Anomalous geo-magnetic effect of acid producing reactions in mine wastes

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Introduction

An issue like mining exploitation or industrial ore processing waste dumps appears today as an important and obvious environmental problem, which, in nowadays' concept of social, economical and ethical development, requests a careful and complex approach of which results must end up at a fast and efficient solving of the problem, respecting meanwhile the sustainable development principles. The geophysical investigation of waste dumps has registered a huge progress in the last two decades, benefiting implicitly of a significant improving until present times of the data acquisition, processing and interpretation techniques. The integrated interpretation of many datasets, each belonging to a different investigation method, proved to be the optimum solution for high quality results in the condition of relatively small investments in the data acquisition stage (P. Soupios et al., 2007). Analyzing the geochemical and mineralogical processes that occur inside the body of the waste deposits can yield important information regarding the interpretation of some geophysical datasets, offering in the same time more possibilities for geophysical investigations of these kinds of targets and ideas for their remediation.

Theory and models

Sulfides are the most common minor constituents of the Earth's crust. In certain geological circumstances they represent the majority of the existing rocks in those areas, typical case for the most of the metalliferous ore deposits (Cu, Pb, Zn, Au, Ni, U, Fe). The *pyrite* mineral (FeS_2) is the most common sulfide on Earth. Its weathering in mining areas causes the biggest environmental problem facing the industry today: *the acid mine drainage* (AMD).

In the case of tailing ponds, the oxidizing process of pyrite starts with the direct oxidation, process characterized by the following stoichiometrical reaction:

$$FeS_{2(s)} + 7/2\,O_{2(g)} + H_2O_{(l)} \rightarrow Fe^{2+}_{(aq)} + 2SO^{2-}_{4(aq)} + 2H^{+}_{(aq)} + \text{energy}$$

This reaction leads to lowering the infiltration water pH and implicitly, lowering the interstitial water pH inside the dump. The Fe^{2+} goes into Fe^{3+} which becomes itself an oxidizing agent:

$$FeS_{2(s)} + 14Fe^{3+}_{(aq)} + 8H_2O_{(l)} \rightarrow 15Fe^{2+}_{(aq)} + 2SO^{2-}_{4(aq)} + 16H^{+}_{(aq)} + \text{energy},$$

reactions of this kind leading to an accelerated oxidation of pyrite and implicitly to increasing acidity for the percolation waters. One of the results of this process, the Fe^{3+} ion, is stable only in low pH conditions. When migrating outside the oxidation "core", in higher pH waters, it gets oxidized: $Fe^{3+}_{(aq)} + 2H_2O_{(l)} \leftrightarrow FeOOH_{(s)} + 3H^{+}_{(aq)}$. The result of this process is an oxyhydroxide found in nature as αFeOOH and is known as the Goethite mineral. In sedimentology, Goethite is known for its important magnetic properties (χ = 1 100 – 12 000 x 10^{-6} SI (P. Blum 1997)), being the only magnetic weathering mineral, although so far couldn't be identified a geomagnetic anomaly caused by concentrations of this mineral, its properties being useful in laboratories analyses on samples.

Assuming that around pyrite oxidations cores there can be found important concentrations of goethite, forward modelings were realized to yield the class of the anomaly's size. The method used was the one proposed by M. Ivan (1996), which assumes a polyhedral homogenous body, with size and shape defined 'a priori'. The computation of the synthetic field was made using a set of 3 QBasic codes, modeling the effect of the lower surface, the upper surface and respectively lateral surface of the body, followed by their addition. We supposed a mean concentration of goethite of 30%, a sample of body material having a mean magnetic susceptibility of 1000 x 10^{-6} SI. The distance between the body and the survey plan was chosen to be 1.50 m, simulating measurements executed practically on the anomalous body. The obtained model (Fig. 1) was represented using Surfer (by Golden Software). The result showed that in the given conditions, goethite concentrations can give powerful enough anomalies to be clearly identified using geo-magnetic surveys.

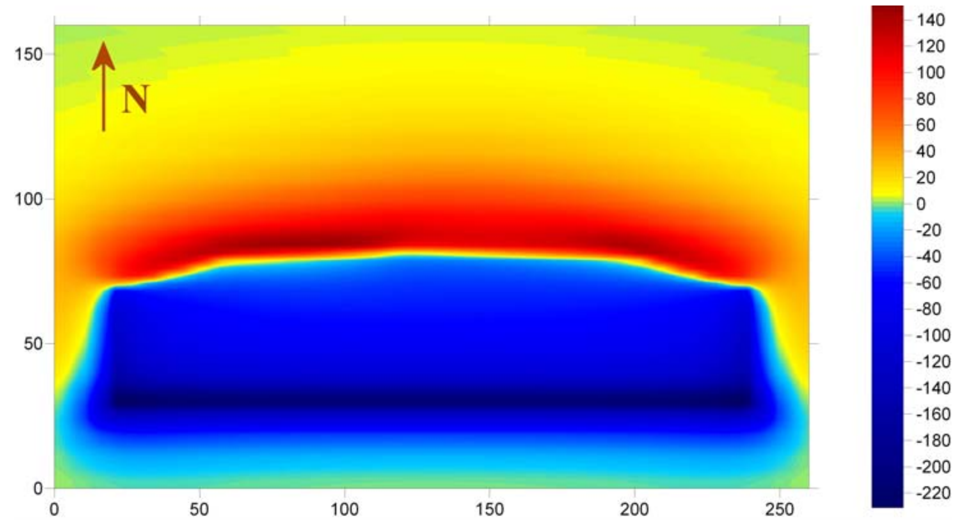

Fig. 1 – Synthetic geo-magnetic field obtained by forward modeling

Field data – site description

For the field tests, a tailing pond was chosen with characteristics almost similar with the modeled body. This is the case of the tailing ponds located near industrial objectives, placed on a flat artificial basement and with a sulfides-dominated composition, the dumped material coming from the industrial processing of poly-metallic ores (Cu-Pb-Zn – the most common sulfides paragenesis).

The site is located in central-western Romania, Alba County (Apuseni Mountains), being included into the Zlatna-Stanija metalogenetic district.

Characteristics: former elutriation pond of the Zlatna Ore Processing Enterprise, 40 000 m^2 in size and 18 m in height. The dump is located in the flooding valley of Ampoiu river, placed directly over Holocene clays. Its main structure consists of thin horizontal layers of clays.

The mineralogical analysis of the exploited geological formations showed high concentrations of pyrite and other iron and copper compounds. The X-Ray Fluorescence geochemical analysis of the waste material showed high concentrations of iron oxides (10 – 30 %).

Methods and data collecting

Geophysical methods provide an efficient tool for characterizing subsurface geology and hydrology. The methods used in this study measured the electric, magnetic and elastic properties of the subsurface. Iterative and integrated data collection and interpretation using multiple geophysical methods provides a more synergistic interpretation of data that often results in a more accurate model of the complex structures and processes of the subsurface.

Geophysical surveys were conducted on a 240/60 m grid over the top of the Zlatna dump. The magnetic measurements were realized with a Geometrics proton magnetometer that acquired total field data on the entire surface of the designed grid. The resistivity measurements were realized on parallel profiles with an Abem SAS 1000 electrometer and the chosen investigation method was the Vertical Electric Sounding (VES) using a Schlumberger method. The GPR (GSSI SIR-2000 unit – 200 MHz antenna) and seismic (Geometrics Geode) profiles followed lines of the magnetic surveys grid.

Samples of waste material were collected from the dump surface and from shallow drills (2 m) for magnetic susceptibility measurements. The analyses were executed at the Paleomagnetism Laboratory of the University of Bucharest. The 10 samples collected gave magnetic susceptibilities between 850 – 1300 x 10^{-6} SI.

Data processing and results

The primary raw data processing was realized using Matlab codes designed by us. The data representation was mainly realized using Surfer, by Golden Software.

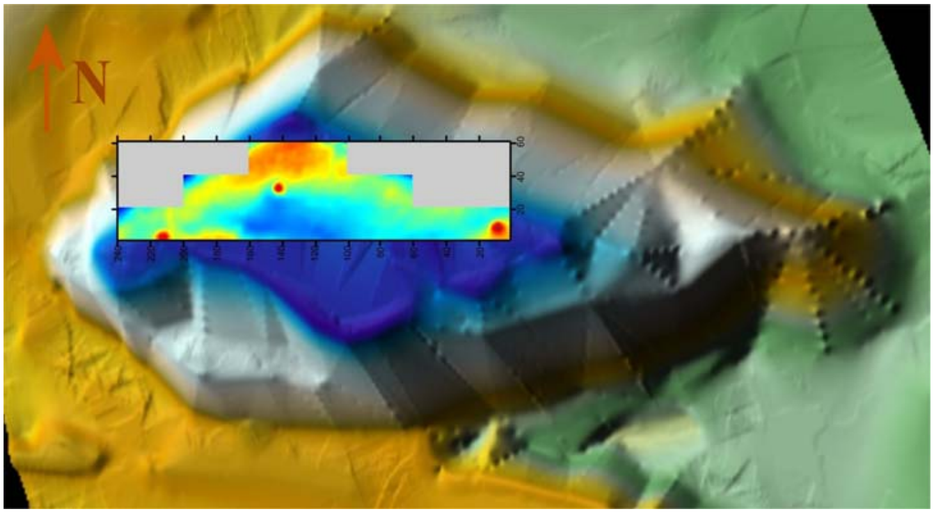

Fig. 2 – Zlatna dump – the geo-magnetic measured map placed over the topographic plan

On the geo-magnetic distribution map (Fig. 2), 4 important anomalies were identified. 3 of them had very small lateral extends but very high amplitudes. They are caused by the three metallic vertical pipes used in the construction process of the dump to pump the mud into the pond for elutriation. The 4th anomaly had smaller but still important amplitude, a big lateral extend and multiple similarities with the modeling results.

Integrating the results from the processing and interpretation of resistivity, GPR and seismic surveys, we excluded the presence of other bodies of any nature inside or at the bottom of the dump. The only two responsible sources for the 4th anomaly finally remained the goethite accumulations inside the dump and the iron pipe located almost in the center of the anomalous area.

Using the same processing tools, we realized forward modelings to estimate the effect of a body with the characteristics of the investigated dump and of the iron pipe in the real data collecting

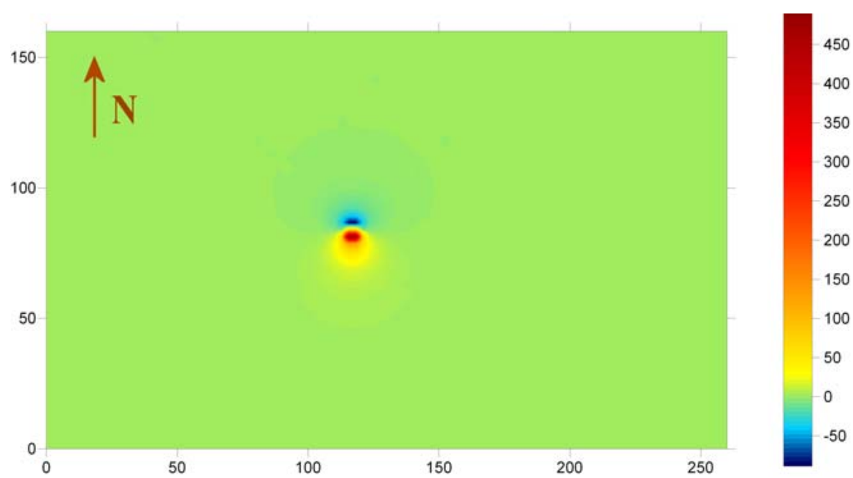

Fig. 3 – Synthetic magnetic effect of the pipe

conditions. All the field models for the pipe (Fig. 3) gave a high amplitude anomaly, but with small lateral extend, this subject couldn't explain the big anomaly identified on the dump.

The models for the dump body with the known magnetic susceptibilities gave anomalies with multiple similarities with the measured one. Cumulating the effects of the modeled body and pipe we obtained models very close to reality (Fig. 4).

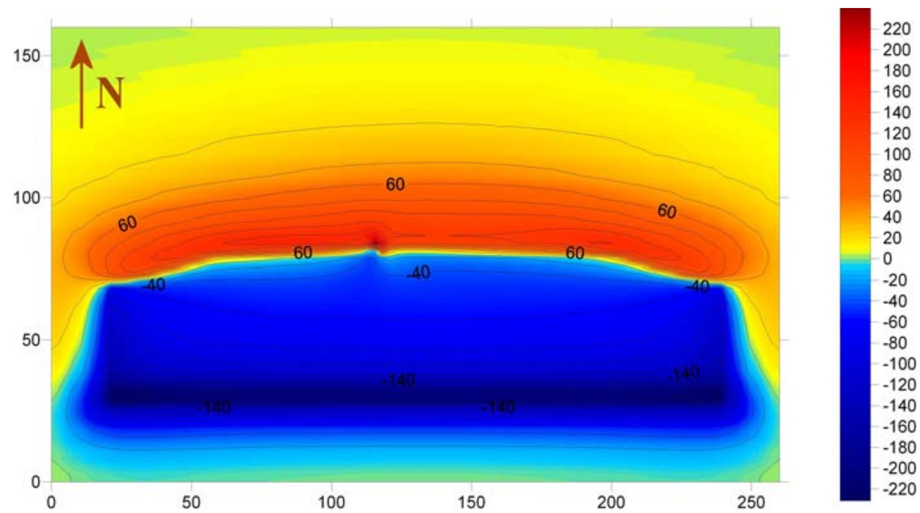

Fig. 4 – Cumulated effect of the modeled body and pipe

Conclusions

Mining waste deposits are today one of the biggest environmental problems, whose solving is urgently demanded because of the important negative impact upon the human society that they represent. In their investigation process, geophysics comes with very fast valuable and cheep information about their size, structure and composition, offering the necessary image of the problem before starting the remediation processes. This study brings another possible application of the geophysical methods in investigating mining wastes. Using geo-magnetic surveys over the top of tailing ponds with sulfides, the main oxidation cores can be emphasized, offering a huge advantage for the environmental engineers in choosing the proper remediation method and settings.

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