint inversion might be questionable. In such a dilemma it is worth applying a traditional approach. Namely, we interpreted separately the TM and TE mode magnetotelluric sounding curves. As expected, the TM mode curves well express the resistive basement structure, already known from boreholes and seismic exploration, while the TE mode curves (together with the induction vectors of very low values) definitely show the conductive root of the deep fractures, at a depth of about 8 km.

The TE mode inversion (supported by a detailed 1D analysis) seems to be not too far from the geological reality.

Keywords: Magnetotellurics, CELEBRATION, TE mode, TM mode, 2D inversion

INTRODUCTION

Along one of the profiles of the CELEBRATION (“Central European Lithospheric Experiment Based on RefrAcTION”, Guterch et al. 2001) deep refraction network experiment (namely the Hungarian section of line No. 7, CEL-7), we carried out 72 magnetotelluric (MT) soundings (Figure 1). We used instruments from the MT pool of GFZ Potsdam. Along the 140 km long magnetotelluric profile, the MT spacing was the same (about 2 km) as the seismic spacing. The most important tectonic lines are as follows: the Rába (Raab, Insubric) line, the Balaton (Periadriatic) line and the Mid-Hungarian (Zagreb-Zemplén) line.

An overview about the Pannonian Basin is given by Haas (2001). Németh (1997) gave a more detailed description about the geology of the region, as follows: The metamorphic belt at Szentgotthárd (upper East Alpine nappe, at the Northernmost part of the profile); the Rába line; the Preneogene deep zone at Kőrmen; continuation of the Mesozoic, mainly carbonatic, thousands m thick mass of the Transdanubian Central Range at Salomvár-Nagylengyel oil field (Zala basin); Pretertiary grabenlike structure at Nova and Bak; Mesozoic carbonatic highland at Hahót; Balaton-line as a Pretertiary graben structure (Nagykanyiza, Oltár, Budafa); Mesozoic horst as continuation of the Kalnik MtS (at Pátró, Liszó, Pat); Mid-Hungarian tectonic line: (with other name the Zagreb-Zemplén line); the Gyékényes-Inke graben; Prealpine polymetamorph
crystalline schist complex (Szenta-Kutas) with northward gravitational creep. From the MT survey we expected to reveal the conductivity anomalies in the region, and to get complementary information to the seismic, gravity and magnetic data.

**DATA**

The MT measurements (72 soundings in the 1000 Hz-1000 s range) were carried out in August 2003, by using GFZ Potsdam instruments (Castle, EDL and LMT ones). One example (showing TE mode (blue) and TM mode resistivity (red) sounding curves, together with corresponding phase- and geomagnetic deep sounding parameters) is shown Figure 2.

Figure 1. MT profile CEL-7 shown on the Pretertiary basement map (Kilényi and Sefara 1991) of SW-Hungary

Figure 2. Apparent resistivity- and phase values, together with GDS parameters at site No. 35, as a function of the period between 1/1000 s and 1000 s. In Figure 3 gravity and magnetic data, long-period MT apparent resistivities (the mean values of TE and TM mode resistivities), anisotropy, and the length and direction of the induction vector are shown along the profile CEL-7. The middle part of CEL-7 is characterized by high and varying anisotropy, a relatively high resistivity value (due to the geometric mean of low TE mode- and high TM mode resistivities), while the geomagnetic deep sounding (GDS) parameters indicate a very high-conductivity structure about in the middle of the profile (see the zero transition and the complete reversal of direction).

Figure 3. Magnetic, gravity, MT apparent resistivity (at T=800s), MT $Z_{max}/Z_{min}$ anisotropy, and direction and length of the geomagnetic induction vector (at T=500s).

**JOINT TE+TM INVERSION**

Results of the automatic inversion by using the WinGlink software are shown in Figure 4a. The separate inversion results by using the TM mode data only are shown in Figure 4b, while the TE mode inversion results are shown in Figure 4c. (Figure 4d gives the same information as Figure 4c, only the isolines are interpolated.) Due to the diverging character of TM and TE mode curves (illustrated in Figure 2), in the TE mode inversion high-conductivity-, in the TM mode inversion mainly high-resistivity zones are indicated. Consequently, an automatic joint
inversion produces a fluctuating series of high-conductivity and high-resistivity vertical zones. In spite of the excellent numerical agreement between the field-and model data, obtained by using an automatic TE+TM mode (+tipper) inversion, we consider this solution with some criticism, first of all because of the over-dominance of the high-resistivity character of the TM mode. This is probably due to the imperfect 2D character of the regional geology. Some presentations even at the 17th EM Induction workshop itself confirmed our feelings. Namely, Uchida et al. (2004) stated that conventional 2D inversion may create strange deep 2D models; Siripunvaraporn (2004) suspected that a numerical overfitting that would result in spurious structures or unrealistic resistivities; Pedersen (private communication, 2004, based on Smirnov and Pedersen 2004) mentioned that the TM mode supresses conductors.

On basis of the aforementioned arguments we think, besides of such an automatic 2D joint inversion it is worth carrying out a classical analysis, based on a careful separation of the two polarizations.

THE CLASSICAL INTERPRETATION

It is a simple thumb rule that the TM mode is more sensitive to near-surface high-resistivity bodies (in our case, to the bottom of the sedimentary basin), while the TE mode (together with the induction vectors) gives information rather on the high-conductivity structures (in our case about the upper-crustal ones). In this way, following Ádám (2001), the steps of the interpretation are as follows: (1) producing the pseudosections of the TE and TM modes, (2) 1D inversion of sounding curves, (3) 2D inversions, with involving the induction vectors.

Results

The 1D inversion of the TM mode sounding curves gives correct values for the depth of sedimentary basin. Results of the 1D inversion of TE mode curves are especially different from the TM mode based depths only in the middle part of the profile (see in Figure 3 the higher anisotropy values).

The crustal conductivity appears only on the TE mode curves. The 2D inversion of TE curves (together with the H_z data) in Figure 4c and 4d (where the mathematical results are identical, only the representations, as block and interpolated ones, are different) indicates three major high-conductivity zones: between sites 47 and 51 a clear indication about the Middle-Hungarian tectonic line, between sites 25 and 35 a wider zone related to the Balaton line, and between sites 10 and 25 the third (and the least) high-conductivity zone (assumed to be the continuation of TCA, that is the Transdanubian high-conductivity anomaly, Ádám, 2001). Since the TE inversion shows integrated effects, each of these three major zones can easily be rather fault populations than single dike, and the TE anomalies show only their so-called “backbones” (Wannamaker, 2004). A 1D inversion of TE soundings (where the depth estimations for the high-conductivity dikes were about 7-10 km) supports this hypothesis. The conductance maximum of these fractures is 3000S. On basis of Ádám (1987) this conductance value might be due to pore fluids.

COMPARISON WITH GRAVITY, MAGNETIC AND SEISMIC DATA

In Figure 4e a velocity pseudosection, obtained from the CELEBRATION deep refraction seismic experiments is shown. The hypothetical gravity and magnetic discontinuities (determined after Hartman et al. 1971, Thompson 1982, Hansen and Simmond 1993) are also shown in the velocity pseudosection. The black points mean possible gravity discontinuities, corresponding to the gravity anomaly shown in Figure 2, while the red points refer to the magnetic profile. Their correlation with the TE mode pseudosection is even stronger than with the combined TE+TM mode inversion results. Moreover, the TE inverted pseudosection is much more informative than the seismic one. (E.g. the TCA high-conductivity zone accompanies with enhanced velocity.)

CONCLUSIONS

In this paper we present two different approach: (1) an automatic joint inversion of TE and TM modes. In spite of the excellent mathematical agreement between the measured and the modeled data and of the good correlation with the gravity and the magnetic data, the geological reality is not guaranteed. Therefore, as an alternative solution, we are proposing a careful, classical analysis of 2D data, based on a separate inversion of TE and TM modes.

As a summery of further steps to be done, we are going to make further experiments. It is certainly possible to minimize the static shift reduction (which is not significant in this area) by introducing much more dense near-surface grids (Smirnov and Varentsov 2004). Alternatively, the TE+TM joint inversion could be carried out with downweighted TM mode (Varentsov, private communication, 2004). Again, some anisotropy could be included (Pek and Cerv 2004).
3D inversion of field data by using the full tensor (as done on model data by Siripunwaraporn 2004) is not yet a realistic option. We are working on 3D imaging, without losing information content of the tensor (7 independent invariants, e.g. the WAL ones + the measuring direction = 8 parameters). Invariants instead of tensor elements are especially ideal in data visualization (Szarka 2005).

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REFERENCES


Figure 4. CEL-7 pseudosections (from top to bottom):
   a) Results of automatic joint inversion of TE+TM modes (completed with Hz)
   b) Results of inversion of TM mode magnetotelluric data
   c) Results of inversion of TE mode magnetotelluric data
   d) Interpolated version of c)
   e) Results of the deep refraction experiment (after Hegedüs et al. 2004), and the hypothetical block boundaries
      from gravity (black points) and magnetics (red points).