**Integrated interpretation of geophysical data from Zagros mountain belt (Iran)**

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**Abstract**

Fluid composition and distribution, the key factors determining geoelectric structure in a seismically active region, are controlled by local and regional stresses and rheological contrasts. In the central Zagros collision zone, one of the world’s most seismically active mountain belt, almost coincident magnetotelluric and seismic velocity profiles are jointly interpreted to recover more accurately structural boundaries and fluid distribution within the crust.

A multi-site and multi-frequency approach was used for the strike analysis of regional structure and decomposition of distortion effects contaminated MT data. Distortion corrected MT data were then used for two- dimensional inversion modeling. The results image a thick conductive overburden in the southwest of the profile, high conductivities attributed to the fault zone conductors (FZCs) and an almost concave conductor extending from middle to lower crust in the central- eastern portion of the mountain belt, beneath the High Zagros (HZ).

Comparison with the s- velocity structure, obtained by joint inversion of P-wave receiver functions and the surface wave dispersion data, shows that these main conductive features are spatially correlated with a low-velocity layer representative of the sedimentary cover overlying the Arabian platform and a velocity contrast bounded by the main Zagros thrust (MZT) fault, indicating the presence of fault zone fluids. The joint interpretation of MT inverse modeling and seismicity data also shed light on fluid generation influencing rock deformation and seismicity in this region. It suggests that beneath the HZ, deep crustal fluids generated through metamorphism may promote aseismic deformations before high stresses are buildup and cause the north- eastern part of the Zagros Fold and Thrust Belt (ZFTB) to be seismically inactive compared to its south- western part.

**1. Introduction**

Subsequent to the closure of the Neothetys ocean and its subduction beneath Iran during Mesozoic and early Cenozoic, the deformed north-eastern edge of the Arabian plate collided obliquely with central Iran continental block and the Zagros mountain belt formed as the surface exposure of this collision. Based on topography, exposed stratigraphy, and seismicity, the Zagros Fold and Thrust Belt (ZFTB) can be divided by the High Zagros fault into two distinct zones: the Simply Folded Belt (SFB) in the southwest and the High Zagros (HZ) in the northeast. While the topography rises from the sea level to 1.5 Km throughout the SFB with rare exposes of Paleozoic strata, the topography averages 1.5-2 km and the stratigraphy exposes Paleozoic and Mesozoic levels in the High Zagros (Nissen et al., 2011).

There is no basement outcrop in the Zagros, however different estimates of the total sedimentary cover show its thickness varies from ~ 14 km in the northwest SFB to ~ 10 km in the far southeastern SFB and to the northeast, into the High Zagros, it decreases to lower values, due to the erosion (Sherkati et al., 2006). Furthermore, a recent inverse modeling of potential field data shows high density contrasts of the embedded units among active faults in this region (BF, KZF, MFF, and HZF faults), representative of basement rocks uplifted close to the surface (Abedi et. al., 2018).

Earlier studies based on instrumentally recorded earthquakes (Talebian& Jackson 2004) and also the lack of surface rupturing in the Zagros suggest that larger earthquakes occurred in the basement, but more recent studies of earthquake faulting based on radar interferometery (In SAR) show a depth distribution of coseismic faulting; while the moderate size (5- 6 Mw) earthquakes ruptured the competent group of mechanically strong strata in the lower sedimentary cover (at depths of 5- 10 km), their micro-seismic aftershocks are vertically separated and occurred within the basement at depths of ~ 10- 20 km. Coulomb stress changes, the effects of loading or shaking and dynamic stress transfer caused by shaking are possible scenarios lead to the separation(Nissen et. al., 2011).

To improve our knowledge about the crustal structure of Zagros collision zone, we analyze broadband MT data, recorded at 46 stations along a 470 Km profile, crossing the main morpho-tectonic units in this region (figure 1). It starts near Busher on the northern coast of Persian Gulf, crosses the ZFTB, where a high level of seismicity is accommodated with earthquakes magnitudes smaller than 7 whose hypocenters are concentrated at a depth between 8-15 Km. To the NE the profile further crosses the Precambrian metamorphic rocks of SanandajSirjan Zone (SSZ), bounded by the Urumieh-Dokhtar magmatic assemblages (UDMA) produced by the Eiocen to present time volcanic activities. The profile ends near Yazd, in the SW of central Iran micro-continent (CIMC) block. The data were preliminary interpreted by 2D inverse modeling (Oskooi et al., 2013) and further investigated by sensitivity analysis of the inversion results (Layegh-Haghighi et al., 2018). This paper extends our previous findings by removing distortion effects from measured data and jointly interpreting inversion results with the seismicity data as well as the seismic velocity models.

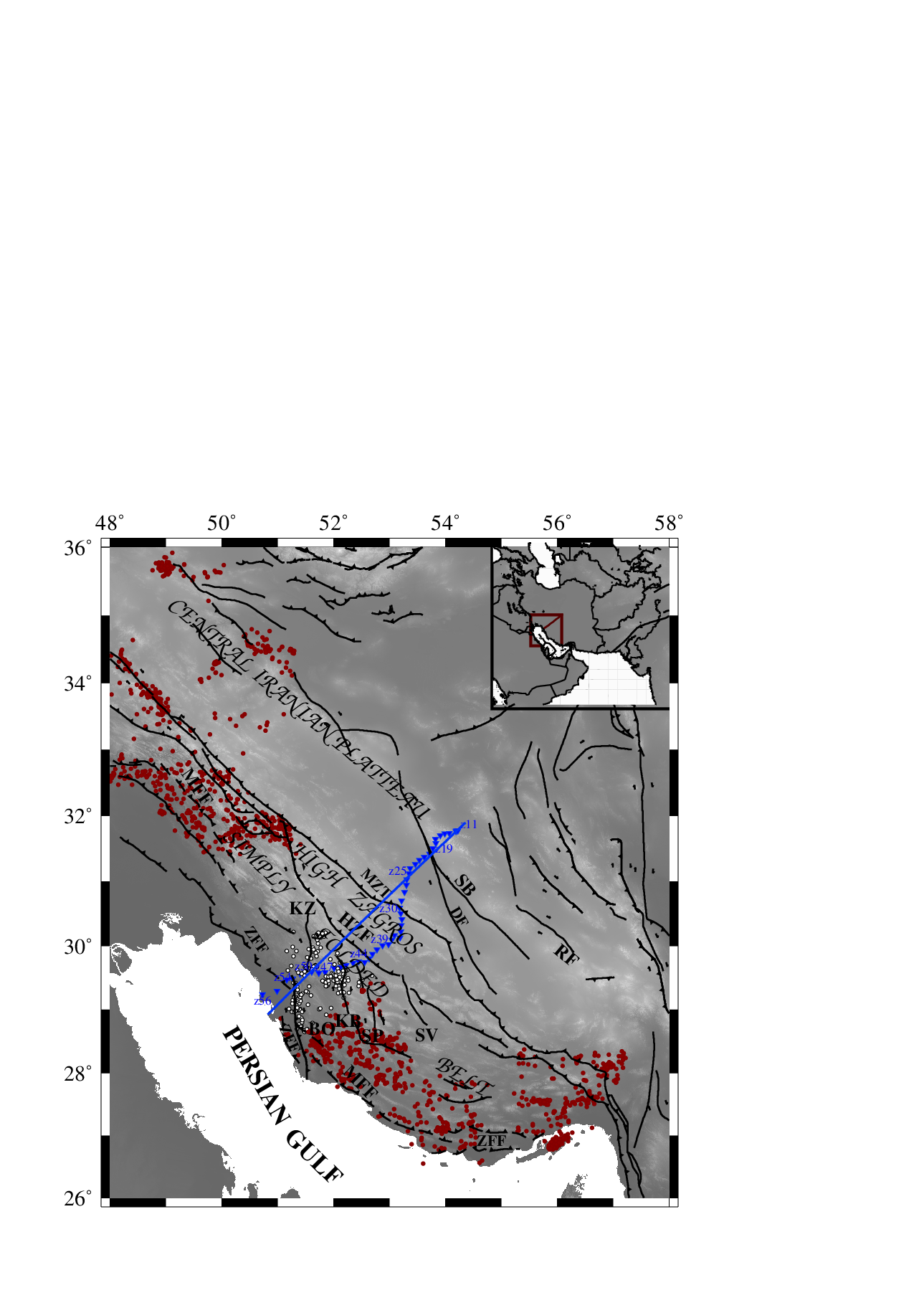


Figure 1. Geological map of the Zagros mountain belt showing the location of MT sites (red inverse triangles) and the 2-D modeling profile (red line). Also shown are the main structural units (ZFTB, SSZ, UDMA, and CI) and the major faults (black lines, dashed if blind): BO, Borazjan Fault; DEF, Dezful Embayment Fault; KZF, Kazerun; MFF, main front fault; HZF, High Zagros Fault; MZT, Main Zagros Thrust Fault; SV, Sarvestan Fault; SP, SabzPushan Fault; SU, Surmeh Fault; ZFF, Zagros Foredeep Fault; DF, Dehshir Fault; SB, Shahr e Babak fault. Dots are Epicentres from GCCEL database (Karasozen et. al., submitted for review). The inset shows the location of the regional map.

**2. Geological setting and geophysical background**

The geodynamic framework of Zagros region is composed of the two Arabian and Eurasian plates moving westerly relative to the mantle. Eurasia is faster and overrides the Arabia SW ward, up to 16-25 mm/yr (Vernant et al. 2009), leading to the formation of Zagros mountain range as a result of the continent-continent collision.

Although the boundary conditions changed during the long-lasting convergence history (from subduction/obduction process to the current collision), but lithospheric scale reconstruction of the Zagros orogeny based on geodynamic studies emphasized the crucial importance of subduction throughout the whole record of convergence, making the Zagros orogeny a unique natural laboratory to test different hypothesis of subduction procedures (Agard, 2011).

Assuming that the foreland evolves in relation to the orogenic wedge according to an Andean tectonic context, Magneto-stratigraphy and strontium isotope stratigraphy of the foreland basin sedimentation, along two profiles near Zagros suture, in high Zagros with presumably older foreland deposits, restricted the initial stage of mountain building at 27±2 Ma. Thereafter, thrusting of Eurasia over Arabia initiated a forebuldge migration of ca. 650 km southwestward to its present location, southwest of the Mesopotamian- Persian Gulf (Pirouzet.al., 2017). The estimates of underthrust Arabian lithosphere (≈ 350 Km) and the average shortening rate across the Zagros (ca. 13.5 mm/yr) provided by investigating the relationship between facies and isochrones of foreland basin deposits and the kinematics of their underthrusting by the growing orogenic wedge, relatively compare with those reported by the seismological observations (Paul et. al., 2010) and combined analysis of earthquake and geodetic data (Masson et. al, 2005). They also imply that almost half of the convergence between Arabia and Eurasia is manifested by the crustal thickening across the Zagros and the remained shortening is due to the thrusting and eclogtization of the Arabian crust (Pirouz et al., 2017).

Complex geometry of the Zagros folding system with highly dipping layers, thrust faults, presence of intermediate decollements in sedimentary pile and geological units with strong velocity contrast (like salt and anhydrate) results in poor-quality estimation of seismic velocity (Soleimani et al., 2017), making control-source seismic imaging of Moho depth variation impossible. Accordingly, most of our knowledge about crustal and lithospheric upper mantle velocity structure comes from seismology and non-seismic geophysical data (Paul et al., 2010).

The first coarse map of MOHO depth variation beneath the Zagros Orogeny was provided by the conversion of gravity data (Dehghani and Makris, 1984) and further improved by more detailed modeling of the Bouguer anomaly data (Snyder and Barazangi, 1986). However, receiver function analysis of teleseismic earthquake details recorded by temporary passive seismic stations, along with a profile almost coincident with the MT profile (Zagros profile hereafter), delineated crustal thickness variations with a high lateral resolution (Paul et. al., 2006). The results showed that crustal thickness is 42±2 km beneath the ZFTB, compatible with those estimated for the pre-collisional Arabia and confirming the previous finding that the thickness of the ZFTB crystalline basement has not been increased by the collision yet (Hatzfeld et. al., 2003). From 30 km SW of the MZT, crustal thickness increases on a 170 km length and reaches a maximum value of 69±2 km beneath low elevation of SSZ (and not beneath the High Zagros) between 50 and 90 km NE of the MZT. The MOHO depth decreases to its average value around 45 km, beneath CI. These values are consistent with the crustal thicknesses obtained from 1D absolute s-velocity model beneath each station (Motaghi et. al., 2015) and also the depth section of S-wave receiver functions (SRFs, Motaghi et al., 2017).

Paul et al (2006) introduced crustal scale under-thrusting of Arabian plate with respect to CI along MZT, a major thrust fault cross-cutting the whole crust, in order to coordinate seismic Moho with the Bouguer anomaly data. However, Motaghi et al (2015) scrutinized the inconsistencies between the variations of the MOHO depth and surface topography which even was evident below the NE-ward extension of the Zagros profile; the MOHO depth reached a minimum value of about 30 km beneath high elevation of KopehDagh Mountains with the topography as high as 3000 m. They suggested that these regions were not isostatically raised and introduced a deeper feature composed of thickened and multi-layered upper mantle to reconcile the v-shaped s-wave velocity anomaly with the long wavelength negative Bouguer anomaly beneath the MZT. The authors alleged that like some collisional belts such as the Alps and Himalayas, the model is compatible with continental lithospheric subduction hypothesis.

Motaghi et al., (2017) joined the P-wave receiver functions (PRFs) of 17 stations along the NE-ward extension of the Zagros profile with the previous dataset (Paul et al. 2006, 2010) and derived PRF migrated depth section down to 800 km depth to unravel the upper mantle structure and mantle transition zones. An outstanding feature in PRF cross-section, not documented for the well-studied collisions like Himalaya, is the spatial correlation between footwall syncline in the lower lithospheric mantle and the shallower antiform of MOHO beneath the SSZ. This requires an intra lithospheric mantle decoupling, a transition zone which separates opposite folds, lets on differential buckling and introduces a deforming viscose layer representative of the lid rheological parameters. Furthermore, the authors concluded: i) lithospheric scale accommodation of the south Zagros contract, (ii) minor thrusting of lithospheric mantle beneath central Iran, indicating that Zagros collision is in its initial stage and (iii) a low dip slab subduction coincident with the slab stagnation close to the transition zone, suggested by shear wave velocity model (Manaman et al, 2011).

P-wave receiver functions (PRFs) and surface wave dispersion data of teleseismic earthquakes were jointly inverted to obtain 1D velocity models beneath 35 broadband stations along a transect following the similar trend of the Zagros profile and extended about 600 km farther to the north-east (Motaghi et al., 2015). Investigating the depth in which a low-velocity layer was distinguished, the authors delineated the lithosphere-asthenosphere boundary (LAB). The results coincide with those reported for the Middle East by Priestly et al., (2012) from a large multimode surface wave dataset. They found that lithosphere is thick beneath Zagros (thicker than 240 km) and becomes relatively thinner beneath CI (~130±15 km).

2D S-velocity structure down to 300 km depth shows Low velocity upper crust beneath the Zagros area, covered by at least 10 km of Cambrian to Miocene sediments, while the higher velocity upper crust is located beneath SSZ, UDMA, and CI (Motaghi et al., 2015). A low-velocity layer is extended in the upper mantle, beneath the whole profile up to a depth of 70 km. At deeper parts (depths between 60-240 km) the velocity structure is more heterogeneous with a high velocity (Vs~4.8 km/s) and density(ρ≥3.4) lithosphere beneath Zagros, submerging NNE-ward beneath SSZ, UDMA, and CI and some localized low velocities distributed between 120- 180 km depth beneath MZT (an evidence for a thickened, collided lithosphere), north of the UDMA and NW of the Lut block, coinciding with the surface projection of volcanic extrusions (possible evidences of melt residence in the upper mantle). 3D partitioned waveform inversion of broadband seismic array data along the Zagros profile also revealed the high-velocity tongue beneath the SSZ and UDMA down to 250 km depth (Manaman et al., 2011).

Abedi et al., (2018) investigated potential field anomalies derived from airborne magnetic and ground-based gravity data along the Zagros profile. Total gradient map of the RTP magnetic data, intensifying the boundaries of geological structures, revealed the MZT fault as a prominent lineament coinciding with the western boundary of the SSZ and separating low amplitudes of magnetic field over the ZFTB zone (covered by thick sequence of sedimentary deposits) from increased magnetic field intensity observed over the UDMA (composed of intrusive Granotoid melange magmatic arcs). All inversion models exhibit a susceptible element almost coincident with the UDMA boarders and some scattered susceptible spots associated with the intrusive magmatic sources in the Iranian continental crust. Residual gravity map, obtained by performing free air, Bouguer, isostatic and trend corrections on measured data showed positive and negative gravity anomalies, discriminating NW-SE tectonic stripes aligned with the MZT. Gravity data were also inverted employing the mixed norm and smooth inversion methods. The result reveals high-density contrast for UDMA zone (than SSZ and CD) and around BF, KZF, MFF, and HZF faults, representing basement rocks uplifted to the surface.

**3. Magnetotelluric data Analysis and Inversion**

The MT method is a passive electromagnetic exploration technique which records naturally varying horizontal electric (Ex, Ey) and magnetic (Hx, Hy) fields as well as the vertical component of the magnetic field (Hz). MT transfer functions are calculated at different frequencies of each station as the ratio of mutually perpendicular electric and magnetic field components in the horizontal plane, termed as Impedance tensor elements and also the ratio of horizontal to vertical magnetic field components, known as tipper vectors. The magnitude (scaled as apparent resistivity) and phase of impedance tensor elements are commonly used for MT data presentation. Penetration depths of EM fields depend on their frequencies (increase with decreasing frequency) as well as the electrical conductivity of the subsurface and provide depth sounding estimates of the MT transfer functions. In 2D earth situations, where electrical resistivity is constant along one of the horizontal direction (strike direction of the regional structure) EM fields are decomposed into two distinct modes; transverse electric (TE) and transverse magnetic (TM) modes (Chave and Jones, 2012).

Extremely low frequencies of EM fields, utilized in MT method allow unraveling the electrical resistivity of the subsurface at lithospheric scales and define complex structure and tectonic history of collision zones (Unsworth, 2010 and the case studies therein).

In the first step of MT data analysis, the dimensionality of the regional subsurface structure, the number of perpendicular directions along which electrical resistivity varies, is determined. Whether it has no variation in the horizontal plane just varies with depth and the 1D inverse modeling approach is adequate for data interpretation or it varies in horizontal and vertical directions and the 2D or 3D inverse modeling approach should be adopted. The phase tensor method (Caldwell et al., 2004) was employed for dimensionality analysis of the dataset.

A map of phase tensor ellipses at the different periods of all sites is presented in the figure 2. For most sites at short periods, where EM fields have small penetration depths, they are circles, characteristic of 1D regional geoelectric structure at these depths. Increasing the period, penetration depths get larger and the phase tensors delineate ellipses whose major and minor axes are parallel or perpendicular to the N45˚W direction. Considering the 90˚ ambiguity inherent in the method, the direction is coincident with the general trend of the ZFTB, as the main geologic structure in this region. Furthermore, the face color of the phase tensors is determined by the β skew angle, a distortion free measure of asymmetric properties introduced in the data by 3D structures. The accepted value of this parameter above which the structure could not be considered as 2D is 5˚. The small β skew angles calculated at most periods for all sites implement that a 2D inverse modeling strategy is acceptable for this data set.

Figure2. The phase tensor ellipse map showing the dimensionality for the Zagros profile. The major and minor axes of the ellipses correspond to the strike direction of regional geoelectric structure. The colors of the ellipses express the β skew angle, which is a measure of asymmetry produced by 3-D structures.



However, an accurate interpretation of MT impedance data is usually hindered by small near surface electrical inhomogenities whose inductive responses are negligible but their galvanic effects, frequency-independently distort MT responses from those of regional structures. We applied Groom-Bailey decomposition approach to each site employing the multisite multi frequency of McNeice and Jones (2001) to correct MT data for distortion parameters (shear and twist).

The low RMS values, measuring the least square misfit between distortion model responses and the observed data, calculated at most periods of all sites, indicate that the proposed distortion model of local 3D inhomogenities superimposed on a regional 2D structure striking in an approximate N45˚W direction, appropriately resembles the MT dataset (figures S1 and S2 in the electronic supplement).

Distortion corrected TE and TM mode responses of regional structure recalculated by the GB decomposition approach are then modeled throughout the regularized inversion algorithm suggested by Rodi and Mackie (2001). The algorithm is implemented in the Geosystem’s WinGLink interpretation software and employs a non-linear conjugate gradient (NLCG) method to minimize a penalty function composed of a least-square measure of data misfit and squared Laplacian of the horizontal and vertical resistivity gradients representative of model roughness.

TM mode impedances expanding over six period band decades, between 0.0039- 1448 seconds, have been considered for the inversion. However, in order to avoid intermediate-scale three-dimensional effects that substantially can distort the TE mode responses (Ledo, 2005), their maximum period was restricted to 10 s for the first 30 iterations and 100 s for the remaining. Inaccurate data points with large error bars and those representing random scattering were removed before the inversion. Furthermore, the D+ consistency assessment was performed where essential and inconsistent data points were excluded from the inversion procedure.

Data errors have been used; otherwise, 10% and 5% (≈1.45˚ absolute) of the measured data were set as the error values contaminated resistivities and phases, respectively.

Three-dimensional numerical experiments have shown that the TM mode impedances are more robust to structural changes along strike (Ledo et al., 2002; Ledo, 2005; Wannamaker et al., 2009). In addition, electric currents associated with the TM mode electromagnetic fields flow across geoelectrical strike and enhance the resolution of large-scale conductive fault structure. Accordingly, the TM mode impedances were emphasized through the model construction. The inversion runs initiated from a homogeneous half space as the starting model, where the Persian Gulf was the only feature fixed in order to model accurately the effects of the conductive sea water. The error floors were 5% (≈1.45˚ absolute) for TM phases and 50% for TM resistivities. In the following numerical experiments, the error floor of TM resistivities reduced to 10% and TE phases and resistivities incorporated through the procedure, sequentially. The error floors of the final inversion run were 5% for phases and 10% and 25% for TM and TE apparent resistivities, respectively.

Different data composition including TE, TM and bi-modal were examined through inverse modeling (results are presented in the supplementary material, figures S3 and S4). The fit of model responses with the measured data is determined by the RMS misfit, for each mode at each site (results are presented as the normalized data misfit for all stations along the profile (figure S5) and pseudo sections of measured data and model responses in the supplementary material (figures S6 and S7)). It appears that while the RMS is in general less than 4 for the TE and TM modes, but the TM mode responses provide a better fit with the measured data, in term of global RMS misfit criterion. The average site misfit is 2.21, not directly comparable to the overall misfit of 2.48 (due to the different weightings used in their calculations).

Figure 3. Non-linear 2-D inversion models of electrical resistivity beneath the Zagros profile obtained for joint TE and TM modes of the impedance tensor. Arabian plate below the SW of the profile is dipping NE ward, beneath Central Iran. Major faults are labeled as in figure 1 (red: SW-NE striking faults, blue: N-S striking faults).

**4. Discussion**

**4.1. Regional Geoelectric Structure**

The results of bi-modal MT data inversion (figure 3) will be argued in the following. The Arabian crust is more conductive and heterogeneous than Eurasia. Fixing the Persian Gulf as a conductive body in the starting model, a resistive structure (R1) is recovered beneath the southwest end of the profile, resembling the downgoing Arabian plate. It was absent in the previous inversion results of the data. To the southwest of the Kazerun fault, the resistivity model shows for the uppermost part of the crust, a thick conductive layer (C1) from the surface to a depth of about 15 km, underlain by the Pre-Cambrian crystalline basement of Arabia. Two resistive bodies (R2, R3) are imaged coincident with the surface traces of right-lateral strike-slip faults: Kazerun and Karebas faults. They are major basement faults which dragged and displaced anticline axes by at least 10 Km (Khadivi, 2011). A prominent conductive feature on the MT image appears at the crustal depths in the middle part of the profile (C2), underneath the high Zagros. The surface trace of the MZT coincides with the sharp conductivity contrast at the eastern edge of this feature. A thin near-surface conductive layer, representing massive Neogene sediments of Central Iran is also imaged in the upper crust, beneath the NE part of the profile.

The maximum smoothness constraint used in the MT inversion algorithm to find a unique inverse model smears the conductor to unrealistically great depths. Furthermore, MT data are most sensitive to the conductance (the product of the layer thickness and conductivity) of the subsurface and different models with constant conductance but dissimilar thicknesses and conductivities can fit equally well a given set of MT data. The solution is the constrained inversion where the bottom of its starting model is fixed at a high value of 1000 Ωm. Then by moving upward the top of the resistive half-space until model responses could not fit the data properly, one could find the shallowest depth of the conductor's bottom, permitted by the data (Li et al., 2003). We applied this strategy and found that the conductive layer beneath the southwest of the profile is at least extended deeper than 10 km depth (figure S8, supplementary material).

Although the comparison with previous modeling results (Oskooi et al., 2013; Layegh-Haghighi et al., 2018) shows major conductive anomalies recovered at similar locations beneath the profile (figure S9 in the electronic supplement), but their spatial extent is much more restricted on the resistivity cross-section represented in figure 3, implying the fact that the MT data have been corrected for the twist and shear distortions prior to modeling. However, major differences in figure S9 occur in regions of high conductivities recovered beneath the stations Z51-Z47 and Z30-Z28 (C3 and C5 in figures S9b, c) which are absent in figure 3. Phase tensors show erratic behavior and large β skew angles at these stations (figure 2). The recovered conductors can be mere artifacts generated by the algorithms to match 3D effects.

**4.2. Origin of High Conductivity in Central Zagros**

A significant property of the model presented in figure 3 is the very high conductance (up to 6000 S, coincident with the conductance of two km of seawater) recovered in the upper crust with a generally decreasing trend from SW to the NE along with the profile (figure S10 in supplementary material). The best explanation for such a high electrical conductance is saline fluids (reported in the eastern Zagros (Bosak et al., 1998)) filling the fractures and giving rise to the high electrical conductivity. Meteoric waters transported towards the fault zone by topography and/ or fluids circulating in the damage zone of a fault system characterize the upper few kilometers of the crust within a fault as a conductive zone, known as a fault zone conductor (FZC), (Ritter et al., 2005). The width and depth extent of the FZCs vary along the Zagros profile. A distinct lack of FZC is observed beneath the MZT, implying that an FZC is not required to fit the data.



Figure 4. Conductance of the FZC related to ZFF as a function of depth. It peaks between 2.5-3 km depths. The histograms in gray show the distribution of earthquakes within 100 km of the MT profile. Note the spatial separation between depths of high fault zone conductance and high seismicity.

To further examine the potential role of fluids at the FZCs, Bedrosian et al. (2004) suggested calculate the conductances (horizontally integrated conductivities) of these regions and compare it to the depth distribution of earthquakes associated with faults. Figure 4 shows the result for the FZC close to the ZFF (the results for the FZCs associated to the KZ and KB faults are presented as figures S10 and S11 in the electronic supplement). The conductance peaks at 5000 S throughout the FZC of ZFF and can be compared with that around KB fault. In all FZCs the conductance is greatest between depths of 2.5 and 3.0 km. An outstanding feature in figure 4 is the spatial separation between the depths of the peak FZC conductance and high seismicity. Seismicity begins at the depth where the conductance decreases with increasing depth. The preferred explanation for this scenario is the aqueous fluids for the enhanced conductivities of the FZCs around the faults. Fluid rich regions are usually devoid of seismicity since shear stresses associated with brittle failure could not be maintained in these regions.

An almost concave conductor has also been recovered in the MT image beneath the High Zagros (C2 in figure 3). The surface trace of the MZT coincides with a sharp conductivity contrast at the eastern edge of this feature. Aqueous fluids, metallic minerals, grain boundary graphite films and molten rocks are different physical causes that can be suggested for the observed conductor. However it’s unlikely that mineralization is responsible for C2 conductor, since such a large mineral deposit would be expected to produce detectable magnetic and gravity anomalies that are not observed (Abedi et. al., 2018). Furthermore, graphite films could not remain connected in crystalline basement rocks (documented for Zagros (Hatzfeld et al., 2003; Talebian and Jackson, 2004)) and cause an effective conductor. There is also no geological or geophysical evidence for molten rocks in mid-crustal depths of High Zagros. There is no volcanic fields in this region and Plio-Quaternary volcanism is widespread across eastern and central part of Iran close to the zones of presently active faulting, for instance Dasht e Lut desert and Makran mountains (Walker et al., 2009). Fluids generated from dehydration reactions within the subducting Arabian plate may be considered as the hydrological implication for High Zagros conductor. This assumption entails the saline fluids at hydrostatic pressures filling the interconnected fractures of the crystalline basement which inhibit the seismicity in this region. The distinct lack of FZC corresponding to the MZT implies an impermeable fault seal preventing the cross fault fluid flow transport or a very narrow FZC that cannot be resolved by MT.

**4.2 comparisons with seismic velocity and seismicity data**

A reasonably comprehensive picture of the region is obtained by integrating seismic velocity model and seismicity data with the final MT inversion model.

1D joint inversion of P-wave receiver functions and the surface wave dispersion data at seismological stations along the same profile were juxtaposed to obtain a 2D S-velocity model whose lateral variability was constrained by the Bouguer gravity anomaly data (Motaghi et. al., 2015).

A qualitative comparison between the velocity and resistivity models is presented in figure 5. Through this integrated interpretation approach, the limitations in sensitivity and resolution of independent geophysical datasets as well as different numerical strategies used to invert these data have to be considered. MT data were inverted using a 2D approach consisted of a minimum smoothness constraint to regularize the inverse problem. However, 2D S-velocity model with more continuous low and high-velocity domains (figure 6 in Motaghi et. al., 2015) was obtained by combining 1D absolute S-velocity models of individual stations and smoothing the result with a Gaussian filter width of 30 Km.

Figure 5. The same model as in figure 5, overlain by S- wave velocity contours from Motaghi et al. (2015). Velocities are labeled in Km/s. The locations of major faults are indicated by the red (mainly striking along NW-SE direction) and blue (mainly striking along N-S direction) arrows.

Figure 6. quantitative correlation between resistivity and velocity models. A general increasing trend (dashed line) of velocity versus resistivity is apparent in this histogram. Also, three labeled zones of high correlation are presented in this figure.

In general, it seems that domains of low velocities and resistivities beneath the south west of Zagros, are spatially coincident which is consistent with the known geology of the region where an upper layer of at least 10 km thickness composed of Cambrian to Miocene sediments overlays the crystalline basement and produces an almost negligible magnetic response (Abedi et al., 2018)

Sparse lateral sampling of MT data (caused by large average site spacing of 15 km) as well as smoothest 2D inversion modeling approach cause the upper crustal conductive layer(C1) to be recovered discontinuous, beneath the SW of the profile. However, coincident seismic studies based on juxtaposed 1D velocity models imaged more homogenous velocity structure in this region.

We interpolate the coincident and independently derived seismic velocity (Motaghi et al., 2015) and electrical resistivity (figure 3) models on to a common grid to obtain a histogram of the correlation between Vs and electrical resistivity in the upper 28.5 km of the Zagros profile. A general increase of electrical resistivity with increasing seismic velocity, representative of decreasing porosity, is apparent (figure6).

Since the histogram grid is very coarse (of 1000 m, limited by the size of seismic model grid), only three localized zones (A, B and C in figure 6) have been chosen. The zones were mapped back into the resistivity section to determine the spatial regions where these zones derive (figure S13 in the electronic supplement). The region of high ressistivity/velocity (zone C) corresponds to the upper crust of central Iran Continental block. The zone (B) is defined by moderate resistivities and moderate to high velocities and is located beneath High Zagros and SSZ. The zone (A) has the lowest resistivity/velocity values and coincides with the sedimentary cover of the Arabian crust (figure S13).

The prominent conductivity contrast beneath the MZT corresponds to steep gradient in both Bouguer gravity and magnetic intensity (Abedi et al., 2018) as well as sharp boundary between low velocities of the ZFTB upper crust and higher velocities beneath SSZ and UDMA (figure 5). These concurrent changes in different physical properties provide strong support for a deep seated fault, cross-cutting the whole crust and upper mantle, as estimated by joint interpretation of seismic and gravity data (Motaghi et. al., 2015). Although they show that a high velocity/density lithosphere beneath Zagros (Vs ~4.8 km/s, ρ ≥ 3.4), representative of the leading edge of Arabian shield, is sinking beneath SSZ, UDMA and Central Iran, but this is not confirmed by our resistivity model. Long period MT measurements being able to penetrate deeper levels up to the lithosphere- asthenosphere boundary will be required to constrain more accurately the deep structure beneath Zagros suture zone.

Figure 7. Seismicity data (black stars) provided by Karasozen et al. (2019) for 100 km strip on either sides of the MT transect (whose epicenters are plotted by the white dots in the figure1) are superposed on the electrical resistivity section.

Figure 7 shows pattern of crustal seismicity occurred within 100 km distance from the MT profile (white dots in figure 1) superposed on electrical resistivity section. Earthquake hypocenters are from an updated catalogue of 2500 earthquakes (red and white dots in figure 1) whose source parameters have been determined from locally and teleseismically recorded earthquakes (Karasozen et al., 2019, submitted for review). The authors used a calibrated earthquake relocation method improved by InSAR data. These seismic hypocentral calibrated locations of earthquakes (referred to as the Global Catalog of Calibrated Earthquake Locations (GCCEL)) are uploaded to the GCCEL catalog (<https://www.sciencebase.gov/catalog/item/59fb91fde4b0531197b16ac7>).

Towards northeast of the resistive structure recovered beneath the KB fault (R3), the Zagros mountain belt is nearly devoid of seismicity. Seismicity in Zagros is most pronounced in the SFB. Despite high seismic activity in Zagros belt, no event has been located in the MZT region in central Zagros as well as in the SSZ (Paul et al., 2006).

The high Zagros includes NW-striking thrust and reverse faults with notable surface exposure where the most important ones are the main Zagros thrust (MZT), known as a suture between Arabian and Eurasian plates and the High Zagros Fault (HZF), constituting the boundary with the SFB. However several seismogenic basement thrust faults, without surface rupturing are accommodated beneath the SFB. The main front fault (MFF) and the Zagros Foredeep fault (ZFF) are the two major thrusts in this region. Furthermore, a series of strike slip faults, striking roughly to the N-S direction (KZ, BO, KB, SP and SV faults) are the only major faults scratching the earth surface in this region (Figure 1).

Thrust faulting is the most frequent earthquake mechanism that usually takes place in the Zagros. The earthquakes mainly occur within the lower parts of the SFB sedimentary cover rather than the HZ (figure 7) and are restricted to low elevated regions with an average strike direction along NW-SE azimuth, coincident with the range orientation. They are very rare and usually absent beneath HZ and farther to the north east in the CIMC (figure 1). Weak horizons located at the base (the Hormoz evaporate), in the middle and upper parts (e. g. Gurpi Marls, Gachsaran evaporates) of the cover form a regional barrier to vertical rupture propagation and cause moderate size earthquakes with magnitudes MW≤6.1 to be the typical seismicity of the SFB (Nissen et al., 2011).

The intense deformation within the ZFTB spans brittle damage elements (minor faults and slip- surface with or without striation) around different faults in this region and maintains a connected network for fluids released into the FZCs. Dehydration reactions within the subducting Arabian plate (in continental crust, mostly due to the amphibolites to granulites metamorphism (Glover and Vine, 1995)), provide a continuous recharge of fluids (Bedrosian, 2007).

The Moho discontinuity and the detachment level of the folded sedimentary cover overlay the resistivity model with dashed and dotted lines respectively in figure 8.

Figure 8. Geological interpretation of the MT model (see explanation on the text). The main faults cross-cutting the profile, are indicated by the arrows ( in red with mainly SW-NE strike and in blue mainly N-S strike). The dotted line indicates the detachment level of folded sedimentary cover (10 – 15 km thick), corresponding to the Hormuz salt formation. The dashed line indicates Moho, inferred from seismic studies (Paul et al. 2010).

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The Moho depth is inferred from seismic studies (Paul et al. 2010). The detachment level of folded sedimentary corresponds to the Hormuz salt formation. Both, the salt formation and the sedimentary cover on top are imaged as low resistivity structures in the model (between sites z56 and z42) with values lower than 60-70 Ωm

This detachment level joins the trace of the High Zagros Fault (HZF) at depth (black continuous dipping line in figure 8). The HZF allows thrusting the sedimentary cover and uploading the older and more resistive rocks (Paleozoic rocks), between sites z42 and z32, with resistivity values more than 500 Ωm. The Arabian crust, between the detachment level and the Moho, contains heterogeneous blocks (as Kazerun Fault (KZF)) probably inherited from Precambrian times. They are imaged as zones of low and high resistivities (marked by short vertical black lines in figure 8). The earthquakes are concentrated in a specific seismic zone extended at the basement depths between sites z54 and z46 (see figure 7). By contrast, the seismicity is scarce to the NE of the site z45. To explain this feature the resistive structure beneath Karehbas fault, KB, (sites z47-z46) could be considered as a low permeable zone, retaining the fluids released along with the HZF and leading to a more ductile behavior of the crust located to the NE of the KB fault.

Finally, the second black continuous dipping line (in figure 8) from MZT represents the contact between Arabian and Iranian plates. On the side of the Iranian plate, the section shows lateral changes in resistivity structure that can be associated to heterogeneous blocks of conductive metamorphic materials beneath the SSZ and the resistive volcanic blocks of oceanic crust (ophiolites) beneath the UDMA

**Conclusion**

An integrated geophysical interpretation along a profile across central Zagros is proposed based upon distortion corrected MT data as well as seismic velocity and seismicity data. Within the SFB of Zagros folded belt to the South west of the KZF, the upper crust is characterized by a zone of low resistivity and velocity extending from surface to depths more than 10 km. This feature is attributed to the thick sedimentary sequence of the Arabian platform. A quantitative correlation between resistivity and velocity models shows a general increasing trend of velocity versus resistivity. Furthermore, three regions of high correlation were determined.

Close to the faults, the possible effects of fluid filled voids and fractures within brecciate and damaged zones of the faults have also been considered. An investigation of the conductance around the major faults in this region shows its decreasing trend with increasing depth. The combination of seismicity data with the conductance values at the FZCs suggests aqueous fluids for the enhanced conductivities. It should be noted that the inferred fluids related to the FZCs is best resolved to be far from the source region of the earthquakes. Thus we propose a scenario for the fluid distribution beneath central Zagros controlling its seismic behavior. However, additional geophysical data including 3D studies of the major faults is essential to further understand the tectonic processes at the Zagros collision belt.

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