Anisotropy of out-of-phase magnetic susceptibility as a tool for tracking heavy metals pollution: a new approach to environmental magnetism study

Katarzyna Dudzisz¹, Szymon Oryński¹, Beata Górka-Kostrubiec¹, and Wojciech Klityński²

¹Institute of Geophysics, Polish Academy of Sciences, Department of Magnetism, Warsaw, Poland (kdudzisz@igf.edu.pl)
²AGH University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, Cracow, Poland

Soil contamination by heavy metals has become a severe problem in many parts of the world, affecting people and other living organisms. The anisotropy of magnetic susceptibility (AMS) was successfully used to track deformation and flow directions in rocks and unconsolidated sediment, however, it has been very rarely applied to soils. In this study, magnetic susceptibility, electromagnetic (EM) methods and AMS of soils around three historical mining areas at the Sudetes Mountains (Poland) were studied. These sites are diversified in terms of exploitation time and type of ore (Zloty Stok – gold and arsenic, Janowa Gora – iron and Szklary - nickel). They were selected in order to examine the spatial spread of contamination from mine tailings, their potential sources and to test the potential use of the AMS to study migration pathways.

Magnetic susceptibility ($\chi$), GCM (ground Conductivity Electromagnetic Method) and magnetometric measurements were carried out in situ to get a spatial resolution of the magnetic data. Bartington MS2 magnetic susceptibility meter was used for mapping of $\chi$, whereas GCM measurements were made to obtain conductivity distribution from 6 different depth ranges. Magnetometric measurements were conducted with GEM GSM-19T Overhauser Magnetometer integrated with GPS, allowing for measurement of the total magnetic field and its vertical gradient. Moreover, soils samples were taken for further analyses in the laboratory. For AMS measurements, all samples were oriented northward and carefully placed into 8 cc plastic, non-magnetic cubic boxes to prevent artificial modification of in situ magnetic fabrics. Then, these samples were measured in three mutually perpendicular positions using KLY-5 Kappabridge (Agico).

The highest values of magnetic susceptibility ($1-5 \times 10^{-3}$ SI) are observed around nickel tailings, whereas the lowest values ($60-120 \times 10^{-6}$ SI) characterise iron mining area. Preliminary results of GCM and magnetometry indicate the occurrence of overlapping anomalies in the studied area. Mapping of in situ magnetic susceptibility shows variability within particular sites. For Szklary, all three methods indicate the presence of the elongated anomaly roughly NE-SW oriented. Although AMS axes of in-phase susceptibility are randomly distributed for all sites, the magnetic fabric created by ferromagnetic minerals (out-of-phase, opAMS) indicate well grouped maximum susceptibility axes mainly oriented NE-SW. There is a clear correlation between mapped anomaly
around nickel tailings (Szklary) and opAMS lineation. Outside the anomaly, opAMS directions are oriented SE-NW. For other sites, opAMS is also in line with the results of EM methods. Taking into account these results, as well as landforms and hydrological conditions, it could be concluded that magnetic minerals accompanied with heavy metals, most likely, migrate with subsurface runoff and opAMS is capable of detecting changes in the direction of the pollution spread. However, more study is necessary to fully explain this mechanism.