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Tool kit of Environmental Magnetism

Physics

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ABSTRACT

The chemical and thermal transformation of iron compounds subjected to surficial processes or anthropogenic activity is a precursor to magnetic mineralogy identification and recognition of prevailing and past conditions of the regolith. Iron and its oxides form the carriers of magnetic property largely determining the rock or sediment magnetic property. The qualification, quantification and identification of grain size, shape, concentration of mineral assemblage and amount of magnetic mineral input during sedimentation and diagenesis is possible with measurement of magnetic properties of the geologic material. Magnetic properties used for the identification of presence, formation and source of magnetic minerals are susceptibility (), Induced Remanence Magnetisation (IRM), Saturation Induced Remanent Magnetisation, Anhysteretic Remanent Magnetisation (ARM) and temperature dependence. Instrumentation for Environmental magnetic measurements includes susceptibility meters, magnetizers, demagnetizers and magnetometers. The transformation, comminution, transport, deposition, concentration and dilution of magnetic minerals in environmental systems are characterized by the parameters measured. Interpretation discriminates the mixture of magnetic oxides present than quantifying the components of the mixture. Correlative study of derived ratios such as frequency dependence of susceptibility, SIRM/, ARM/SIRM, S-ratio, HIRM, arm emphasizes the differentiation of input and prevailing environmental conditions during the formation magnetic minerals and post depositional mechanical and chemical processes. Since all type of crustal changes are a resultant of atmospheric changes and thus climate of the source and sink location measured and derived magnetic parameters form proxies for paleoclimatic variation. Hence magnetic properties of materials owe a great deal to environmental reconstructions. Records of environmental change exists in different environmental systems like Lakes, river deltas, oceans etc. Some systems are identified as case studies here.

Introduction

Natural earth processes and thus climate is influenced by the Sun–Earth-Moon system which encompasses the atmosphere, hydrosphere and the lithosphere. Magnetic mineralogy is a net effect of the movement of solid particles during bio-geo activities in this system. Comminution involving reduced size with or without change in shape of magnetic minerals present results from physical weathering, erosion, transport by water or ice. This might also involve conversion from multidomain to stable single domain. Transport and deposition sorts the sediments which affects the fractions of magnetic and non-magnetic fractions in the material which crucially deters the magnetic behavior the sediments from that of the source material. Concentration and dilution of magnetic minerals is a function of the competence of the weathered source.

Magnetic oxides present in the crust, paramagnetic iron and cosmic flux form the primary source for magnetic minerals considered for environmental magnetic studies. Secondary magnetic oxides are formed due to weathering of exposed bed rock, concentration, dilution and transformation resulting in the formation of soil, called pedogenesis. These secondary minerals differ from the substratum from which it is formed and this difference can be used for the identification of source. Primary iron compounds are transformed to magnetic oxides by anthropogenic activates also. The magnetic enhancement in topsoils can be monitored for the particulate emissions by industrial processes and domestic fossil fuel combustion. This implies the degree of anthropogenic pollution in the top soil.

Environmental Magnetic Parameters

(i) Magnetic Susceptibility: Magnetic susceptibility measures the magnetisability of a material. Volume susceptibility measures the ease with which a material can be magnetised.

(ii) Natural Remanences: Natural remanences are those induced in a mineral under natural geological conditions under the influence of the Earth's magnetic field.

(iii) TRM: When a magnetic mineral is cooled from Curie temperature it acquires a magnetization called Thermoremanent magnetization. The intensity of remanence is porportional to the applied field for small fields. This remanence withstands time.

(iv) CRM: When a magnetic mineral is produced by chemical changes at temperatures below its curie temperature it acquires a field, when the crystal grows larger than its critical size then it acquires chemical remanence.

Artificial Remanences-

(i) VRM: Viscous remanence is acquired when the sample is exposed to a new magnetic field. The remanence is by definition, time dependent.

(ii) ARM: Anhysteritic remanence is the remenance acquired by a sample in the presence of a strong alternating field which is smoothly decreased to zero in the presence of a small steady field.

(iii) Isothermal remanence: The remanence acquired when a magnetic mineral is subjected to a steady field. The magnitude of remanence depends on the strength of the steady field applied. This is a function of composition, microstructure, eg : grain size.

Instrumentation-

(i) Susceptibility Meter: Magnetic susceptibility can be measured by using an inductance bridge that produces weak alternating fields

of high frequency. The instrument is called susceptibility meter.
(ii) Pulse Magnetizer: Artificial magnetic fields can be induced in samples by using electromagnets. Pulse magnetizers can generate a field from 0 to 9 Tesla. The remanence induced in a sample is known as Isothermal Remanent Magnetisations at that particular field.

(iii) Demagnetizer and ARM attachment: The system produces an alternating magnetic field, the size of which decreases linearly with time from an initial field size, that can be set. For magnetic cleaning techniques the sample is rotated in the field so that no preferred orientation is developed in the presence of alternating magnetic field. NRM measured between each demagnetization can be measured until secondary NRM is effectively randomized and primary NRM due to the Earth's paleomagnetic field orientation is obtained.

(iv) Magnetometer: Remanent magnetisation of a sample can be measured using Magnetometers. The magnitude of the current is proportional to the remanence of the sample. To determine the unknown direction of remanence the sample is spun in different orientations.

Interpretation of Mineral Magnetic Parameters-
Mineral type, concentration and grain size are the major factors controlling magnetic parameters. Direct measurements are affected by mineral concentration and type. But ratios cancel this effect and indicate grain size.

Minerals which are of concern to the environmental magnetist have strong magnetic characteristics and carry magnetic remanence. They form the solid solution series. There is also a temperature dependence of magnetic properties since minerals like siderate behaving as paramagnet at room temperature become remanence carriers when below 40 K.

Magnetism varies with grain size. Ultrafine crystals below 0.03m in diameter possess no remanence at room temperature but have huge susceptibility values. Larger crystals (0.1m) carry strong remanence. They are called Stable single domain (SSD) grains, but with increasing grain size, stablility declines. In large grains (>1m) minerals are waek magnets as they are Multidomain(MD) and have competing magnetic energies.

In order to understand the magnetic mineralogy ratios are selected. Ratios which are in common use are S-ratios which show degree of remanence acquisition, IRM/ and ARM/ which measures squareness of hysterisis loop, ARM/SIRM relates strength of grain interactions.

Once correlation of magnetic parameters and standard interpretation is done statistical analysis can follow which could give insight into relationships and patterns in magnetic data sets. Statistical techniques like cluster analysis and principal component analysis are essential tools in grouping according to characteristic properties. Multivariate data analysis methods reduce the number of variables in the system and simplify the complex data set. Simultaneous equations can be used to model the system which is governed by two or more variables. Climate proxy data is time variant. Any time variant data contains frequency of events in it.

Climate or environmental change has two components a global component and a regional component. The global climate is influenced by variations in polar ice in the artic. World's climate is in many ways related to human activities. Regionally climate is influenced by variety of factors like day to day variations in temperature, annual or biennial variations etc. These events are punched into sediments as magnetic remanences or nature and concentration of magnetic minerals present. These properties furnish insight into the climate change recorded while and after formation of sediments. Like the sources of magnetic minerals, depositional mechanisms and depositional environments affect the processes. This past record contains information relevant to the evolution of humans, periodicity of Ice ages, development of agriculture, the Industrial revolution and the greenhouse effect.

Susceptibility variations indicate changes in nature and amount of magnetic grains transported into the depositional environment in Lakes form the surroundings. All changes from changes in drainage pattern, landslides, fire, and deviation form normal climate are telegraphed into the Susceptibility variations.

In lakes during warm drier periods the supply of detritus sediment form the near vicinity of the lake is reduced and weathered iron oxides gets deposited and during periods of glaciation sedimentation rates are higher and hence magnetite is found in the sediments reflected in magnetic susceptibility, ARM and S-ratios. In oceans magnetic concentration is high during the glacial with less biogenic carbonates and interglacial are characterized by low magnetic concentrations and more biogenic material.

Magnetic minerals reach the atmosphere as a result of volcanic eruptions, wind erosion, Industrial and combustion processes and as cosmic flux. Volcanic ash concentrations in the atmosphere affect climate as well as significant contributor to magnetic minerals in deep sea sediments like manganese nodules. Wind deflates exposures and regolith is formed above bedrock and this gives magnetically strong signals than bed rock.

Case Study 1: Chinese Loess Record

Authors like Kukla et al.1990, Maher et al. 1999, have reported magnetic susceptibility records over Chinese Loess plateau. Extensive loess deposits are seen in central China. Loess are formed when high velocity winds generates dust in deserts, transports and deposits dust with rain. Chinese Loess owes its origin to Tibetan plateau and the Himalayas. Magnetic chronology can be derived from Natural Remanence measurements. Remanence measurements indicate that the entire loess section encompasses the Brunhes, Mutyuma, and Upper Gaussian Chrons. Loess magnetic signature reflects climatic change, since it is found correlative by different authors with oxygen isotope records. The magnetic susceptibility can be viewed as a seires of positive shifts in paleosols superimposed on constant value in Loess. Loess can be distincitively sited to have lesser magnetic susceptibility while paleosols have stronger magnetic susceptibility. Next step in interpretation would be identifying the grian size and mineral type. Acquired remanence and ratios indicate that the insitu formed magnetite which is more weathered and fine grained concentrated in the paleosols during warm interglacials lead to high susceptibility values. Direct relationship was derived by Han et al (1996) describing relationship of susceptibility, temperature and rainfall. Many factors control susceptibility values in the Loess which includes climate, vegetation, topography, parent material and time. Global variations are a resultant of variation of the Earth's orbital parameters.

Case Study 2: Pollution in Hamilton Harbor

Versteeg et al, 1995 reported application of mineral magnetism in assessment of pollution in Hamilton Harbor. Apart from mineral magnetic analysis geochemical and and physical parameter study was conducted in understanding the effect of agricultural, urban and industrial development in the harbor. Core samples collected from three different locations are analyzed for magnetic susceptibility. An increase in magnetic susceptibility is recorded in all cores above 70 m.

Conclusion
In present article we have discussed the instrumentation and various parameters used to study the change in climate and environment using magnetic mineralogoy. Results from Chinese Loess obtained by Kukla, Maher etc. and results from Hamilton harbor as obtained by Versteeg etc. also support the presented tool kit to be used for the study of environment, climate and pollution. In India this kind of

research is in early stage.

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