Proceedings of the 18th Iranian Geophysical Conference, May 2018, pages 48-51

Applications of the Magnetic and Electromagnetic methods in Geophysical Explorations: some recent case studies

Behrooz Oskooi[1]

[1]*Associate Professor, Institute of Geophysics, University of Tehran, E-mail: boskooi@ut.ac.ir*

ABSTRACT

Magnetic and electromagnetic methods are widely employed in geophysical explorations such as detection of orebodies, archeology, near surface layers, geothermal resources, hydrocarbon reservoirs, deep water, geological structures and tectonic features. In this paper I report some recent interpretations on Magnetic, Magnetotelluric (MT), Radiomagnetotelluric (RMT), Ground Penetrating Radar (GPR) and Airborne Magnetic and Electromagnetic (EM) data on different targets in Iran, Germany and Sweden measured or modeled by the Department of Geomagnetism of the Institute of Geophysics of the University of Tehran (IGUT) since 2007. Ground and airborne magnetic data are amongst very essential datasets for large scale surveys on ore deposits and hydrocarbon reservoirs, respectively. Airborne magnetic and electromagnetic data are also quite informative to resolve subsurface geology and tectonics across Zagros mountain range and Neyriz ophiolites. In Golestan plane there are very successful experiences with deep water investigations employing Magnetotellurics as well as the geothermal surveys in Mahallat region.

GPR data is very helpful in near surface studies like sub grade of railways and roads. It is also used as constraint for RMT data to detect an aquifer in Sweden.

Keywords: Airborne geophysics, Electromagnetic, GPR, Magnetic, Magnetotelluric and RMT.

CASE STUDIES

a) The conductivity structure across the Trans-European Suture Zone from magnetotelluric and magnetovariational data modeling

To achieve an electrical conductivity model of the Trans-European Suture Zone (TESZ), magnetotelluric measurements in the period range of 10–20,000 s along two almost parallel profiles with a total of 65 sites, starting from the North German–Polish Basin, crossing the TESZ and ending on the East European Craton, were conducted. Magnetovariational responses were combined with other magnetotelluric transfer functions, because for large periods they are free of near-surface galvanic distortions and thus lead to more reliable resolution of deep structures. Following the results of strike and dimensionality analysis, input data for two-dimensional inversion were created by rotating all transfer functions to the common strike direction. Models derived from different combinations of data were compared and several sensitivity analyses were carried out. The results show a highly conductive layer of sediments (saline aquifer) and the TESZ as a broad region of enhanced conductivity. It was also clarified that the lower crust and upper mantle of the East European Craton (EEC) are more resistive than the Paleozoic Platform (PP, underlying the Northeast German Basin) and this resistivity extends to the greater depths. (Habibian et al., 2010)

b) An airborne magnetometry study across Zagros collision zone along Ahvaz–Isfahan route in Iran

Convergence between the Eurasian and Arabian plates formed the Zagros orogenic belt between Late Cretaceous and Pliocene as a relatively young and active fold-thrust belt in Iran. The structural geology along Ahvaz to Isfahan route across Zagros is investigated employing magnetic data in order to determine the crustal structure in the colision zone of the two Palaeo-continents. Airborne magnetometry data with a line space of survey of 7.5 km have been used to image the variations of the apparent magnetic susceptibility along this route. At first the airborne data were stably 500-m downward continued to the ground surface in order to enhance subtle changes of the Earth's magnetic field. Then 3D inverse modeling of magnetic data was implemented, while the cross section of the magnetic susceptibility variations along the route was mapped down to a depth of 100 km. The acquired magnetic susceptibility model could appropriately predict the observed magnetic data as well. In addition, the analytic signal filter was applied to the reduced-to-pole magnetic data leading to the determination of active faults in Zagros fold-thrust belt (ZFTB) structural zone based upon the generated peaks. Some probable locations of fault events were also suggested in Sanandaj–Sirjan Zone (SSZ). The locations of faults correspond well to the magnetic susceptibility variations on the inverted section. Probable direction, slope and depth extension of these faults were also plotted on the magnetic susceptibility model, showing an intensively tectonized zone of the SSZ. Themain difference between two domains is that the Eurasian plate seems to contain high magnetic susceptible materials compared to the Arabian plate. The recovered model of the apparent magnetic susceptibility values indicated that the average thickness of the non-magnetic sedimentary units is about 11 km and the Curie depth locates approximately at depth of 24 km for the whole studied area. (Oskooi and Abedi, 2016)

c) Constrained inversion of RMT data using GPR sections versus joint interpretation of their result in an aquifer investigation

Radio magnetotelluric (RMT) and ground penetrating radar (GPR) are known as the near-surface geophysical methods in groundwater investigations. The RMT method provides information about the variation of the electrical resistivity of the uppermost 50 m part of the ground, and high-resolution structural information can be extracted from the GPR processed sections for the very shallow ground. Combining the obtained data from the two methods may lead to valuable results on the near-surface layers and structures. In this study, we proposed a new structural constraint for the two dimensional (2D) inversion of the RMT data. We have investigated a known aquifer located in Heby, Sweden to assess constrained inversion result in comparison with the joint interpretation approach. RMT and GPR surveys have been carried out along two profiles with the length of 870 m and 550 m. The results show that thick vadose and saturated zones were distinguished quite well either in the joint interpretation or constrained inversion approach. In such areas, the main problem is imaging the water table in the inverted RMT sections. Imposing smoothness regularization in the inversion results turns rather sharp boundaries into the gradual transition zone in the final resistivity models. Thus, using the GPR's common-offset (CO) reflections as constraints in the inversion of the RMT can recover water table as a sharp interface in the inverted model. Thin vadose and saturated zone have not been discriminated in the RMT sections, due to its low resolution. For verification on the results, we evaluated a synthetic model with similar physical properties to the study area. In such circumstances, the results needed improvements either in the joint interpretation or constrained inversion approach using CO sections. Hence, harder constraints through our proposed scheme were incorporated into the inversion routine to detect thin aquifer and have a more realistic model. (Mohammadivizheh et al., 2018)

d) Characterization of the Houze-Vali iron ore in the centre of Iran using magnetic gradient tensor data

This work presents a case study on the use of Normalized Source Strength (NSS) to interpret magnetic gradient tensor data. This application was made to explore an iron ore deposit in the Houze-Vali area, located near Ardakan City in the centre of Iran. The source location was estimated by using Euler deconvolution of Total Magnetic Intensity and NSS data, after an upward continuation of 15 m. In general, the NSS is relatively insensitive to the magnetization direction, but it provides more reliable information in comparison with compared to the 3D analytic signal technique. According to the NSS results, the source can be approximated by an N60°W striking contact with its top at a depth of 102 m, which is consistent with the sampling results. (Moghtaderi et al. 2017)

e) Investigation of the electrical resistivity and geological structures on the hot springs in Markazi province of Iran using magnetotelluric method

The Mahalat region of Markazi province in Iran is a popular tourist spot due to the occurrence of hot springs and having the greatest geothermal fields in Iran. We chose a 6 km profile with 12 sites across the hot springs for carrying out a magnetotelluric (MT) survey on July 2011. A 2D inversion was applied on the determination MT data to resolve the subsurface conductive structures using a 2D inversion routine of Occam approach. The 2D model significantly illustrates the geothermal structures at depth, including cap rock (from 100 to 600 m), reservoir (from 500 to 2000 m) and the heat source (starting from 1000 m), and it shows a good correlation with the geological features. One of the interesting results is distinguishing the main faults, which are acting as the preferential paths to circulate the hydrothermal fluids. The resistivity model fits on the geological section along the MT profile. (Oskooi et al., 2013)

f) Magnetotelluric signature for the Zagros collision

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 Palaeocontinents. 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. (Oskooi et al., 2014)

g) Iodine-bearing saline aquifer prospecting using magnetotelluric method in Golestan plain, NE Iran

A detailed magnetotelluric (MT) survey was conducted in March 2011 to recognize regional deep saline aquifer in Dashli-Boroon area, northeast of Iran. In order to delimit the geometry of main aquifer, the MT data of 130 sites along ten E-W parallel profiles were modeled using 1D and 2D inversion schemes. The results suggest that signatures of saline water reservoirs in the area which based on geochemical evidence are distinguished potentially positive to contain some trace minerals such as iodine. From the geoelectric point of view, the study area is generally very conductive and the interpretation of the MT soundings resolves extremely conductive zones (less than 1Ω) at a depth of about 700 m in the less conductive host. These zones can be considered as iodine bearing saline water aquifer. (Oskooi and Mansoori, 2015)

h) Three-dimensional modelling of magnetotelluric data to image Sehqanat hydrocarbon reservoir in southwestern Iran

A detailed magnetotelluric survey was conducted in 2013 in the Sehqanat oil field, southwestern Iran to map the geoelectrical structures of the sedimentary Zagros zone, particularly the boundary between the Gachsaran Formation acting as cap rock and the Asmari Formation as the reservoir. According to the electrical well logs, a large resistivity contrast exists between the two formations. The Gachsaran Formation is formed by tens to hundreds of metres of evaporites and it is highly conductive (ca.1 Ωm–10 Ωm), and the Asmari Formation consists of dense carbonates, which are considerably more resistive (more than 100 Ωm). Broadband magnetotelluric data were collected along five southwest–northeast directed parallel lines with more than 600 stations crossing the main geological trend. Although dimensionality and strike analysis of the magnetotelluric transfer functions showed that overall they satisfied local 2D conditions, there were also strong 3D conditions found in some of the sites. Therefore, in order to obtain a more reliable image of the resistivity distribution in the Sehqanat oil field, in addition to standard 2D inversion, we investigated to what extent 3D inversion of the data was feasible and what improvements in the resistivity image could be obtained. The 2D inversion models using the determinant average of the impedance tensor depict the main resistivity structures well, whereas the estimated 3D model shows significantly more details although problems were encountered in fitting the data with the latter. Both approaches resolved the Gachsaran–Asmari transition from high conductivity to moderate conductivity. The well-known Sehqanat anticline could also be delineated throughout the 2D and 3D resistivity models as a resistive dome-shaped body in the middle parts of the magnetotelluric profiles. (Mansoori et al., 2015)

REFERENCES

Oskooi , B. and Abedi M., 2015. An airborne magnetometry study across Zagros collision zone along Ahvaz–Isfahan route in Iran. Applied Geophysics, Vol. 123, p. 112-122.

Mansoori, I., Oskooi, B., Pedersern, L., 2015. Magnetotelluric signature of anticlines in Iran's Seqant oil field, Tectonophysics, Vol. 654, p. 101-112, http://dx.doi.org/10.1016/j.tecto.2015.05.004.

Mansoori, I., Oskooi, B., Pedersern, L., Javaheri, R., 2015. Three dimensional modelling of magnetotelluric data to image Seqanat hydrocarbon reservoir in the south western Iran. Geophysical Prospecting, DOI: 10.1111/1365-2478.12328.

Oskooi, B and Mansoori, I., 2015. Iodine-bearing saline aquifer prospecting using magnetotelluric method in Golestan plain, NE Iran. Arabian Journal of Geosciences,Vol.8, 5959-5969.

Oskooi, B., Mansoori, I., Pedersen, L. B., Koyi, H., 2014. A Magnetotelluric Survey on Ophiolites in Neyriz, South Western Iran. Pure and Applied Geophysics 172(2), p. 491-502.

Oskooi, B., Abedi, M., 2014. Magnetic and electromagnetic data interpretation for delineating geological contacts in Tomelilla area, Sweden. Arabian Journal of Geosciences, DOI 10.1007/s12517-014-1501-0.

Montahaei, M. and Oskooi, B., 2014. Magnetotelluric inversion for azimuthally anisotropic resistivities employing artificial neural networks, Acta Geophysica, Vol. 62, No. 1, 12-43.

Oskooi, B., Pedersen, L. B., Koyi, H., 2013. Magnetotelluric signature for the Zagros collision, Geophysical Journal International, Vol. 197, No. 4.

Oskooi, B., Darijani, M. and Mirzaei, M., 2013. Investigation of the electrical resistivity and geological structures on the hot spring in Markazi province of Iran using magnetotelluric method, Bollettino di Geofisica Teoricaed Applicata, Vol. 54, No. 3, 245-256.

Shirzaditabar, F., Bastani, L., and Oskooi, B., 2011. Imaging a 3D geologicalstructure from HEM airborne magnetic and ground ERT data in Kalat-e-Reshm area Iran, Journal of Applied Geophysics, Vol. 75, No. 3, P. 513-522.

Habibian Dehkordi, B., Oskooi, B., and Brasse, H., 2010. Using magnetovariational sounding method to image deep resistivity structure of the Trans-European suture zone, Journal of the Earth & Space Physics. Vol. 36, No. 3, 1-11.

Habibian Dehkordi, B., Brasse, H., Oskooi, B., Ernst, T., Sokolova, E., Varentsov, I., and EMTESZ working group, 2010. The conductivity structure across the Trans-European suture zone from magnetotelluric and magnetovariational data modeling, Physics of the Earth and Planetary Interiors, Vol. 183, 377-386.

Moghtaderi, N., Habibian Dehkordi, B. and Oskooi, B., 2017. Characterization of the Houze-Vali iron ore in the centre of Iran using magnetic gradient tensor data. Bollettino di Geofisica Teorica ed Applicata Vol. 58, n. 3, pp. 205-216.

Mohammadivizheh, M., Oskooi, B., Bastani, M. and Kalscheuer, T, 2018. Constrained inversion of RMT data using GPR sections versus joint interpretation of their result in an aquifer investigation. Submitted to JRAG.