Application Note: Magnetic Susceptibility in Environmental Sciences

OVERVIEW

Magnetic susceptibility is the ability that a material has to be magnetized. Whilst this can have some applications in material science, there are also a range of applications related to the measurement of soils and other geological samples.

We look here at the applications of magnetic susceptibility in environmental sciences including pollution studies, archaeology, landscape dynamics or paleoclimate studies.

Naturally occurring magnetic minerals may transform or be transported in particular circumstances, with some of the changes altering their magnetic properties.
It is these changes or the movement of these minerals that are of interest and help understand processes that generated those deposits.

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Equipment

- Magnetic Susceptibility MS3 and MS2

Applications

- Better understand evolution of soils over time and use this information in terms of paleoclimate or pollution.

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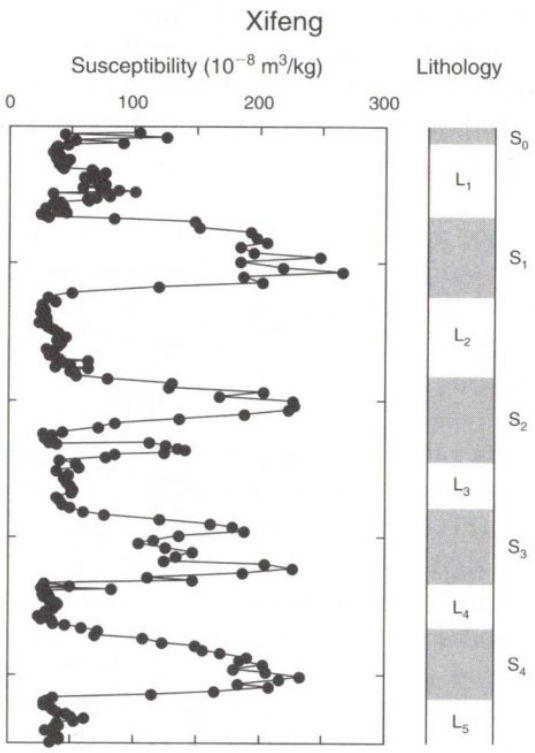
The use of MS3 in Paleoclimate studies

The change in climate patterns can lead to alteration of the mineralogical content in paleosols compared to their parent deposits. Wetter and warmer climate can promote biological activities which can lead to the creation of magnetite of biological origin.

Additionally existing iron oxides may, under different redox conditions, change from their Fe2+ to their Fe3+ or vice versa, potentially changing their magnetic properties.



The change in magnetic properties when it leads to an increase in magnetic susceptibility is referred to as magnetic enhancement. It can therefore be observed in paleosols compared to their parent deposits. The best-known example is the Chinese Loess plateau. This sedimentary plateau consists of an accumulation of wind-blown deposits, usually originating from periglacial environment. Their deposition is usually synonymous of colder and dryer periods. In the loess sequence, the loess deposits alternate with paleosols sequences.

The magnetic enhancement is clearly visible in the paleosols with much higher susceptibility levels compared to the loess from which the soils are derived (see figure, from Environmental Magnetism, M. E. Evans and F. Heller).

Depending on the nature of the samples, measurements can be taken on soil samples with the MS2B, or directly in the field on outcrops using the MS2K.

Magnetic susceptibility for monitoring of pollution

Since the start of the industrial revolution, the burning of coal has helped industry develop. However, its burning leads to the generation of vast quantities of fly ash which carry ferromagnetic minerals (coming from chemical changes taking place during the burning of coal). Their deposition will lead to magnetic enhancement of topsoils but can also be found deposited on vegetations.

Susceptibility measurements of soil samples or vegetation can help track the deposits and their source. Whilst enhancement does not necessarily only reflect pollution, the combination of magnetic susceptibility enhancement and the absence of frequency dependent susceptibility usually indicate a human origin to the deposits. Indeed, frequency dependency occurs when the magnetic minerals have a very small physical fraction (below a few nm or tens of nm). These dimensions are achieved by natural degradation of minerals through erosion process and will be the result of natural processes, whilst deposits from man-made activities will be composed of much larger grains.

The MS2B sensor allows to take measurement on soil samples at two different frequencies enabling frequency dependent measurement. This will allow a user to determine the grain

size present within a sample and identify whether the magnetic enhancement is from naturally occurring process, or due to pollution.

Additionally, roadside pollution can also be tracked using susceptibility, with magnetic enhancement associated with heavy metals.

Benefits of magnetic susceptibility in Archeology

Nowadays, magnetic prospection of archaeological features is widespread. This method, usually relying on a magnetometer or a magnetic gradiometer, detects magnetic anomalies associated with a change in the magnetic properties of the feature. This magnetic property (magnetic susceptibility) can vary locally for a feature for a number of reason including heating or digging/refill (where the surrounding topsoil has a different susceptibility from the infill).

Whilst these features could be directly detected using susceptibility, the process would be rather slower. Susceptibility can however help within a large site in determining the area where magnetic enhancement is visible, and therefore the most likely location for finding archaeological features. As such large-scale surveys (10mx10m individual grid) can be setup using the MS2D to narrow down the area to be mapped with more detailed techniques (gradiometry).

Susceptibility can also be used in shallow downhole application to find horizons of archaeological interest at a particular site.

Magnetic susceptibility's application to landscape dynamics

Understanding the processes of transportation of sediments, as well as their sources can provide insights on local conditions. This can help improve both local knowledge about past climate fluctuations or land occupation, but will help provide a wider understanding of climate patterns as well.

Magnetic susceptibility, amongst other techniques are commonly used to analyze sediments, with the magnetic susceptibility giving information about the source.

For example, increase in susceptibility of lake or river sediments if this is related to an increase of topsoil influx could suggest a change of land use. Other enhancement could be linked to increase amount of erosion of bedrocks under the effect of glaciers, and thus magnetic enhancement could be correlated to glacial period.

Other changes that can be a trigger for rapid, but typically short lived changes in the magnetic susceptibility of deposits (alongside other parameters such as grain size), are earthquakes. As these even can trigger landslides, the uncovering of new deposits, or the dust associated with the event can be markers. As such susceptibility can also find application in reconstructing the paleo seismicity of a region, helping to construct a longer history of a fault.

Whichever the mechanism, susceptibility measurements can be taken directly on cores using either the MS2C or the MS2E, or on individual samples using the MS2B.
The dual frequency on the MS2B can provide some additional information about frequency dependency and grain size.