Magnetic susceptibility as an indicator of heavy metal traffic pollution

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A b s t r a c t : Heavy traffic presents a problem with pollution not only of the air, but also of soils around the frequently used roads. In this case, significant pollutants are heavy metals – mostly lead, iron, chrome, nickel and their compounds. In the Malé Karpaty Mts. we picked a stretch of the mountain road experiencing heavy traffic for testing the magnetic mapping - the progressive proxy method of detecting the heavy metal pollution in the surrounding soil. The total number of 96 topsoil samples were collected along the road, and investigated for the mass specific magnetic susceptibility. The results show that this physical parameter is significantly increased in the topsoil close to the road. These elements and their compounds are often altogether bound on the humid soil constituents; therefore higher values of magnetic susceptibility and their decrease with distance from the road displace positive correlation not only with ferrimagnetic, but also of the affined paramagnetic components. The measurement of magnetic susceptibility of soils can be, in this case, used as a supplemental method to the geochemical mapping; method, which allows to assess, in a simple, cheap and rapid way the level of soil pollution at sites, where the geochemical data are missing.

Key words: magnetic susceptibility, pollution, heavy metals

1. Introduction

The magnetic susceptibility is the physical parameter reflecting the degree of magnetization of a material in response to an applied magnetic field. The volume magnetic susceptibility κ is defined by the relationship

$$M = \kappa H,$$

where M is the magnetisation in SI units (the magnetic dipole moment per unit) of the material [A.m^{-1}] and H is the applied field magnetic strength [A.m^{-1}]. The mass magnetic susceptibility κ_{mass} measured in m^3.kg^{-1} in SI units is defined as:

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$\kappa_{\text{mass}} = \kappa/\rho$,

where ρ is the density in kg·m^{-3}. The ferromagnetics are distinctive for highest positive susceptibility, the ferrimagnetics for moderate positive susceptibility, paramagnetics by low positive and diamagnetics by negative susceptibility.

Environmental pollution caused by different industrial activities has direct influence on the quality of life and health risks. The advanced chemical and spectroscopy analyses are decidedly most accurate methods fort the assessment of the anthropogenic pollution of soil, but they are expensive and time consuming, as well. Therefore the proxy, but more effective methods, were developed. One of them is the magnetometry – the determination of the magnetic properties of soil. The most convenient is the measurement of magnetic susceptibility as this method is rapid and cheep (for a review cf. *Petrovský and Elwood, 1997*).

In general, magnetic susceptibility reflects the concentration of strongly magnetic iron oxide particles in a material. The application of magnetometry as a proxy method for the detection of environmental contamination is based on the fact that heavy metal pollution in many cases is accompanied by emission of ferri(o)magnetic particles (*Strzyszcz, 1991*) because of the abundant presence of Fe in natural resource materials, like fossil fuels. Many mineralogical and geochemical studies have proven the presence of a significant amount of iron oxides (magnetite, maghemite, hematite) together with different heavy metals in fly ash and waste products from the steel industry *(Petrovský and Elwood, 1997; Strzyszcz, 1991, 1993; Scholger, 1998; Kapička et al., 1999; Georgeaud et al., 1997; Strzyszcz et al., 1996)*

For the determination of the magnetic susceptibility of the rock and soil samples the kappa-bridges are broadly used. These instruments are commercially available and posses high sensitivity. Furthermore, a large number of samples can be processed within a short time (one specimen takes approximately 3 min). Soils and sediments are most often the subject of the magnetic studies applied to environmental problems *(Shu et al., 2000)* and only a few results for needles *(Schadlich et al., 1995; Knab and Eberhard, 2001)* and tree leaves *(Matzka and Maher, 1999)* are reported.

Preliminary studies indicate a possible correlation between magnetic susceptibility values and atmospheric contaminants. Particles below the PM

10 limit (10μm) can significantly affect human health as they can easily be transported into deeper parts of the respiratory tract and accumulated in the alveoli (*LfU - Landesanstalt für Umweltschutz, 1998*). It is well known that due to their specific surface, such particles are excellent absorbers and carriers of pollutants such as heavy metals. Sediments and soils can act as natural storage for many types of pollution. Here, we report results of magnetic susceptibility investigations of the heavy metal soil pollution along the roadside. The main aim of study is to test the applicability of the magnetic mapping method.

2. Investigated area and research method

The Malé Karpaty Mts., the south western geomorphic unit of the Central Western Carpathians, was tectonically uplifted during the Late Tertiary. The pre-Tertiary complexes represented by Variscan crystalline core with residues of metamorphic mantle are surrounded by Neogene sediments of the Vienna basin to the NW and of the Danube basin to the SE. In the southwest, the crystalline basement involves the large Bratislava granitoid massif (Variscan S-type monzogranites to granodiorites) and the northern part is built by the Modra I-type granodiorite and tonalite massif. Both these massifs are separated by the Pezinok - Pernek crystalline group of two regional metamorphosed complexes of late Proterozoic and early Paleozoic age, build mostly by biotic and biotic-quartz phyllites and gneisses and locally by amphibolites, limestone and mica schist.

The mountain road to be studied is situated in the mentioned Pezinok – Pernek crystalline complexes. It passes from one mountain side – from Pezinok city through the Baba mountain ghaut to another side – to Pernek city (Fig. 1). The decision was motivated by several proper conditions: (1) a high level of pollution can be expected along this road experiencing heavy traffic, (2) traffic and road engineering are the only significant source of pollution in this area (combustion gases, asphalt), (3) there is only natural land on both sides of the road and the magnetic signal is not disturbed by agricultural activities, (4) the present road-line is many years old and an undisturbed accumulation of the pollution due to traffic can be expected for this time span, (5) to our best knowledge, the soil on both roadsides has

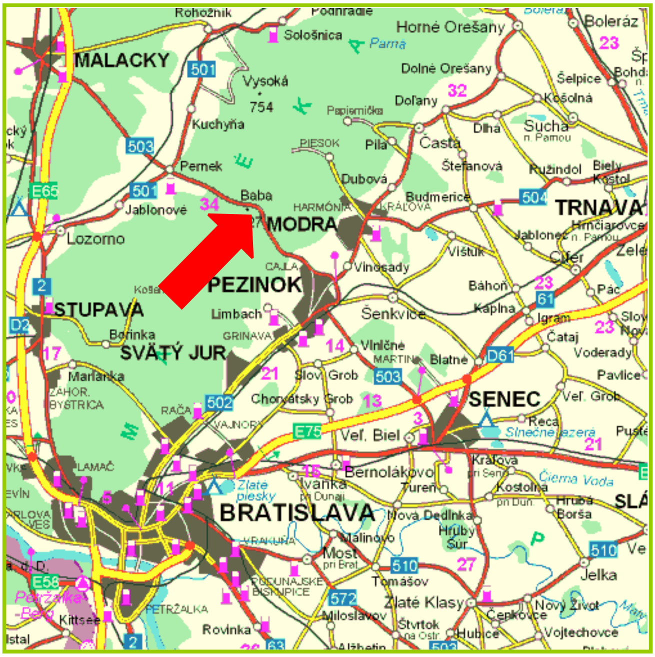

Fig. 1. The investigated area.

not been disturbed significantly within the last few years.

The pollutants accumulate in the topsoil, migrate mainly by wind, rain and surface water or are accumulated by plants or microorganism. Only solid particles are responsible for the enhancement of the magnetic signal in the topsoil. These include soot particles, metallic or fly-ash particles produced by abrasion (e.g., brake system), rust or paint particles due to corrosion.

Along the selected 3 kilometres long stretch of road 96 samples of the topsoil were collected. Every 50 metres three samples – one adjacent to the roadside, second half meter and the third 2 metres off the road were collected. The samples were air-dried, sieved and measured for the mass magnetic susceptibility on the Kappabridge KLY-2 (former Geofyzika Brno state comp. production). Only three samples were chemically analyzed via Atomic Absorption Spectroscopy (AAS). In these three samples the thermal dependence of magnetic susceptibility was also measured to determine the mineralogical characteristic of the magnetic soil components. This investigation was performed on the modern kappa bridge KLY3S/CS3 (Agico Inc. production).

The principles of the method of environmental magnetism, namely of the magnetic-proxies technique, which is used in this study for the screening and detection of pollution is based on following assumptions:

1. Most of the rocks, sediments and soils contain a certain, mostly accessory portion of ferri(o)magnetic minerals.
2. These phases are: Fe-oxides (magnetite, Fe_3O_4; maghemite, γ-Fe_2O_3; hematite, α-Fe_2O_3), Fe-hydroxides (goethite, a-FeOOH), Fe-sulfides (pyrrhotite, Fe_7S_8; greigite, Fe_3S_4) or similar phases.
3. In addition, aerosols and dust of anthropogenic origin containing different ferri(o)magnetic phases with Fe partly substituted by other cations like Ni, Co, Cr, Ti, Al, Mg are deposited and accumulated in soils and sediments.
4. Only the magnetic signal related to the secondary ferri(o)magnetic phases of anthropogenic origin is of interest.
5. Many – primarily natural processes are responsible for the final magnetic properties of soils or sediments (*Hoffmann et al., 1999*). Therefore, the anthropogenic contribution to the magnetic signal must be discriminated from the background (derived from lithogenic and other secondary ferri(o)magnetic mineral phases).
6. Anthropogenic ferri(o)magnetic phases mainly consist of highly magnetic spherules produced during processes such as combustion (fly-ash), welding, steel production, smelting and others *(Knab et al., 1998; Leven et al., 1998; Thompson and Oldfield, 1986).*

3. Results

Clearly enhanced values of the magnetic susceptibility were found adjacent to the roadside. The magnetic susceptibility of the samples collected nearest to the road average out the value of 4.8×10^{-6}m^3 kg^{-1} with the maximum of 10.4×10^{-6}m^3 kg^{-1}. For the samples half meter aside from

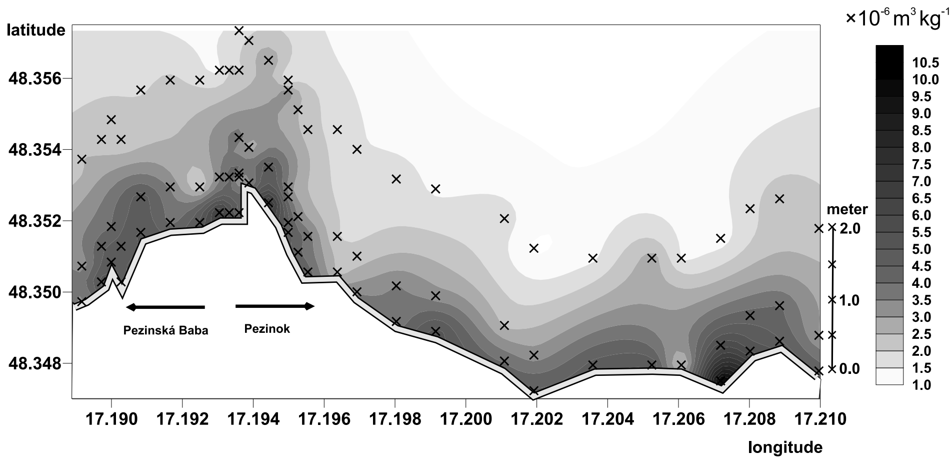

Fig. 2. Contour map of magnetic susceptibility degree on the investigated area. The road is figured in the geographical scale, while the distance of the sampling points are displayed in the scale on the right side of the plot.

the shoulder these values are $3.6 \times 10^{-6}\mathrm{m}^3\ \mathrm{kg}^{-1}$ and $5.8 \times 10^{-6}\mathrm{m}^3\ \mathrm{kg}^{-1}$, respectively. The lowest magnetic susceptibility was found in the samples furthermost off the road (2 meters) – the average is $2 \times 10^{-6}\mathrm{m}^3\ \mathrm{kg}^{-1}$ and the maximum exhibits $3.3 \times 10^{-6}\mathrm{m}^3\ \mathrm{kg}^{-1}$.

From the comparison of mass magnetic susceptibility results and these of Atomic Absorption Spectroscopy the significant correlation with Pb, Cu, Mn and mainly with Zn (from 129 mg/kg up to 1157 mg/kg) cations follows.

Thermomagnetic analysis is widely used for determination of the Curie point of ferromagnetic minerals, allowing identification of magnetic phase mineralogy *(Thompson and Oldfield, 1986)*. The shape and inflexion characteristics of the thermomagnetic curves are presented Fig. 3.

The thermomagnetic heating curves display 2 peaks. A smaller one around 300° C demonstrates the transition of probably maghemite to hematite due to thermal instability. The second anomaly around 500° C reflects the chemical reduction of hydroxides to magnetite, what is affirmed by the rapid temperature decrease at around 570° C (Curie temperature of magnetite). The organic components of soil significantly contributed to these processes, as they induced the reducing conditions by the higher temperature.

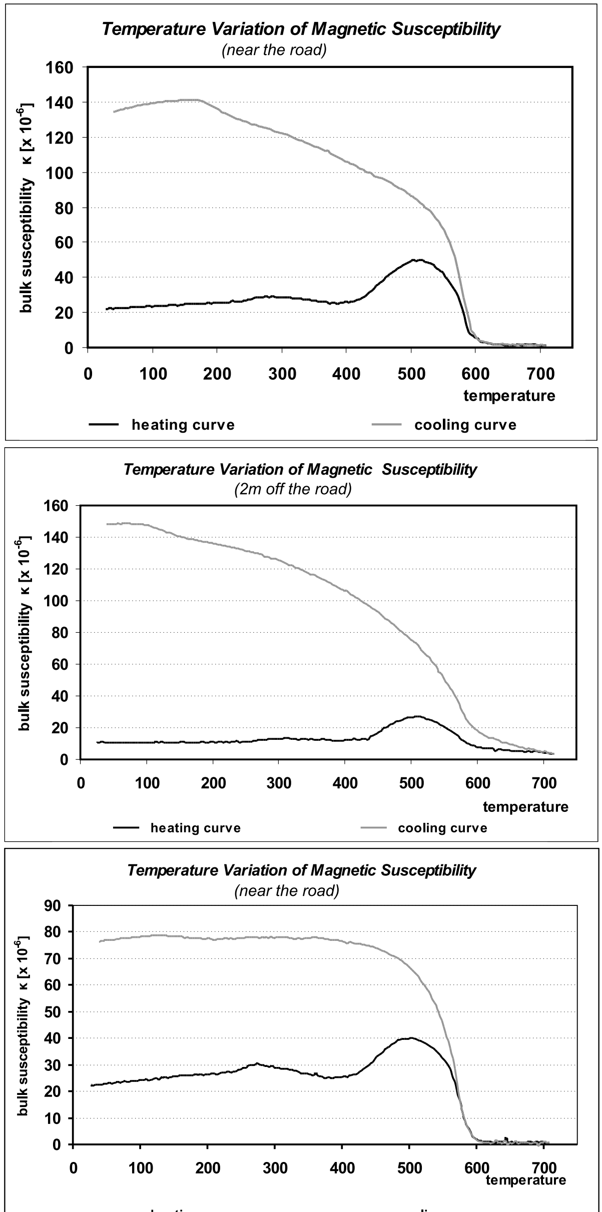

Fig. 3. High-temperature behavior of magnetic susceptibility for representative soil samples.

5. Conclusion

Clearly enhanced values of the magnetic susceptibility were detected in the soils on the investigated stretch of the roadside. The trend of decreasing susceptibility with the increased distance from the road is significant – it ranges from the average value of $4.8 \times 10^{-6} m^3\ kg^{-1}$ adjacent to the road to the mean mass susceptibility value of $2 \times 10^{-6} m^3\ kg^{-1}$ about two meters off the road. The chemical analyses (AAS) confirm the higher values of metallic elements such as Pb, Cu, Mn, and mainly Zn in the topsoil samples with the highest magnetic susceptibility values. These results substantiate the use of the method based on measurement of magnetic susceptibility as a very effective primary assessment of the heavy metal pollution of soil.

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