Magnetotelluric signature for the Zagros collision

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SUMMARY
Zagros is a relatively young and active fold-thrust belt, which has formed due to convergence between the Eurasian and Arabian plates. Magnetotelluric (MT) soundings along a transect were carried out to determine the crustal structure in the collision zone of the two Palaeo-continents. MT data were analysed and modelled using 2-D inversion schemes. The models show clear conductive and resistive domains along the MT profile consistent to a great extent with documented tectonic features and surface geology. The models obtained from the joint inversion of transverse electric and transverse magnetic modes as well as the inversion of the determinant data show similar features along the profile. The new MT results reveal that the transition between two continents at the surface coincides with the western boundary of Sanandaj-Sirjan Zone (SSZ) at the Main Zagros Thrust (MZT). Along the profile towards northeast the conductors at top indicate massive Neogene sediments of the central domain (CD) while the very thick, shallow-located, resistive body (5–25 km thick and 100 km long) beneath is unlikely to be of oceanic affinity, but continental. Another main feature along the profile is the main resistive and conductive parts of the Arabian Plate, which coincide with the tectonic events of High Zagros Fault and Mountain Front Fault. Two highly conductive thick zones are recognized at the southwest part and in the middle of the profile apparently extending to a depth of about 50 km, possibly related to a downward smearing effect due to the presence of thick sedimentary columns in the upper crust. Along the profile, conductive features are recognized at the metamorphic SSZ and Urumieh-Dokhtar Magmatic Assemblage units as well as at CD. Below site 31 along the surface trace of the MZT, the transition between the two continents is distinguished by a complex sequence of conductive and resistive zones both varying laterally as well as vertically. The main difference between the two domains is that the Eurasian Plate seems to be more resistive than the Arabian Plate, although some part of the difference can be related to the thick sequence of conductive sedimentary rocks on the Arabian Plate.

Key words: Electrical properties; Magnetotellurics; Continental margins: convergent; Asia.

1 INTRODUCTION
Collison of the Arabian Plate with Eurasia after the closure of the Neotethys ocean formed the Zagros mountain belt and its surrounding zones (e.g. Berberian et al. 1982; Koop & Stonely 1982; Beydoun et al. 1992; Besse et al. 1998; Paul et al. 2006). Compared to many other orogens, the Zagros fold-thrust belt (ZFTB; Koyi 1988) is less explored and many questions about its architecture and evolution history remain unanswered. Questions related to the precise timing of the orogenic processes and of the kinematics of the Eurasia–Arabia Plate motion (e.g. McQuarrie et al. 2003; Molinaro et al. 2005) are outside of the scope of the present research project. The configuration of the Zagros basement, which is not outcropping anywhere within the belt, is also one of the unknown elements. We investigate the vertical and lateral electrical conductivity changes across Zagros putting emphasis on the crustal part and its relation to the geological and tectonic features along the magnetotelluric (MT) profile.

The Zagros area can be divided into a number of structural units related to the specific geology and tectonics for each part (Alavi 1994). From the southwest (SW) to the northeast (NE), at the northern shore of the Persian Gulf, the ZFTB consists of large parallel concentric folds related to Neogene inversion of the margin of the Arabian Plate (Koyi 1988). Parallel to the ZFTB are the Sanandaj-Sirjan Zone (SSZ), consisting mainly of Precambrian metamorphic rocks and the Urumieh-Dokhtar Magmatic Assemblage (UDMA), an Andean-type volcanic magmatic arc including rocks ranging in age from Late Jurassic to Quaternary. These two zones are...
Figure 1. Location map of the MT-sites. The blue box on the geological map of Iran in inset shows the location of the regional map. MT sites used in this study are plotted as black circles. The thick blue line is the MT profile where MT-sites projected as a 2-D section. The main faults are shown as thick black lines. Geological map modified from the structural map of NGDIR (National Geoscience Database of Iran, http://www.ngdir.ir, after Paul et al. 2006). MZT, Main Zagros Thrust; KZF, Kazerun Fault; MFF, Mountain Front Fault; HZF, High Zagros Fault and DF, Dehshir Fault.

separated from the ZFTB by the Main Zagros Thrust (MZT), considered by many authors as being the suture between the Arabian and Eurasian plates. A narrow belt of strongly tectonized ophiolitic melange marks the MZT, and more ophiolites are found aligned in a belt separating the UDMA and SSZ zones (Fig. 1; Molinaro et al. 2005).

Even though most authors agree on the location of the suture at the MZT, Alavi (1994) proposes that it coincides with the northern boundary of the SSZ. And according to Ghassemi & Talbot (2006), one of the main problems concerning the geological history of the Zagros orogeny is the tectonic setting of the SSZ, although they follow most geologists who have worked in the region (e.g. Stöcklin 1968; Takin 1972; Berberian & King 1981) and take the SSZ to lie along the southern edge of the Iranian Plate. Another relevant question is if the UDMA has the signature of a magmatic arc. Mohajjel et al. (2003) argued for a continental collision scenario for this belt. Mohajjel (2011, private communication) encouraged conducting MT investigations in the region to collect electrical/conductivity evidence to support this idea.

Paul et al. (2006) used seismological network data on the same profile to image the Moho depth variations and the crustal structure. Snyder & Barzangi (1986) claimed that the continental lithosphere in the Zagros is buoyant compared to the asthenosphere. As such, sutureting between Arabia and Iran was followed by the Arabian Plate indenting into the Iranian Plate, increasing the thickness of SSZ crust to about 55 km. Shomali et al. (2011) also discovered a thick continental lithosphere (more than 200 km) at the ZFTB. In addition they claim that in the northern part of the profile (central Iran) a thin lithospheric mantle exists and the transition between Arabia and central Iran coincides with MZT at the surface.

The natural-field MT method has proven very useful for mapping suture zones and continental features as resistivity sections (Unsworth et al. 2005; Habibian-Dekordi et al. 2010). Generally the depth of investigation of MT method is also sufficiently large to penetrate deep into the mantle. To improve our knowledge of the electrical conductivity variations in the crust and upper mantle, we deployed a MT survey across Zagros (Fig. 1). The profile crosses all the morpho-tectonic units of the Zagros collision zone. In the southwest, it first traverses the ZFTB with the main faults namely MFF, Kazerun fault (KZF), HZF, MZT and then Deshir fault (DF) in the SSZ zone shown as thick black lines in Fig. 1. The preliminary results were reported by Oskooi (2010) as a technical report.
To our knowledge the present paper includes the first interpretation on MT data across the Zagros hoping to be a good start for future more intensive MT investigations in the region. We present our findings supporting some of previous ideas which were put forward by geologists and seismologists about the region and provide an interpretation of the electrical features from surface down to a depth of approximately 100 km.

2 GEOLOGICAL AND TECTONIC SETTINGS

Early in the Middle Triassic, crustal spreading ceased in the first sea-way known as Neo-Tethys1. A new spreading trough, Neo- Tethys2, began to form to the northeast. The boundary between the two troughs is best seen in the SSZ (Fig. 1) northeast of the Zagros Mountains. The SSZ is described as a geological microcontinent which narrows southwards. The oceanic crust of Neo-Tethys2 probably continued to spread for the next 100 million years or more until about the mid Cretaceous when it possibly reached a width of some 2000 km (Ghassemi & Talbot 2006). The ZFTB is known in the literature for its spectacular folds. The lower Cambrian to Pliocene sedimentary sequence of the Arabian platform is strongly folded and thrusted with a basal decollement horizon in the lower Cambrian Hormuz salt at 9–12 km depth (Stöcklin 1968).

Formation of this sedimentary column is thus believed to be decoupled from the crustal shortening of the basement on distributed reverse faults (Jackson 1980; Jackson & Fitch 1981; Berberian 1995). It is worth mentioning that the ZFTB is affected by frequent earthquakes of magnitude generally smaller than 7 concentrated at a depth of 8–15 km in the upper crystalline crust beneath the sedimentary sequence (Talebian & Jackson 2004; Tatar et al. 2004). Northeast of the High Zagros, the profile crosses the Main Zagros Thrust, which is believed by most authors to be the suture zone between Arabia and Central Iran (e.g. Dewey & Grantz 1973). It separates the ZFTB from the Sanandaj–Sirjan Zone, a highly deformed and moderately metamorphosed remnant of the southern active margin of the Iranian continental block (e.g. Stöcklin 1968; Agard et al. 2005). The SSZ is bounded to the northeast by the Urumieh–Dokhtar Magnetic Assemblage characterized by an almost continuous volcanic activity from Eocene to present (e.g. Berberian & Berberian 1981; Berberian & King 1981), and believed to be the Andeante type arc related to the subduction of the Neotethys (Berberian et al. 1982). Some authors have discussed the cumulative NE–SW shortening of ZFTB (Blanc et al. 2003; McQuarrie 2004; Sherkati & Loutouzey 2004). Tatar et al. (2004) used fault plane solutions to claim that in the Zagros basement, shortening is accommodated at least partially by distributed thrusts. However, at the same time, the deformation processes that enable the lithosphere to accommodate the shortening at greater depths remain unknown.

3 PRIOR GEOPHYSICAL SURVEYS

Several studies of the Zagros collision belt, using different geophysical techniques have been conducted to explain the crustal structure as well as the deeper geometry of the lithosphere and upper mantle beneath the Zagros mountain during the last decade. Integrated lithospheric modelling, based on the combined interpretation of gravity, geoid and topography data sets, by Molinaro et al. (2005) proposed a recent slab break-off of the subducted Arabian Plate.

Hatzfeld et al. (2003) showed that the sedimentary thickness across the Zagros thickens from 3 km beneath the Arabian Platform, to 7 km beneath the Persian Gulf and to 11 km beneath the Zagros fold belt.

Mapping of Moho depth variations and S-velocity structure of the upper mantle across the Zagros have been reported recently (e.g. Dehghani & Makris 1984; Hatzfeld et al. 2003; Shad Manaman & Shomali 2010; Keshvari et al. 2011; Shad Manaman et al. 2011; Shomali et al. 2011) to better understand the dynamics of the belt. These authors used receiver functions (RFs) and inversion of P and S traveltimes of local earthquakes as well as the teleseismic events.

Paul et al. (2006) and Kaviani et al. (2007) applied the RFs technique and tomography on the data from a temporary seismological network along a 620-km-long profile between Busher on the coast of the Persian Gulf and Posht-e-Badam, 160 km northeast of Yazd to gain information on crustal thickness variations across Zagros. Alavi (1994) suggested that the suture zone of MZT is located between the SSZ and the UDMA and redefined the SSZ as a zone of thrust faults that have transported Phanerozoic units of the Arabian margin and obducted ophiolites to the southwest. Paul et al. (2006) compared Alavi’s hypothesis to their Moho depth profile and the Bouguer anomaly data to conclude that fitting the gravity observations requires that the basement reaches the surface in the SSZ and that the lower crust is twice as thick beneath the SSZ than beneath the ZFTB. This requirement of a very thick lower crust is quite different from Alavi’s model, which assumes that the crust beneath the SSZ is composed of a stack of thrusted slices (see cross-section in Fig. 4, Alavi 1994). Anyway, the gravity modelling of Paul et al. (2006) shows that the assumption of crustal scale thrusting of the margin of the Iranian microcontinent over the ZFTB is compatible with Bouguer anomaly data.

4 MT DATA ACQUISITION AND ANALYSES

In 2009 April and May, an MT survey was carried out at 46 sites along a 470 km profile with an approximately northeast (NE) and southwest (SW) direction across Zagros from Yazd to Bushehr in the Fars province of SW Iran (Fig. 1). The MT-sites are located on the same route along which Paul et al. (2006) conducted their seismological experiment. The profile crosses all the morpho-tectonic units of the Zagros collision zone. In the SW, it first passes the ZFTB and then the MZT located NE of the High Zagros, then through SSZ, UDMA. The 70-km-long northeasternmost segment of the MT profile crosses the southwestern part of the central Iranian microcontinent (CIMC) south of Yazd.

All five MT-channels (two horizontal electric dipoles and the three components of the magnetic field) were measured using MFS05 induction coils from Metronix (Germany) as well as non-polarizable Pb/PbCl2-electrodes. The time series were recorded on Earth Data PR 6–24 portable field recorder, GPS clocks secured synchronized recordings. We used two sampling modes to obtain transfer functions in overlapping frequency bands: 1000 Hz during 2 hr at nighttime, and a three day run with 20 Hz. In general, the data quality was good with a low noise level although due to an unknown source of noise the vertical component of the magnetic data were not with sufficient quality at most sites to be useful.

The plane wave magnetic source fields are highly correlated over distances up to several hundred kilometres (Schmucker 1984) whereas the noise on the magnetic field is assumed to be completely uncorrelated between the local and the remote sites (Gamble et al. 1979). We replaced disturbed magnetic data at a few stations with those of neighbouring (typically 10–20 km away), synchronously.
5 DIMENSIONALITY ANALYSIS

5.1 Skew and strike

Prior to 2-D inversion of the MT data dimensionality analysis of the impedance tensor after Zhang et al. (1987) was performed to examine the geoelectrical strike along the SW–NE profile. Smirnov & Pedersen (2009) explained the importance and significance of strike analysis in detail. Strike angles (with a 90° ambiguity) and Swift's skew values (invariant for the dimensionality of the impedance tensor; Swift, 1967) were calculated for all sites and frequencies applying an error floor of 5 per cent on the impedances (Figs 3a and b). The results show small skew values (<0.2) for most sites and periods, which indicates that the underlying resistivity structure can locally be considered as 1-D or 2-D including even the effect of near surface galvanic distortors. While the estimated strike angle deviates from the expected strike of N45° W along the whole profile, the green colours in Fig. 3(a) indicate acceptable agreement with the strike of the main geological structures in the region. More complex dimensionality (skews higher than 0.2 and no unique strike directions) are observed for some sites and frequencies along the profile. Since we can directly observe on the geological map of Fig. 1 that the MT-profile runs orthogonal to the main tectonic and geological strike in the region we still represent the conductivity structure by a 2-D model striking in the SE–NW direction. To obtain quantitative estimates of the deviation from two-dimensionality as well as strike direction we applied Q-function analysis of Zhang et al. (1987) as further explored by Smirnov & Pedersen (2009). The analysis involves least squares (LS) minimization of a quadratic objective function (Q), constructed within a selected frequency range and selected sites. Savvaidis et al. (2012) simplify the calculation of the Q-function through the following equation,

$$Q = \sum \sum Q_{ij},$$

where

$$Q_{ij} = \frac{1}{4N-2} \left[ \frac{1}{\sigma^2_{xx}} |Z_{xx,ij} - \beta Z_{yx,ij}|^2 + \frac{1}{\sigma^2_{yy}} |Z_{yx,ij} - \gamma Z_{yy,ij}|^2 \right]$$

and index i refers to the stations and index j to the periods over which the averaging is done, N = NpN, with Np denoting the number of periods and N, the number of stations, $\sigma^2_{xx}$ and $\sigma^2_{yy}$ are estimated variances of the diagonal elements $Z_{xx}$ and $Z_{yy}$, $\beta$ and $\gamma$ parameters are real galvanic distortion parameters for the particular average of the Np periods and N stations, which in the case of a regional 2-D structure with strike direction along the x-axis have the following simple physical interpretation: $\beta$ is the ratio between the electric field along strike to the horizontal electric field perpendicular to strike (B polarization) and $\gamma$ is the ratio between the horizontal electric field perpendicular to strike to the electric field along strike (E polarization). Q is a function of rotation angle and attains its minimum in the regional strike direction. The quality of the 2-D assumption for the chosen strike is given by the Q-function. We investigated strike directions in the azimuth range N30° W to N60° E by analysing the $\sqrt{Q}$-function. $\sqrt{Q}$ gives a quantitative measure of the deviation of the impedance tensor from two-dimensionality. We calculated the $\sqrt{Q}$-function for the selected strikes with variances $\sigma^2_{xx}$ and $\sigma^2_{yy}$ calculated from 5 per cent error bars of the corresponding main off-diagonal elements of the impedance tensor (Figs 3c and d). $\sqrt{Q}$ equals to 1 signifies that the impedance tensor satisfies 2-D assumptions with respect to the given error floor (Hübert et al. 2009). A $\sqrt{Q}$-misfit calculation for the estimated strike angles N45° W (Fig. 3c) and N60° W (Fig. 3d) show a more or less identical fit for the impedance tensor. Actually the rms fits using all stations and periods for the three strike directions N30° W, N45° W and N60° W were 1.72, 1.61 and 1.66, respectively. It is usually not possible to find a common strike angle for all sites and periods dealing with MT data along such long profiles. However, strike directions for stations 24–35 over the MZT are very stable and close to N45° W as shown in Fig. 3(e). All information from the dimensionality analyses of the MT-data combined with the obvious geological structure (Fig. 1) guided us to select a strike direction of N45° W for further 2-D inversion. This requires the rotation of the transfer functions into the new coordinate system and the projection of the station positions onto a profile perpendicular to the estimated strike direction. The MT sites were projected onto a SW–NE line for later 2-D modelling. We chose to work with the determinant average (DET) data as well as the TE and TM mode data for inversion.

6 INVERSION

We started with the inversion of the determinant impedance which is very practical because it is rotationally invariant and because
3-D effects and galvanic distortion effects can be reduced (Pedersen & Engels 2005). We then inverted TE- and TM-mode data simultaneously in order to better constrain the deeper parts of the conductivity model, especially the transition in electrical conductivity to less conducting regions (Oskooi et al. 2002, 2005).

We performed 1-D and 2-D inversion of the determinant average data (DET) as well as a 2-D inversion of joint TE- and TM-mode
Figure 3. Estimation of strike directions after Zhang et al. (1987): (a) strike angle, (b) swift’s skew for each station and frequency and square root of Q misfit for strike angles, (c) –45° and (d) –60°, (e) estimated strike directions from sites 25–36 for all periods as a cumulative rose diagram of regional strike estimates according to Q-function analysis strike. An approximate strike direction of N45W can be identified from the rose diagram.

data, using a code from Pedersen (2004) for the 1-D inversion and a code from Siripunvaraporn & Egbert (2000) modified by Pedersen & Engels (2005) for the 2-D inversion. Here we only show the results of the 2-D inversion. Prior to 2-D inversion we deleted small parts of the data that were obviously biased, like the TE-mode data at station z54 for periods greater than 100 s (Fig. 2). The profile starts right on the shore of the Persian Gulf in a thick sedimentary basin which continues under the Gulf. The bathymetry in the Persian Gulf is very shallow with a maximum depth of 75 m. We therefore did not explicitly constrain the model away from the length of the profile, but allowed the inverse process to vary the model beyond the length of the profile. Since the quality of the data in both modes is reasonably good and due to the predominance of the 2-D conditions in the data along the profile, we performed joint 2-D inversions of both the TE- and TM-mode responses. However, to compare the results with the models from the 1-D inversion of the DET data we also tried 2-D modelling of the DET data. The final 2-D model and the DET data and responses of the DET model are depicted in Fig. 4. Data and model responses of the joint inversion of TE- and TM-mode are shown in Fig. 5. Two models of the joint inversion are shown in Fig. 6, the upper one in Fig. 6(a) with equal weights on horizontal and vertical smoothing parameters and the lower one in Fig. 6(c) with weights on the horizontal smoothing five time greater than the weight on the vertical smoothing. We note that the models are very similar. A more detailed display of the upper 10 km of the models are shown in Figs 6(b) and (d). To remove the static shift effects on the TE-mode data a relatively large error floor of 90 per cent was used for the apparent resistivity data of TE-mode while for the phase data, TM-mode data and the DET data an error floor of 5 per cent on the impedance was assumed. With these error floors the resulting data fits for both phase and apparent resistivity in both TE- and TM-modes were very similar, thus justifying the use
of the high error floor on the TE-mode apparent resistivity. By these levels of errors on the data, the fits of the computed model responses to the observed data were satisfactory as shown in Figs 4(a) and 5. The overall rms misfit is about 3 for the joint TE- and TM-mode data inversion and 2.5 for the DET data inversion. In order to check the convergence of the inversion, we took several half-space models with different resistivity as initial models. The resulting 2-D models showed relatively little variation. However, due to the occurrence of high conductance in the upper crust, to reduce the smearing effect introduced by the regularization in the inverse process (Smirnov & Pedersen 2009) we tested several a priori models with high resistivity starting at an upper mantle level of 40 km. The final model together with a plot of cumulative conductance down to different depths along the profile are shown in Fig. 7. In order to sharpen the transition from conductive crust to resistive mantle we used a two layer a priori model with a 40 km thick upper layer with 100 Ohm-m resistivity and an underlying half-space of 1000 Ohm-m. We note that the change of a priori model greatly shifts the resistivity of the mantle part of the model, but the lower crust and the upper mantle of the Arabian Plate still appear to have much lower resistivities compared to typical platform basement.

7 INTERPRETATION

Generally the Arabian Plate appears more conductive than the Eurasian Plate, which is dominantly resistive down to at least 100 km. To the SW though the conductor representing the crust and upper mantle extending to 100 km depth cannot be resolved due to the overlying conductive sediments, whereby resistive structures become smeared out (Smirnov & Pedersen 2009). A possible interpretation is that the upper part of the Iranian Plate protrudes into the Arabian Plate to the SW and/or that more resistive sedimentary rocks like limestones or ophiolite slivers dominate. Even though there are no outcropping ophiolite bodies along the profile, there is probably a ‘hidden’ ophiolite body covered by sediments between the sites 19 and 20. The extension of this body is outcapping about 10 km southeast of the position of the MT sites. Geologic maps of the area (Haghipour & Aghanabati 1985) show outcapping ophiolite bodies separated and covered by Neogene sediments. In an earlier work, Thiel et al. (2009) studied the electrical resistivity distribution along a short profile over the Samail Ophiolite to investigate the tectonic evolution of its emplacement through attempting to outline the major faults and geological boundaries on a crustal scale. Similar to Thiel et al.’s (2009) strike estimation, our measurements show a NW–SE trend of the main structures (Fig. 3e). The only difference in our estimation was in choosing the whole span of frequencies rather than splitting them. Thiel et al. (2009) argued that the data for the shallow part of their section corresponding to the periods less than 100 s is influenced by local 3-D structures. This 3-D influences are less likely along the middle part of the transect where the main trend of the structures is NW–SE. In our transect, the ophiolitic bodies which are relatively
Figure 5. Apparent resistivities and phases data and 2-D model responses of the joint inversion, (a) TE-mode data, (b) TM-mode data.

small and exist only along the northeastern 15–20 km of the profile, mainly strike NW–SE compatible with the main trend of the Zagros.

In Fig. 7(a) we have marked outcropping conductors and resistors by letters C1–C6 and R1–R7, respectively in order to relate them to the surface geology. Furthermore, we have also marked possible dips of the major faults along the MT profile as indicated by the dips of the corresponding conductors along the resistivity section. The model of Fig. 7(a) depicts three highly resistive blocks (R1, R2 and R3) within the middle to southwest part of the profile (Figs 1 and 7). These anomalies coincide with the location of three major structural elements in the Zagros; the High-Zagros Fault, the Mountain Front Fault (MFF) and the Kazerun Fault (Fig. 1). The Kazerun Fault (KZF) is a major strike-slip fault which produces a step in the basement. However, the other two basement faults have significant amounts of vertical displacement along them. According to Berberian (1995) the High Zagros Fault has up to 6 km of vertical displacement. In addition, the topographic difference between the Dezful embayment and the Izeh zone across the Mountain Front Fault has been estimated to be approximately 4–5 km (Safari et al. 2009). The highly resistive blocks along the MT profile are thus interpreted to be due to basement rocks brought close to the surface by these two main faults.

Another significant feature is the very high conductance, which can be observed in the upper crust (Fig. 7b). Conductance up to 10 kS and more can be identified in the SW part close to the Persian Gulf (C1), at 130 km a branch of the Mountain Front Fault (C2), at 165 km the main branch of the MFF (C3), the High Zagros Fault (HZF), (C4) at 215 km, the SSZ at 320 km (C5) and the CD at 380 km (C6) along the profile (Fig. 7). The high conductances can probably be related to sedimentary basins with high concentrations of saline fluids (brines; Fürst 1970, 1976; Bosak et al. 1998). The 11 km sedimentary thickness reported by Hatzfeld et al. (2003) along a profile a few hundred kilometres to the south of our profile compares well with the 5 Ohm-m contour shown in Fig. 7(a) close to the Persian Gulf and SW of the KZF. The main difference is that we see a dominant resistive structure in the between the two conductive structures.
Figure 6. 2-D model derived from joint 2-D inversion of the TE-mode and TM-mode data while smoothing parameters are the same in both vertical and horizontal directions, (a) 100 km depth, (b) 10 km depth. (c) 2-D model when the smoothing is weighed by a factor of 5 at the horizontal direction, shown down to 100 km and (d) 10 km depth.

There are some distinctive features in the ZFTB which add to its complexity. The thickness of the sedimentary cover varies significantly (6–12 km) along the ca. 2000-km-long belt. The decollement beneath this unevenly thick sedimentary pile possesses different mechanical behavior (low-friction when the Precambrian Hormuz salt in the SE is present to high-friction where such a weak salt layer lacks (e.g. northwestward of the KZF) resulting in different modes of decoupling between the basement and its sedimentary
Figure 7. (a) 2-D model derived from joint 2-D inversion of the TE- and TM-mode data when a two layer a priori model with 40-km-thick upper layer with 100 Ohm-m resistivity and an underlying half-space of 1000 Ohm-m as the resistive mantle, (b) conductance along profile accumulated from top to the depths of 5, 10, 15 and 20 km.

cover (Kent 1979; Bahroudi & Koyi 2003). Furthermore, in addition to the NW–SE trending, inherited normal basement faults of the Arabian passive margin, which are inverted as high-angle reverse faults during the collision (Jackson et al. 1981), there are several N–S trending Pan-African and E–W trending faults in the Zagros basement which are and have been active throughout the evolution history of the belt (Hessami et al. 2001). The basement faults have played a significant role in governing the sedimentary basin configuration (Farzipour-Saein et al. 2009), thickness variation of the cover units and their later deformation since the collision. These elements strongly influence the structural configuration of not only the cover, but also the basement architecture.

During collision between Arabia and Eurasia, the normal basement fault of the Arabian passive margin must have been reactivated as high-angle reverse fault (Jackson et al. 1981). This inversion is likely to have been variable along the belt. McQuarrie (2004) re-stored three profiles across the belt and showed that the basement is more involved in the deformation along the Fars domain than the Izeh and Lurestan provinces. Furthermore, it is expected that basement faults in the northeastern part of the belt, closer to the suture, are inverted more relative to those located further to the southwest. Before the collision, these northeastern faults were representing the outermost and deepest part of the Arabian continental passive margin where the sedimentary pile was relatively thin compared to the margin closer to the continent. During the collision, the northeastern normal faults must have been inverted sooner and significantly more than their equivalents away from the collision zone in the southwest. As such, these inverted northeastern faults must have brought the basement, which were covered by relatively thinner sedimentary rocks, closer to the surface and contribute to the structural complexity of this strongly deformed suture zone.

Our data show a regular interval between the resistive domains along the traverse. This regular interval may represent the spacing between inverted basement faults, which bring basement blocks closer to the surface. It is equally important to underline here that there are abundant non-outcropping diapirs and pillows in this part of the Zagros (Ghassemi & Talbot 2006; Koyi et al. 2008). The stem of some of these salt structures can be as wide as 3–4 km in diameter (Kent 1979; Koyi 2001). The Hormuz salt, which feeds these diapirs, is mapped to extend to this part of the Zagros (Kent 1979; Ghassemi & Talbot 2006; Koyi et al. 2008). These salt structures and the salt layer itself, which are more resistive than the non-evaporitic
sediementary rocks of the cover, are also likely to influence the MT data and complicate their interpretation.

8 CONCLUSIONS

This paper represents the first attempt to characterizing the electrical conductivity across the Zagros. The MT data include the full impedance tensor in the period range 0.005–1000 s. Analysis of the strike direction and different skew parameters indicate that the impedances can be explained in terms of 2-D models with a strike direction coinciding with the strike of the regional geological structure. The final 2-D models of the DET data as well as the joint inversion of TE and TM mode data are stable, that is, they do not depend on the initial models and are consistent and comparable, whereas in the initial model using an a priori model with a resistive upper mantle, the transition length from crust to mantle and the resistivity level of the mantle are reduced and increased, respectively.

Down to depths of 100 km the Arabian Plate is more conductive than the Eurasian Plate. In the southern part a massive conductor extends to 100 km depth with a gradual increase in resistivity towards the NE possibly due to the Iranian Plate protruding into the Arabian Plate or that more resistive sedimentary rocks like limestones or ophiolite slivers dominate. The very high conductances up to 10 kS observed in the upper crust can probably be related to sedimentary basins with high concentrations of brines.

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