Contribution to the characterization of soils occupation type using magnetic properties

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Introduction

Soil magnetic properties are usually different from their parent rock. This fact has been established more than forty years ago and is of great importance in Archaeology. This constitutes the basis of magnetic prospecting use and more generally it corresponds to a link between the magnetic properties and pedogenesis over which the human activity may have had great impact. In order to try to answer the question **what are the relationships between human activity and soil magnetic parameters**, we have planned a laboratory detailed study of magnetic characteristics, and particularly of the **magnetic susceptibility**, using firstly both micromorphology and the full panel of macroscopic laboratory magnetic measurements (thermomagnetic and hysteresis measurement, frequency complex susceptibility and time domain responses).

Definition of the magnetic susceptibility

The magnetic intensity, or *magnetization*, *J*, of a material is the net magnetic dipole moment per unit volume. To compute the magnetization of a particular volume, the vector sum of magnetic moments is divided by the volume enclosing those magnetic moments:

$$J = \frac{\sum_i M_i}{V}$$

When a magnetic material is exposed to a magnetic field *H*, it acquires an *induced magnetization*, *J*. These quantities are related through the **magnetic susceptibility**, *K*:

$$J = K\,H$$

Thus, magnetic susceptibility, *K*, can be regarded as the *magnetizability* of a substance.

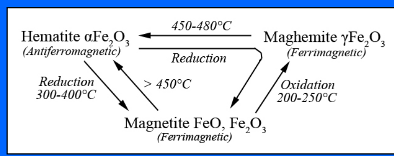
Magnetism of soils

This is due to magnetic minerals mainly composed of **iron oxides**. More precisely, **magnetite** and **maghemite** are characterized by a huge magnetic susceptibility and are consequently the main responsibles of soils magnetism.

Besides the oxidation of detrital magnetite, three processes are responsible for the formation of these iron oxides:

1. Formation of maghemite (and sometimes magnetite) from oxides or oxyhydroxides by repeated **oxidation-reduction cycles** during soil formation;

2. The **heating** of any soil in reducing conditions (presence of organic matter) is responsible for the general **enhancement of the magnetic susceptibility** of superficial soil horizons by reducing hematite in magnetite, which can be in a second time oxidized to maghemite in subsequent aerobic conditions *(Le Borgne, 1955)*;



(Dabas, 1989)

3. Dehydration of lepidocrocite (γFeOOH), a common iron-oxyhydroxide weathering product of iron silicates.

➞ Importance of these high susceptibility magnetic minerals: in a given geologic, topographic and floristic context, the **relative enhancement of the magnetic susceptibility is a reliable signal of anthropisation**.

Thermomagnetic and hysteresis measurements in laboratory

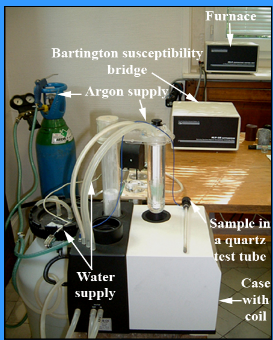
Thermomagnetic curves

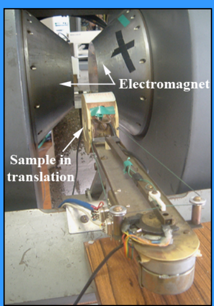
We measure the **induced magnetization** in high or low fields during laboratory heating and cooling, i.e. the **thermal variations of the magnetic susceptibility**. We can thus identify:

1. The **Curie temperatures** of several magnetic minerals in the sample which corresponds to marked decreases of total susceptibility during the heating process;

2. The **mineralogical and chemical transformations** that may occur during the heating process and that can be identified by non-reversible cooling curve.

Equipment: a *Bartington susceptibility bridge* equipped with a *furnace*.





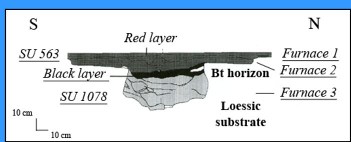
Hysteresis loops

A sample is submitted to a magnetic field varying between high positive and high negative fields. The saturation magnetization, J_S, the remanent saturation magnetization, J_{RS}, the coercive field, H_C, and the remanent coercive field, H_{CR}, are measured. The **grain-sizes** of the different magnetic minerals are obtained.

Equipment: a *translation inductometer* used in high fields.

An example of anthropogenic signal on the Medieval Site of Roissy-en-France (East of Val d'Oise, 95)

During their study, *Marmet et al. (1999)* collected among others samples from a Merovingian furnace (seventh century), which is composed of three parts: the **upper red layer** corresponding to the periphery of the furnace (interpreted as walls by an archaeologist), the burnt central zone (**black layer**) and the **lower layer**, which looks similar to the accumulation horizon (Bt horizon) of the paleosol.

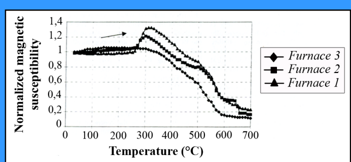


(Marmet et al., 1999)

Results:

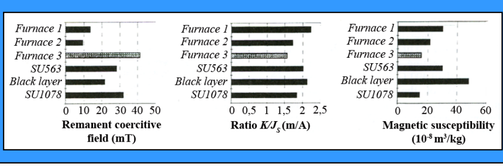
1. We can distinguish the sample of the furnace from the other sediments in the same section by the **absence of magnetic susceptibility peak at about 300°C** (no lepidocrocite) and the presumed presence of **substituted maghemite**;

2. The high values of susceptibility and of J_S for the **black layer** may correspond to the **production of magnetite** from hematite after a heating **temperature higher than 400°C**;



(Marmet et al., 1999)

3. The more abundant the archaeological remains are, the higher the ratio K/J_S is, especially when they have been heated, as was the case for the furnace ➞ **ultrafine magnetic grains would be produced during the heating, which generates the magnetic susceptibility enhancement.**



(Marmet et al., 1999)

Frequency complex susceptibility measurements and time domain responses

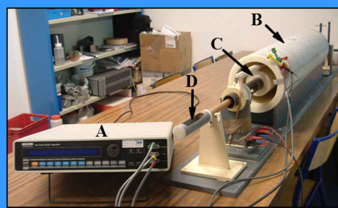
Measure of the frequency complex susceptibility in laboratory

We measure the **magnetic susceptibility** of samples for **different values of the frequency**. We use for this a *gain-phase analyser* (**A**) coupled with three concentric tubes:

1. The *external tube* (**B**) supports a primary coil which will create an induced field;

2. The *second tube* (**C**) is composed of six smaller coils wound in opposite direction so that theoretically no signal appears when the inducing current flows in the primary coil;

3. The *more internal tube* (**D**) supports the sample placed horizontally.



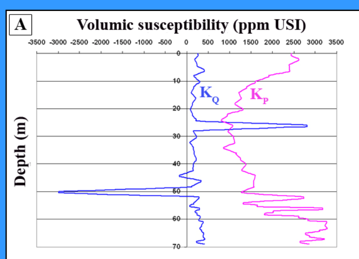
Principle of the measure:

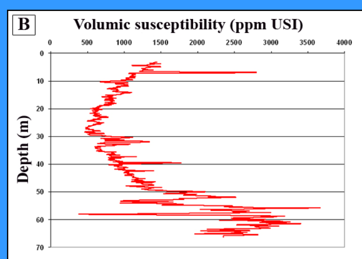
We inject an alternative electrical current in the primary coil with the generator of the gain-phase analyser. The created moment in the sample generates a flux and the second coil records its temporal variation. This **flux temporal variation** creates a corresponding **electromotive force** in the secondary coil. The gain-phase analyser is a **vector voltmeter** which allow us to measure either the amplitude and the phase difference, or the ratio of the electromotive force in the secondary coil to the one in the primary coil. We can also calculate the **in phase** and **quadrature out of phase components of the magnetic susceptibility (K_P and K_Q** respectively).

Example with samples coming from a drilling (Épenèdre, Charente, France):

We performed susceptibility measurements on 43 samples taken of a drilling of 69 *m* at Épenèdre (86) and at a frequency of 173 *Hz* ➞ we compare our results (**A**) to a magnetic susceptibility log (**B**) carried out using a two coil sonde (in phase response) operating at the same frequency.

Results:



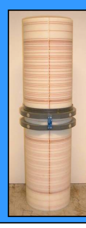


➞ The obtained K_P curve (**A**) looks very similar to the log (**B**), while these two methods work on different volumes, of dm^3 order of magnitude for the laboratory and of m^3 order of magnitude for the logging. So the values obtained for magnetic susceptibility versus depth on the site of Épenèdre are very reliable.

TDEM responses

We know that some materials exposed to a magnetic field will acquire an induced magnetization. Sometimes, the acquisition or the loss of this magnetization is delayed: this is the **magnetic viscosity** or **the viscous remanent magnetization (VRM)**.

Contrary to measurements in the frequency domain, we measure here susceptibility (or magnetization) variations versus time. The only huge difference between the two methods is that **primary and secondary coils are wound on the same tube** for measurements in time domain. This enables the apparatus to be less voluminous, easy to handle and have great mechanical stability.



➞ We will compare our susceptibility results obtained both in frequency and time domain.

Study prospects

Our goal is to perform magnetic susceptibility measurements on **sites characterized by different features** (period; geologic, topographic, micromorphologic and sedimentary context; anthropogenic occupation). We have decided to study:

- The **mettalurgical site of Melle**, in Aquitain (department of Deux-Sèvres, 86): it is characterized by an important lead and silver deposit exploited between the VII^e^ and the X^e^ century;
- A site in Bavaria (Germany): we will work on **Celtic square enclosures**;
- The **polluted site of Achère spreadings**, in the Yvelines (78): site occupated since the Neolothic and marks of Gallo-Roman settlement.