II International Interdisciplinary
Technical Conference of Young Scientists
20-22 May 2009, Poznań, Poland

Magnetic Susceptibility of Soils, Including Iron Oxides of Anthropogenic and Natural Origin - Measurements Using the Bartington Instrument

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Abstract: **The aim of the paper was to describe the use of magnetic susceptibility in assessment of soil pollution and localization of ochre soil. Reconnaissance researches were performed in Cracow (hydrogenic soils) and in the region of Hermanowa village (Carpathian ochre deposit). Measurements were carried out using the Bartington MS2 System. The enhancement of susceptibility of hydrogenic soils was observed. Ochre soil showed quite stronger magnetic properties than nearby lying soil.**

Keywords – magnetic susceptibility, soil, Bartington MS2 System

I. INTRODUCTION

In the presented paper the results of magnetic susceptibility of hydrogenic and ochre soils from southern Poland are introduced. Magnetic susceptibility determines magnetic properties of matter which are connected with presence of iron. Magnetic susceptibility is also a very good indicator of soil contamination by heavy metals. Investigations were performed on the area situated between “Cracow” power plant and “Mittal” steelwork in the city of Cracow. Researches were also performed on the not polluted area located near Hermanowa village (to the south of Rzeszów). In this case, measurements of the magnetic susceptibility of ochre and the magnetic field over the deposit were carried out. Laboratory studies of magnetic susceptibility and f_d coefficient were executed on the samples of soils.

II. THEORETICAL BASIS

Magnetic susceptibility is the ability of matter to magnetizing oneself under the influence of applied magnetic field. In the case of matter with weak magnetic properties, bulk magnetic susceptibility is given by following formula:

$$\kappa = \frac{J_i}{H} \tag{1}$$

where:
J_i – induced magnetization [A m^{-1}],
H – magnetic field intensity [A m^{-1}].

In environmental investigations, mass magnetic susceptibility and frequency dependence of magnetic susceptibility are used. Mass magnetic susceptibility concerns the mass of the sample:

$$\chi = \frac{J_i}{H \cdot \rho} \tag{2}$$

where:
J_i – induced magnetization [A m^{-1}],
H – magnetic field intensity [A m^{-1}],
ρ – specific density of the sample [kg m^{-3}].

Frequency dependence of magnetic susceptibility (f_d coefficient) allows determining of the origin of magnetic particles in a soil (the natural or anthropogenic origin):

$$f_d = \frac{\kappa_{lf} - \kappa_{hf}}{\kappa_{lf}} \cdot 100\% \tag{3}$$

where:
κ_{lf} – bulk magnetic susceptibility of the sample measured at low frequency,
κ_{hf} – bulk magnetic susceptibility of the sample measured at high frequency.

Researches of magnetic susceptibility were performed using the MS2 instrument

(Bartington, UK). This device consists of meter and sensors which use magnetic induction and detect magnetization of matter (Fig. 1). At the end magnetic susceptibility is calculated.

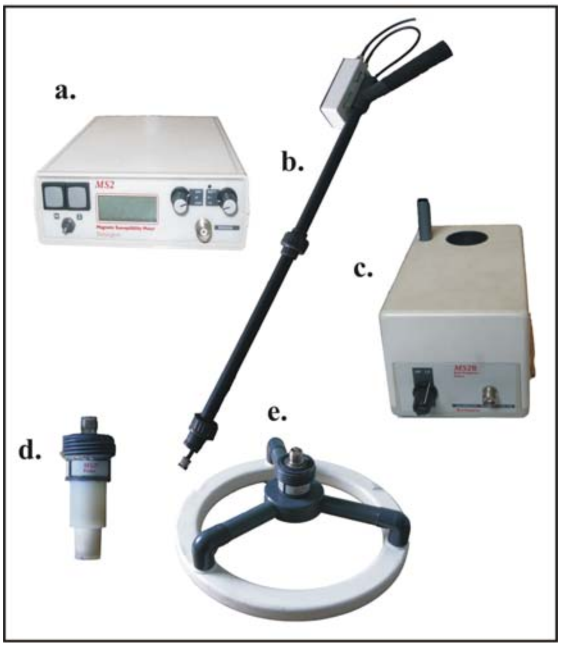

Figure 1. The MS2 System - magnetic susceptibility meter with some sensors (Bartington, UK) a. magnetic susceptibility meter b. handle to the MS2C and the MS2F sensors c. MS2B sensor d. MS2F sensor e. MS2C sensor (photo A. Wojas)

In field investigations the MS2D and the MS2F sensors were used. In laboratory, measurements were done using the MS2B sensor. One of advantages of the MS2 meter is possibility of measurement of susceptibility at two different frequencies (4.65 and 0.465 kHz). It allows calculating f_d coefficient.

III. Investigations of magnetic susceptibility of soil on the Cracow area [1]

Kappametrical map (map of magnetic susceptibility) of soils in Poland shows high values of magnetic susceptibility (> 100 • 10^{-8} m^3 kg^{-1}) in the region of Cracow [2]. Investigations of magnetic susceptibility of soil in Cracow were conducted on the Łąki Nowohuckie area. Hydrogenic soil laying on a non-magnetic bed rock occurs there. According to geochemical analyses, soils in this region are not very polluted [3].

Field investigations of magnetic susceptibility were carried out using the MS2D sensor. The length of profile was 630 m and a distance between measurement sites was 10 m. The measured values of the magnetic susceptibility range from 27 to 138 (• 10^{-5} SI units).

In laboratory studies of 10 samples of soil were executed. Samples were taken on the profile from two depths: 0 – 5 cm and 15 – 20 cm. Measurements of magnetic susceptibility were performed using the dual frequency MS2 meter. Mass magnetic susceptibility of the soil samples and frequency dependence of magnetic susceptibility (f_d coefficient) were calculated. The samples of soils taken near the surface (0 – 5 cm) possess higher magnetic susceptibility than samples from larger depth. Only one sample has the value of magnetic susceptibility which is above the threshold value (380 • 10^{-8} m^3 kg^{-1}) [4]. However, these values are high (> 100 • 10^{-8} m^3 kg^{-1}) according to T. Magiera [2].

Table 1. Mass magnetic susceptibility of the samples of soil collected on the Łąki Nowohuckie area

Mass magnetic susceptibility χ (· 10^{-8} m^3 kg^{-1})			
	Depth of sampling		
	0 – 5 cm	15 – 20 cm	
	350	168	
	414	248	
	322	215	
	83	74	
	121	93	

The calculated values of frequency coefficient of susceptibility (f_d) are low and range from 0 to 1%. It can show the presence of magnetic particles with anthropogenic origin in a soil (e.g. particles of magnetite from coal burning).

IV. Magnetic researches of the Carpathian ochre deposit in the region of Hermanowa village near Rzeszów –

ON THE BASIS OF A. ROLIRAT MASTER'S THESIS [5]

Ochre is composed of sallow varieties of oxide and hydroxide iron minerals [6]. The deposit of ochre was recognized in 1996 and 2002 by J. Kotlarczyk and T. Ratajczak in the region of Hermanowa village. Ochre from this area possesses various colours: yellow, yellowish brown, rubiginous, dark brown and red. Its colour depends on mineral which is presented in it, in large quantity. Goethyt dyes ochre yellow, hematite does it red and oxides of manganese cause dark tinge of ochre. The ochre deposit was arising in hyperorigin zone of iron sulphides rich, sometimes also glauconite rich, menilite layers. The deposit arose by the accumulations of secondary minerals of iron sulphides (iron hydroxides and sulphates) which were created in erosion process of above laying rocks [7].

The researches of the magnetic field and the magnetic susceptibility of ochre were carried out by A. Rolirat and research workers from Department of Geophysics (Faculty of Geology, Geophysics and Environmental Protection, AGH) in 2006 [5].

The measurements of the total magnetic field of the Earth (T) were performed in the place of ochre occurrence and to the south of the deposit using the ENVI MAG proton magnetometer system (SCINTREX Company, Canada). At the same time the magnetic field was measured "on the base". On the basis of measurements of the magnetic field, the values of ΔT anomaly were calculated according to the given formula:

$$\Delta \mathrm{T} = |T_p| - |\mathrm{T_b}| \qquad (4)$$

where:
T_p – value of the magnetic field measured over the deposit of ochre,
T_b – value of the magnetic field measured "on the base".

The presence of microanomalies was shown. The microanomalies values amounted to max. 30 nT (Fig. 2). The exception is a strong magnetic anomaly comes to 150 nT which is situated in the northern part of study area (Fig. 2). Sources of this anomaly are not known. It can be the result of human activity (for example buried iron objects) or can be connected with object of the natural origin.

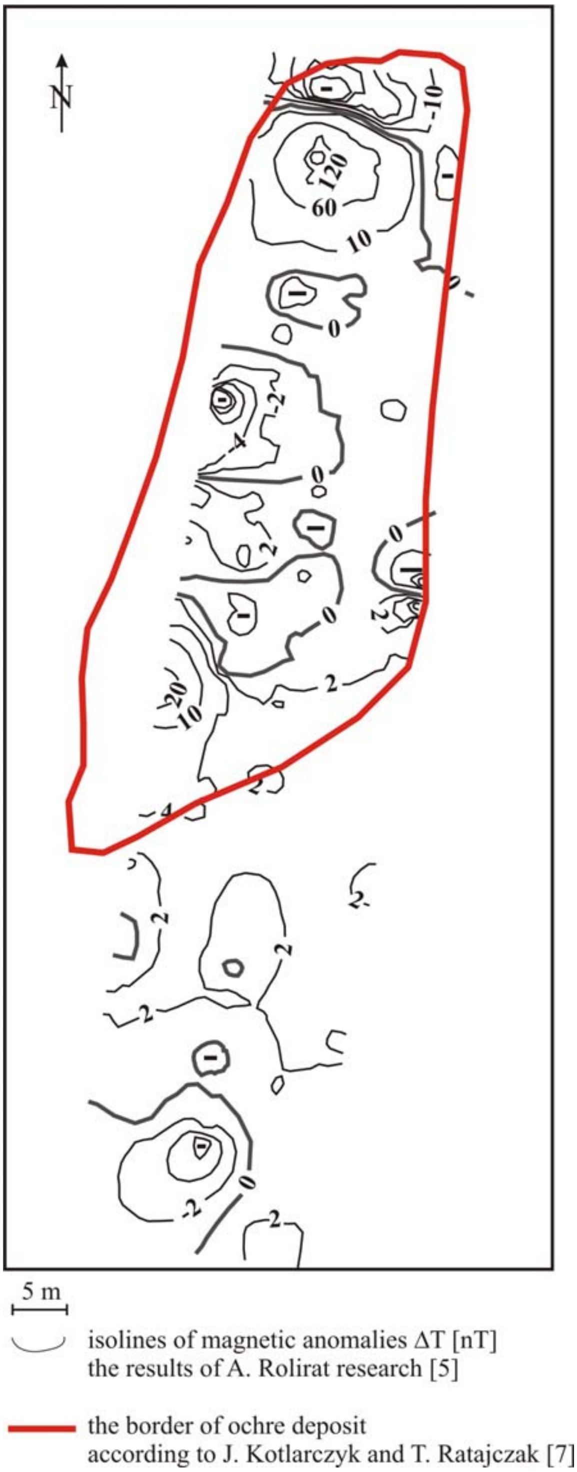

Figure 2. Map of ΔT anomaly over the deposit of ochre and its southern surroundings (the region of Hermanowa village near Rzeszów) (redraw from [5])

Field investigations of apparent magnetic susceptibility of ochre were performed using the MS2F sensor. Thanks to this sensor, direct contact between device and studied matter is possible. The measurements were carried out along seven geological profiles [7]. Distance on profiles between measurement sites was 2 m. The average profile length was 40 m. Profiles were carried out from the east to the west in 10 m distance between itself.

Plots of ochre susceptibility and geological sections along the profiles [7] were put together. One of them is shown in Figure 3. Low values of magnetic susceptibility, more or less 40 - 60 • 10^{-5} SI units, characterize soils which are devoid of ochre cover. Higher values reply places of ochre occurrence.

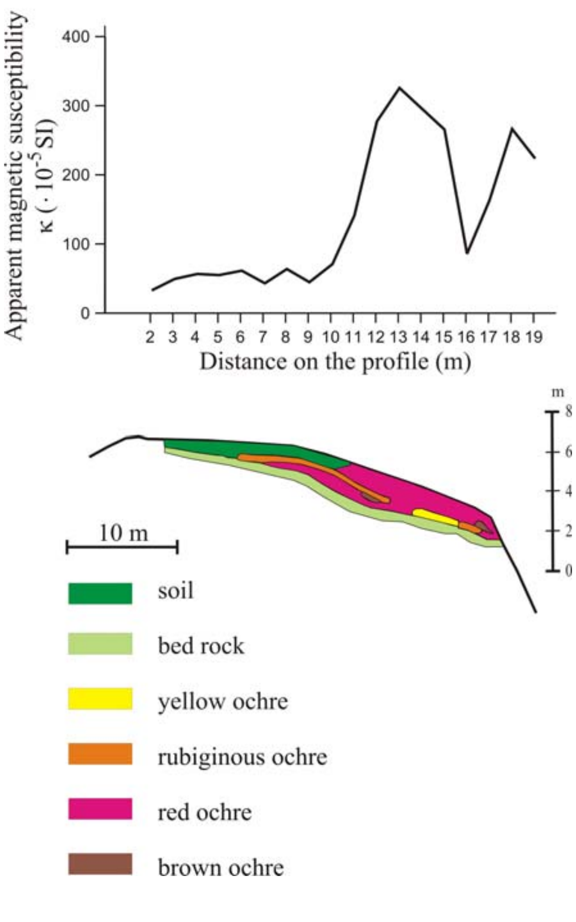

Figure 3. Plot of apparent magnetic susceptibility of ochre deposit in the region of Hermanowa village according to A. Rolirat (higher) [5] with geological section according to J. Kotlarczyk and T. Ratajczak (lower) [7]

The comparison of geological map and kappametrical map was performed. The brown ochre, occurring in the north-west part of the ochre deposit, has the largest values of magnetic susceptibility (approx. 200 - 900 • 10^{-5} SI units). The magnetic susceptibility of yellow and rubiginous ochre is lower and ranges from 60 to 200 • 10^{-5} SI units. The large diversity of the magnetic susceptibility of ochre is caused by physics-chemical processes (beside its chemical composition - according to J. Kotlarczyk brown ochre has the large amount of Fe_2O_3 [7]). One of them is claying with causing the decrease of the magnetic susceptibility.

Apart from field investigations, the laboratory studies were performed in Petrophysics Laboratory of Department of Geophysics (Faculty of Geology, Geophysics and Environmental Protection, AGH University of Science and Technology). The samples were collected on profiles after removing a litter layer. The measurements were done using the MS2B sensor. Bulk magnetic susceptibility of 31 samples of ochre at low and high frequency was measured. Afterwards frequency dependence of magnetic susceptibility (f_d coefficient) was calculated. The majority of studied samples have high f_d values reaching 11%. It can be connected with the presence of very small, superparamagnetic particles (SP) in samples of ochre soil. SP are magnetic grains of the natural origin.

Moreover, mass magnetic susceptibility of samples was determined (Table. 2).

The results range from 37 to 1016 • 10^{-8} m^3 kg^{-1}. Brown ochre has the highest values of mass magnetic susceptibility, lower values are characteristic for yellow and rubiginous ochre.

Iron oxides occurring in the ochre deposit have the unquestionable influence of the enhancement of the magnetic susceptibility. They are the most important components of different varieties of ochre and hydroferrite gel [7].

Table 2. Mass magnetic susceptibility of the samples of ochre soil in the region of Hermanowa village near Rzeszów (A. Rolirat studies, 2006) [5]

Nr	Colour of sample	Mass magnetic susceptibility χ ($\cdot 10^{-8}$ m^3 kg^{-1})
1	rubiginous	69
2	rubiginous	37
3	rubiginous	108
4	yellow	65
5	yellow	74
6	rubiginous	61
7	brown	97
8	rubiginous	116
9	yellow	64
10	rubiginous	190
11	brown	180
12	brown	1016
13	rubiginous	237
14	rubiginous	196
15	rubiginous	227
16	rubiginous	153
17	rubiginous	279
18	brown	986

V. CONCLUSIONS

The enhancement of magnetic susceptibility shows the average contamination of soils on Łąki Nowohuckie area. The study area is not ecologically devastated. Investigations of the frequency dependence of magnetic susceptibility show the possibility that magnetic particles with anthropogenic origin can occur in soils in this region.

The highest values of magnetic susceptibility were obtained in ochre investigations. It can be connected with processes occurring in deposit or strong magnetic properties of bed rock. Magnetic susceptibility of ochre is diverse. The brown ochre has magnetic properties significantly different than properties of soils. They are similar to magnetic properties of acid crystalline rocks. The large diversification of ochre properties can be connected with minerals present in ochre and processes (e.g. claying) occurred in the deposit.

The deposit of ochre causes small disturbances of the magnetic field with the exception of anomaly (150 nT) situated in the northern part of the deposit. The enhancement of magnetic susceptibility of ochre is also observed there.

Investigations of magnetic susceptibility are very useful in studies of soil contamination. They can also be successfully applied in reconnaissance investigations of ochre deposits.

VI. ACKNOWLEDGMENTS

The author is grateful to Prof. Janusz Kotlarczyk, Prof. Tadeusz Ratajczak and MSc. Anna Rolirat for the assent on showing their researches of the ochre deposit.

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