An Investigation on the Environmental Effects of Sulphide Mines Using Geophysical Studies

Ali Moradzadeh [a)], Faramarz Doulati Ardejani [a)], Sara Fallah Pisheh [b)]

[a)] *Faculty of Mining, Petroleum and Geophysics, Shahrood University of Technology, Shahrood, Iran*
e-mail: amoradzadeh@shahroodut.ac.ir
[b)] *M.Sc. in Geophysics, Shahrood University of Technology, Shahrood, Iran*

Abstract
Low grade wastes produced by mining activities particularly in the sulphide deposits may cause detrimental impacts on the environment. In this situation, the remaining sulphide minerals within the waste dump may cause various toxic elements due to oxidation processes. The transportation of such elements into the surface and groundwater flow systems has serious impacts on the human being, aquatic life and other creatures. As the transportation of metallic pollutants by different physical and geochemical mechanisms could considerably change the conductivity of the polluted zone, so the electric and electromagnetic geophysical methods could successfully be used to map these zones. In this research, it is attempted the pollution potential of a sulphide mine located at the north-east of Iran to be investigated using the very low frequency electromagnetic (VLF-EM), resistivity (RES) and induced polarization (IP) geophysical methods. In addition, it is also aimed to perform a suitable numerical modelling on VLF data to provide geoelectrical sections along different profiles so that the capability of this cost effective and fast method to be evaluated relative to the results produced by the time consuming and expensive RES and IP methods. The results of modelling indicate that VLF data could provide geoelectrical sections that are in good agreement with those provided by the RES and IP data. The obtained results further show that the drainages emanating from the waste dump polluted an area with a dimension of 70×40 m^2 to depths more than 30 m in the down stream of the dump.

Key words: Environmental effects, pollution, VLF, IP and RES methods, sulphide mines, electrical conductivity

Introduction
Mining activities and associated waste dumps in particular in sulphide mines are one of the major sources of environmental pollution. The oxidation of sulphide minerals within the waste materials in the presence of oxygen and water may produce various toxic elements. The transportation of these elements into the groundwater flow systems could have serious impacts on the receiving environment. Therefore, in order to develop an appropriate environmental water management plan in the polluted area, it is a crucial task to detect the sacrificial and subsurface extension of pollution plume in the vicinity of such dumps. There are many techniques to investigate the pollution zones associated with sulphide waste dumps. Among them, the geophysical methods have been used as cost-effective approaches.

Since, the various metals produced by oxidation processes in the groundwater flow system may change considerably the conductivity of the polluted zone, so the electric and electromagnetic (EM) geophysical methods could effectively be used to map these zones (Reynolds 1997). The resistivity, induced polarization (IP) and very low frequency electromagnetic (VLF-EM) are commonly used for this purpose (Benson et al. 1997). For resistivity and IP surveys, we need to install many electrodes into the ground to send electrical current and record the potential differences between the specified electrodes to measure the subsurface resistivity and chargeability changes of an interested area within the earth. In spite of the affectivity of these methods, the cost and the required operational time are considerably very high. To overcome the problem, the VLF-EM method can be economically used. In this method, only the components of the elliptically polarised magnetic field are measured. The VLF-EM method uses radio signals in the bandwidths of 15- 30 kHz and is a powerful tool for quick detection of near surface structures. Because of the easy operation of the instrument, speed of field survey and low operation cost, this method is suitable for rapid preliminary surveys and has been widely used in many geophysical investigations (Milson, 2002; Sharma and Barnawal, 2005).

In this research, the extension and dispersion of pollution originated from a sulphide mine and associated waste dumps is investigated using VLF-EM, RES and IP geophysical methods. In addition, the necessary geoelectrical sections along different profiles covering the study area are provided by performing a numerical modelling on VLF-EM data. The capabilities of this method with respect to the time consuming and expensive RES and IP methods are also evaluated.

Study area and geological setting

The study area is located at about 45 km north-west of Shahrood city in Semnan province, Iran. The lead and zinc mine in the area belongs to Alborz mountain ranges and is a part of Gorgan 1:250,000 geological sheet. From geological point of view, the area is mainly dominated by Lar Formation which consists of dolomite and limestone with an age of cretaceous. The ore deposit is formed as thin veins form within the dolomite and limestone. The sulphide ore minerals include galena and sphalerite together with pyrite. The main minerals in the oxidation zone of the mine are smithsonite and hemimorphite. The evidence indicates that the mining activity dates back to more than 50 years. The field investigation proved the presence of such minerals within the waste dumps and extracted ore piles which are placed in front of the main existing tunnel. The area under investigations has a narrow valley shape which has been filled by alluvial originated from upper parts. Since, there exist a few springs and a river in the downstream of mining area, so the toxic materials emanating from mining activity may cause many environmental problems. Hence, there is a necessity to investigate any possible pollution.

The VLF-EM method_

The VLF method is one of the most used EM techniques to assess subsurface changes of conductivity. The sources for the VLF measurement are fixed high power radio transmitters used for communications that represent vertical electric dipoles. The radio signals at the measuring sites far from the sources of the primary EM field resembles a vertical plain wave with the electrical field nearly vertical and the magnetic field horizontal. On the basis of EM theory the subsurface conductive bodies act the source of a secondary field (with vertical and horizontal components) which is shifted in phases to the primary field.

In a two-dimensional (2D) conductivity structure with strike in the x-direction and measuring profiles in y-direction, the VLF instruments measure only the vertical (H_z) and the horizontal (H_y) components of the magnetic field. At each site a parameter names tipper (H_z/ H_y) is measured. The tipper is a complex quantity, so it has real and imaginary components. Over a 2D conductive structure this quantity varies along the measuring profiles showing the highest variations in the vicinity of the conductivity contrast. The real and imaginary parts of tipper quantity are expressed as percentage in the field survey (McNeill and Labson 1991).

In the present study, a portable WADI instrument (ABEM 2000) has been used to measure VLF data along 5 profiles as shown in Figure 1. The measuring spacing of VLF data along each profile was 5 meters. The VLF measurement signal was automatically tuned to the GBZ, England transmitter with a frequency of 19.6 kHz. In addition to the VLF data, the resistivity and IP data were also measured along profile 1 using ABEM SAS 1000 (ABEM 1995) instrument. A dipole-dipole array with dipole length of 15 m and N=8 was used for geoelectrical measurements.

Results and discussion

In order to interpret the geophysical data, three computer programs were used. A computer software called RES2DINV (Lock 2002) was used to perform a 2D inverse modelling for resistivity and IP data along P_1 profile. The results are shown in Figure 2. The VLF data were also modeled using a 2D numerical finite element computer program called INV2DVLF (Monteiro Santos et al 2006). The various filtering approaches (Fraser 1969; Karous and Hjelt 1983) were applied on VLF raw data to simplify the interpretation of data before performing an inverse modelling using RAMAG computer program (ABEM 2002). Although not given here, the obtained results confirm those results obtained by modelling of geoelectrical data. Figure 3 illustrates results of 2D inverse model of VLF data for profiles P_1 and P_3.

Figure 1 *Schematic location of the VLF, RES and IP profiles*

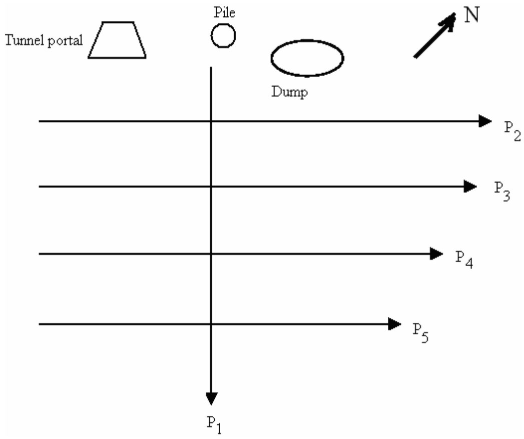


Figure 2 *2D resistivity models obtained by inversion of RES and IP data; resistivity section (upper), chargeability section (lower)*

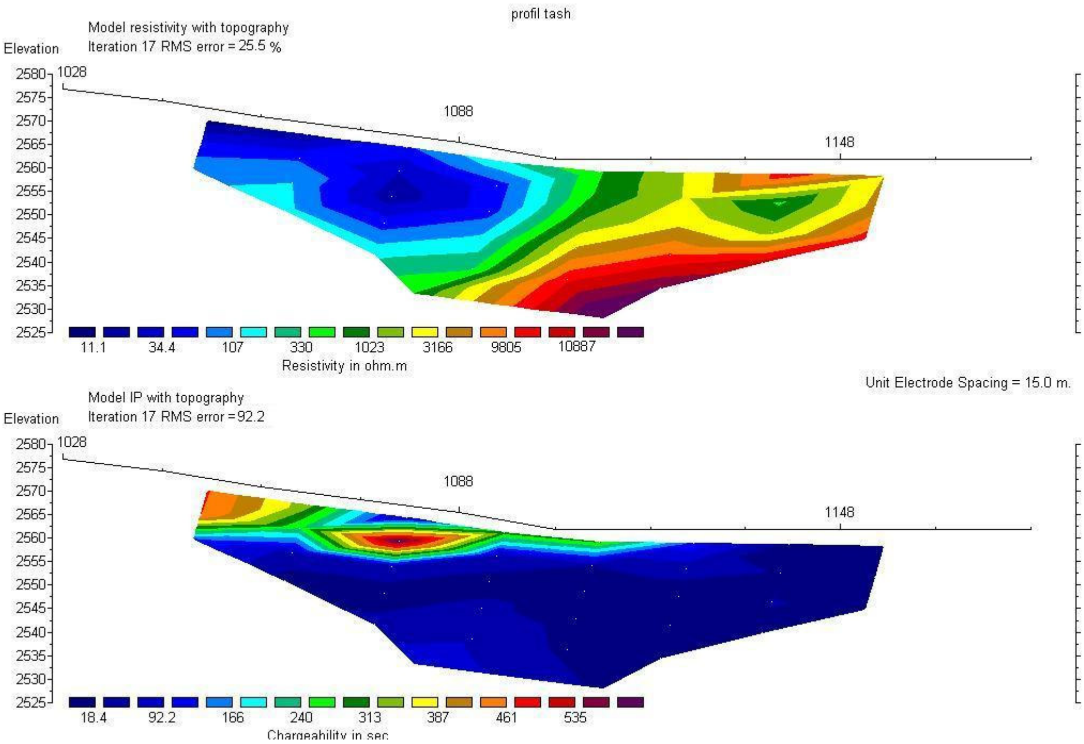
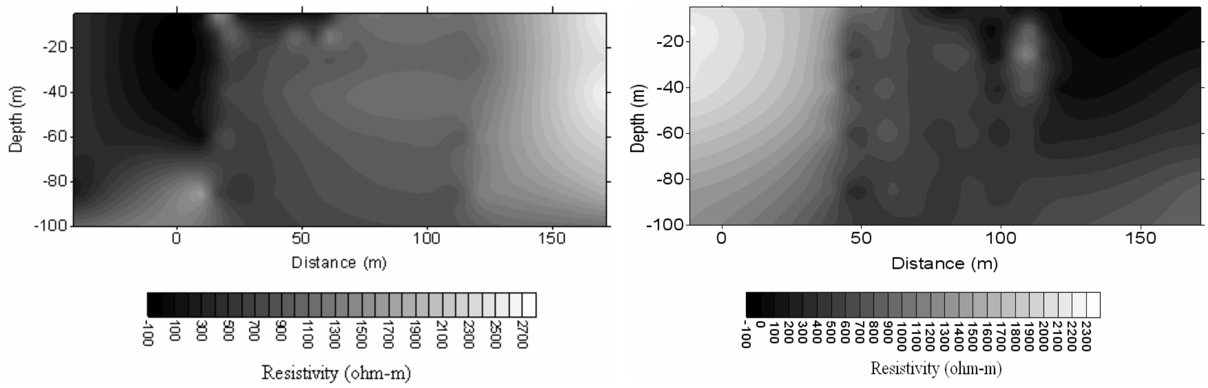


Figure 2 (upper) depicts the resistivity decreases to a value less than 200 ohm-m from the entrance of existing tunnel to an approximate distance of 1100 m in the downstream along profile P_1 which is nearly parallel to axis of valley. The chargeability model (Figure 2, lower) proves the pollution along the profile by increasing of the value of chargeability in the same direction. This matter is also confirmed by the results of 2D inversion of VLF data (Figure 3, left). As it is well illustrated in this figure, the polluted zone is depicted as a low resistivity zone in the left part of the profile. The lateral extension and dispersion of the polluted zone can be detected by the resistivity model of VLF data given for profile P_3. As Figure 1 shows, profile P_3 is perpendicular to profile P_1. As Figure 3 (right) indicates, a low resistivity zone in the right part of this profile is clearly illustrated due to the fact that the waste dump is located at above of this part of the profile.

Figure 3 *2D resistivity models obtained by inversion of VLF data for profiles of* P_1 *(left) and* P_3 *(right)*



Conclusions

This paper investigated the extension and dispersion of pollution originated from a sulphide mine and associated waste dumps, located at the north-east of Iran, using VLF-EM, RES and IP geophysical methods. In addition, the necessary geoelectrical sections along different profiles covering the study area were provided by performing a numerical modelling on VLF-EM data. The capabilities of VLF method with respect to the time consuming and expensive RES and IP methods were also evaluated. The geoelectrical sections provided by modelling of VLF data are in good agreement with those provided by the RES and IP data for detection of polluted zones. The results further show that the drainages emanating from the waste dump polluted an area with a dimension of 70×40 m^2 to depths more than 30 m in the down stream of the dump. Because of the easy operation of the instrument, speed of field survey and low operation cost, the VLF method is recommended for rapid preliminary investigations of polluted zones arising from sulphide mining operations.

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References

ABEM (1995) Instruction manual for Terameter SAS 1000. , ABEM Instrument AB, 91

ABEM (2000) ABEM instruction manual, WADI VLF instrument. ABEM Co., 47.

ABEM (2002) RAMAG instruction manual, VLF survey planning and interpretation software.

Benson AK, Payne KL, Stubben MA (1997) Mapping groundwater contamination using DC resistivity and VLF geophysical methods. Geophysics, 62**,** 80-86.

Fraser DC (1969) Contouring of VLF-EM data. Geophysics, 34, 958-967.

Karous M, Hjelt SE (1983) Linear filtering of VLF dip angle measurements. Geophysical prospecting, 31**,** 782-794.

Lock MH (2002) User manual for Res2dinv ver.3.5. Geotomo software,

McNeill JD, Labson VF (1991) Geological mapping using VLF radio fields. In: Nabighian, M.N. (Ed.), Electromagnetic Methods in Applied Geophysics II. Soc, Exp. Geophys., pp. 521-640.

Milson J (2002) Field geophysics. Cambridge university press.

Monterio Santos FA, Mateus A, Figueiras J, Goncalves MA (2006) Mapping groundwater contamination around a landfill facility using the VLF-EM method- a case study. Journal of Applied Geophysics, 60, 115-125.

Reynolds JM (1997) An Introduction to applied and environmental geophysics. John wiley & Sons Ltd.

Sharma SP, Baranwal VC (2005) Delineation of groundwater-bearing fracture zones in hard rock area using VLF data. Journal of applied geophysics, 57**,** 155-166.