Utilization of the Soil Magnetometry for Environmental Geochemistry of Heavy Metals

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Abstract. The origin of magnetic particles in the soil and a non-conventional way of utilizing magnetic susceptibility - soil magnetometry - was studied in Malé Karpaty Mts. (West Slovakia). Magnetic susceptibility values above background in soil samples indicate higher concentrations of heavy metals in soil, i. e. the soil magnetometry can be used as a preliminary quick and inexpensive method for detection of higher heavy metal contents in soils.

Keywords. Heavy metals, soil magnetometry, Malé Karpaty Mts.

Introduction

Heavy metals are important in several ways: many are used industrially in technologically advanced countries, some are physiologically essential for plants and animals - and thus have a direct bearing on human health and agricultural productivity - and many are significant as pollutants in ecosystems throughout the world.

Heavy metals in soils have received increasing attention in recent years (Chan at al., 1998; Dlapa et al. 2000; Kapička at al., 2000; Magiera and Strzyszcz, 2000). There were recommended by Mikľajev and Žogolev (1990) to use soil magnetometry like a preliminary method that enable to border zones „increased geochemical activity", to bring down a bulk of works and to change flexibly the method of mapping but also in study of surface sediments (Brandau and Urbat, 2000; Milička et al., 2002) and pedological study of paleosols and loess (Verosub et al., 1993; Cocuaud at al., 1998).

Detection of enhanced heavy metals levels in soil using magnetic susceptibility

A need for rapid and inexpensive methods of outlining areas exposed to increased pollution by atmospheric particulates of industrial origin caused scientists in various fields to use and validate different non-traditional (or non-chemical) techniques. Among them, soil magnetometry seems to be a suitable tool, at least in some cases. This method is based on the knowledge that detected higher values of magnetic susceptibility of soils' samples above background indicate higher concentration of heavy metals in soil (Strzyszcz and Magiera, 1998; Ďurža, 1999; Petrovský et al., 2000).

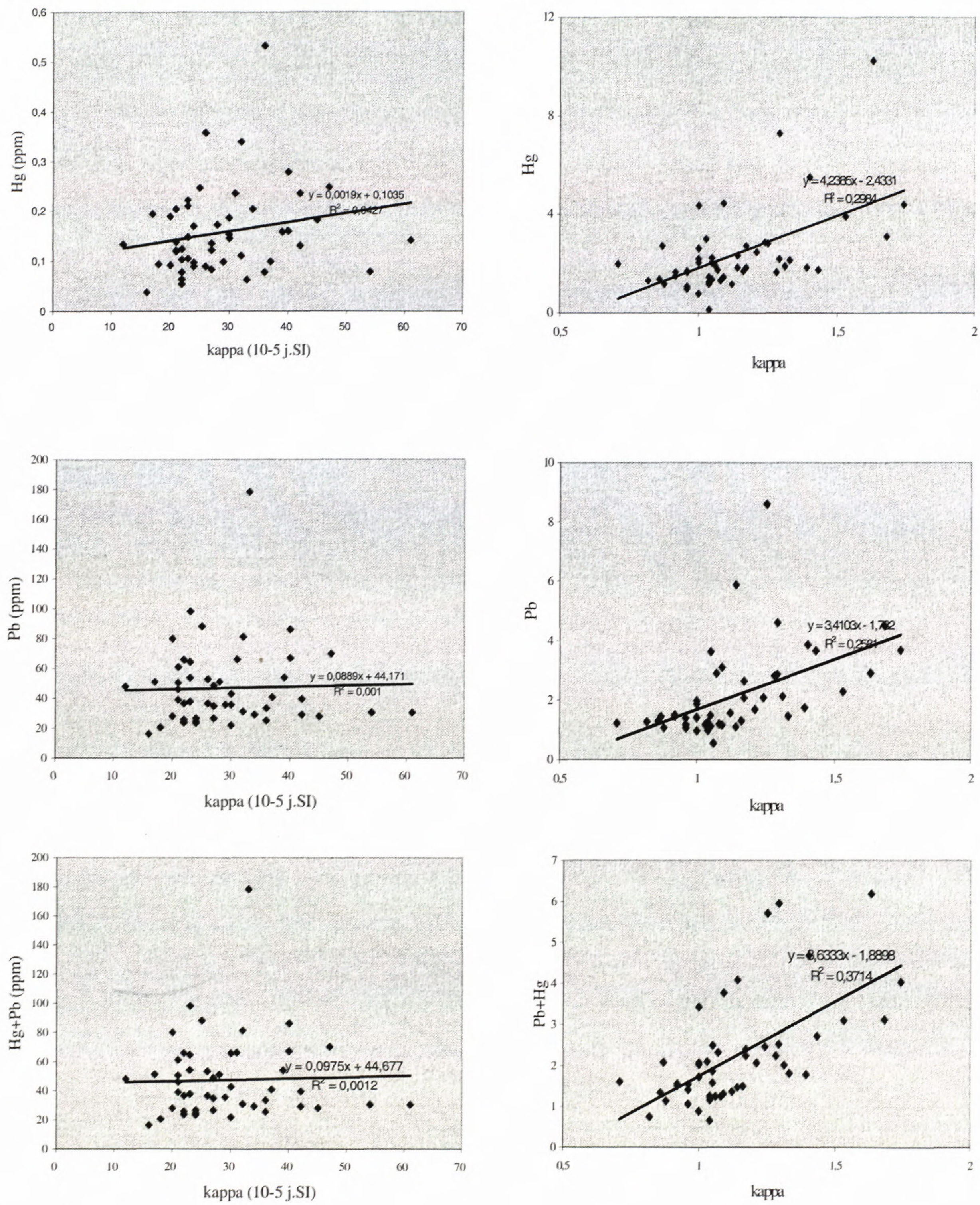
Measurements of magnetic susceptibility of topsoil have been successfully applied for mapping of degree of anthropogenic pollution near power plants, cement and metallurgy industries. All these studies demonstrate increased values of magnetic susceptibility of topsoil in contaminated areas compared to the signal of non-polluted soils.

Magnetic susceptibility of soil. The humus horizon is the most magnetic one. It is interesting that the concentration of heavy metals increases frequently with depth but the magnetic properties of heavy metal compounds decrease. It is in consequence of iron and other transient elements in a ferromagnetic state occur in this horizon and at the same time this trend is connected to the electron structure of non-ferromagnetic heavy metals complexes. These metals are assumed to have the highest concentration in the humus horizon where more kinds of organic ligands occur. These ligands are from humic and fulvic acids but also from other nonspecific soil organic compounds. The dependence of magnetic properties of heavy metal complexes on organic matters is explained by the ligand field theory, which was developed during the 1950s by the physicist J. H. van Vleck. This ligand theory is defined by Cotton - Wilkinson (1973) like a theory of an origin and a consequence of splitting of ions' inside orbits by their chemical surroundings.

However, the magnetic susceptibility of soil especially depends on the shape, size and concentration of ferrimagnetic minerals (maghemite, magnetite and the titanomagnetites) as well as on the method of measurement. Some non-ferromagnetic heavy metals also account for the increase of values of magnetic susceptibility as a consequence of the effect of humic and fulvic and nonspecific organic compounds in the humus horizon.

The origin of magnetic particles in the soil. Magnetic particles in the soil may be derived geologically from atmospheric sources, anthropogenic, if they are derived from industrial emissions, or biogenic in nature. The strong correlation between magnetic susceptibility and several heavy metal concentrations suggests a significant contribution to the magnetism from anthropogenic sources in the topsoil (Chan et al., 1998).

Ferrimagnetic iron oxide particles (mainly magnetite and maghemite) in fly ashes, originating during high temperature combustion of fossil fuels, are potentially the most significant source of anthropogenic ferrimagnetics found in the upper soil horizons (Flanders, 1994). Except



A B

Figure 1 Comparison between absolute values (A) and RTE values (B)

for small amounts of magnetite in coal, the main source of ferrimagnetics is pyrite, the concentration of which reaches up to 15% of inorganic fraction in hard coal (Kuhl, 1961 in Magiera and Strzyszcz, 2000). Pyrite and other iron sulphides are oxidized during the coal combustion process. The sulphur is liberated as gas, whereas iron is converted into ferrimagnetic minerals, which are emitted into the atmosphere together with other dusts. The anthropogenic ferrimagnetics are transported as dusts and aerosols over variable distances to settle on the soil surface. Deposition of atmospheric particulates represents one of the most important contributions to environmental stresses.

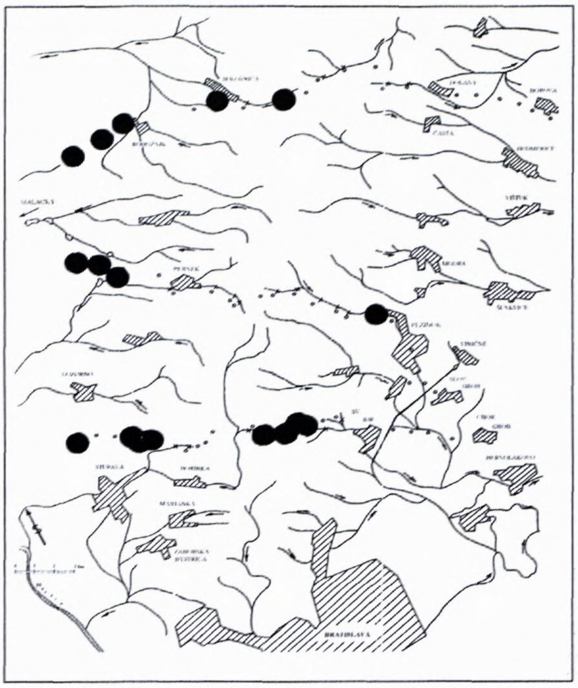


Fig. 2. RTE values of Hg+Pb+As+Sb > 2.0

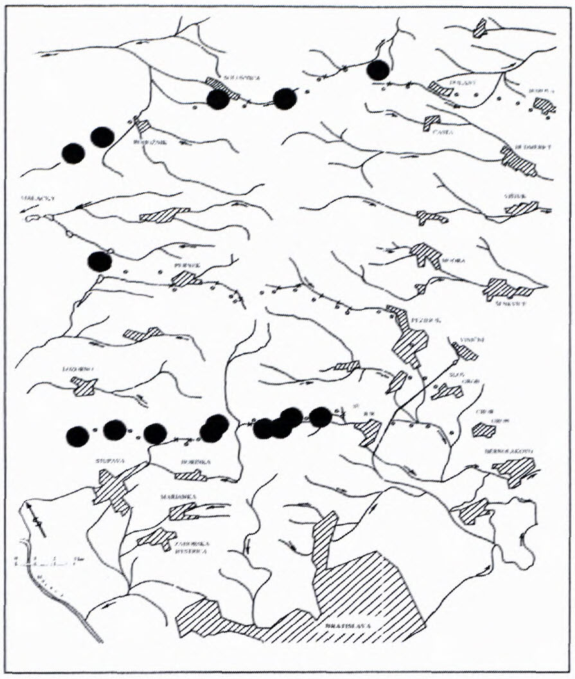


Fig. 3. RTE values of magnetic susceptibility > 1.2

The correlation between magnetic susceptibility and heavy metal content reveals a causal relation between ferric oxide and heavy metals. Previous studies have shown that certain heavy metals, such as Pb, Cu and Zn, are preferentially adsorbed onto the exterior surface of fly ash and aerosols from industrial emissions, which often contain significant amount of Fe and Mn oxides (Chan et al., 1998).

A strong correlation of these metals with the magnetic susceptibility is therefore expected. The coefficients of correlation between the magnetic susceptibility and the heavy metals contents are higher for Pb, followed by Cu and Zn and are weakest for Cr and Ni. The relative order of correlation for these metals with magnetic susceptibility can be explained in terms of the selectivity of clay minerals and hydrous oxide adsorbents for the metal, which generally follows the order Pb > Cu > Zn > Cr (Alloway and Ayres, 1993).

Cement production can also be considered as a major source of air pollution.

Another important source of atmospheric pollution, although limited in extent, is road traffic. In addition to Pb compounds, there are found hematite, magnetite and an iron aluminium silicate. As, Cd, Cr and Co are derived from the exhaust of automobiles and from tires as particles from tire ware. Furthermore, road surface (asphalt additives) represents another significant source of pollutants.

Detection of enhanced heavy metals levels in soil using magnetic susceptibility. It is known the measured values of soil magnetic susceptibility depend on parent rock of soil. In case of the homogeneous one this dependence does not cause the interpretation problems, e. g. magnetic susceptibility in soil around metallurgical plant U. S. Steel Košice (Ďurža, 1999).

In case inhomogeneous ones these dependencies cause the interpretation problems, e.g. magnetic susceptibility in soils from Malé Karpaty Mts., because the measured values of soil magnetic susceptibility are higher above granites as carbonates and the highest are above ore mineralization. Since the aim was not to find the effect of substrata (geological) on soil magnetic susceptibility but the effect of topsoil contamination (anthropogenic), the relative topsoil enhancement (RTE) of elemental concentrations and values of magnetic susceptibility were used. RTE was the ratio of element concentration in topsoil (0--15 cm) to that in subsoil (30-45 cm) as an index of surface contamination (Colbourn and Thournton, 1978 in Alloway, 1990). In this manner the influence of parent rocks was taken off.

Measurements were taken along three profiles situated in the southwest part of Malé Karpaty Mts. There was measured magnetic susceptibility in two horizons - at the land surface and at the depth of 40 cm. There were measured and analysed 67 soil samples for these heavy metals contents: Pb, Hg, As, Sb, Cd, Fe, Ni, Co, Zn and Mn (Geological Institute, Faculty of Natural Sciences Bratislava, Slovak Republic).

The individual heavy metal is not possible to determine by soil magnetometry but their sum (soil's total burden of heavy metals) correlates with magnetic susceptibility values. RTE of contents of Hg, and Pb show relatively the strongest relation with RTE of magnetic susceptibility (+0.55, +0.51 respectively) (Fig. 2). Similar results were found in the surroundings of dry refuse heap of the U.S. Steel Košice and corresponded to Chan et al. results (1988), too. The highest values RTE of magnetic susceptibility and RTE of element contents occur in northwest slopes of Malé Karpaty Mts. and in the profile near Bratislava (Fig. 3 and 4).

Conclusion

1. The magnetic susceptibility values decrease with their distance from the source of contamination.

2. Enhanced magnetic susceptibility values occur in the uppermost part (humus horizon) of the soil profile and they decrease downward.

3. Changes of heavy metal levels in soils are accompanied with magnetic susceptibility values.

4. Values of a magnetic susceptibility of soils samples above background indicate higher concentration of heavy metals in soil, i. e. the soil magnetometry can be used like a preliminary quick and cheap method for the detection of a higher content of heavy metals in the soil.

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