PRELIMINARY STUDIES ON TEMPERATURE DEPENDENCE OF MAGNETIC SUSCEPTIBILITY OF SOME ROCKS WITHIN THE NORTHWESTERN PART OF NORTHERN NIGERIA BASEMENT COMPLEX

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Abstract

The temperature dependent of magnetic susceptibility study of rocks within the Zaria granite batholith was carried out with the aim of investigating the characteristic curve of the magnetic susceptibility versus temperature for representative rocks samples selected from within the study area. Three samples with low, moderate and high concentrations of magnetic minerals were considered. The three samples considered represent the general behavior of susceptibility/temperature curves of rocks in the area. These are HAN10 with magnetic susceptibility of 58 x 10^{-6} [SI], KUF03 with magnetic susceptibility value 803 x 10^{-6} [SI], and DAN02, 1388 x 10^{-6} [SI]. The study revealed that for samples with high magnetic susceptibility values, indicating a high concentration of magnetic minerals, the curve shows a fairly constant variation of magnetic susceptibility with temperature reflecting that the magnetic susceptibility is controlled by magnetite. While, for samples with low and moderate concentration the magnetic susceptibility decreases with temperature, indicating that the magnetic susceptibility is controlled by paramagnetic minerals.

Keywords: *Temperature dependence, magnetic susceptibility, magnetite, Zaria granite batholith and magnetic minerals.*

Introduction

In many rock magnetic studies, information on magnetic mineralogy is of crucial importance. Besides standard analytical methods, such as X-ray spectroscopy, more sensitive thermomagnetic analyses are often used. Temperature dependence of magnetic parameters can serve as basis for determination of magnetic second-order phase transition temperatures. Although limited by several drawbacks, (Petrovský and Kapička, 2006) the most serious being thermally induced transformations of the original minerals, this method provides useful information not only about the presence of magnetic minerals, but also additional knowledge on, *e.g.*, the prevailing grain size distribution or degree of substitution. In thermomagnetic analysis, temperature dependence of two parameters, induced magnetization and magnetic susceptibility, is mostly used. However, because of historical reason (Petrovský and Kapička, 2006), the same approach for the Curie point determination has often been used in analyzing the two parameters.

A hysteresis curve gives information about a magnetic system by varying the applied field but important information can also be gleaned by varying the temperature. As well as indicating transition temperatures, all of the main groups of magnetic ordering; *i.e* diamagnetic, paramagnetic and ferromagnetic has characteristic temperature/magnetisation curves. At varying temperatures the magnetic susceptibility of a diamagnet is constant (Fig.1), while it decreases for paramagnetic materials (Fig.2). The paramagnetic materials obey Curie law, (eqn.1) in which the magnetic susceptibility varies inversely with temperature.

$$x = {}^{C}/_{T} \qquad (1)$$

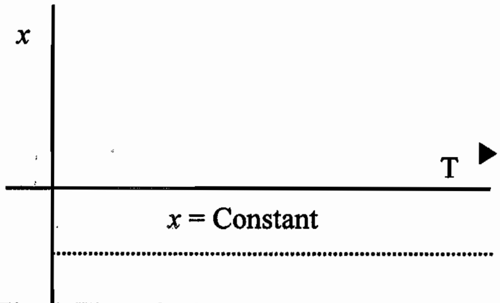

Fig.1:The behavior of diamagnetic material at varying temperature.

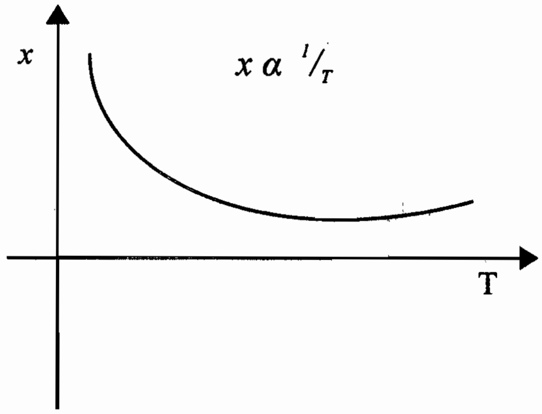

Fig.2: Paramagnetic magnetic susceptibility varies inversely with temperature

The constant C is the Curie temperature characteristic of many minerals, and it is defined as the temperature above which a solid is paramagnetic. Thus, a plot of 1/χ against temperature is a straight line with an intercept θ on the temperature axis (Fig.3). At temperatures T > θ the paramagnetic susceptibility χ is given by the Curie-Weiss law.

$$\chi = \frac{C}{T-\theta} \qquad (2)$$

where θ is a specific temperature for a particular substance (equal to 0 for paramagnets).

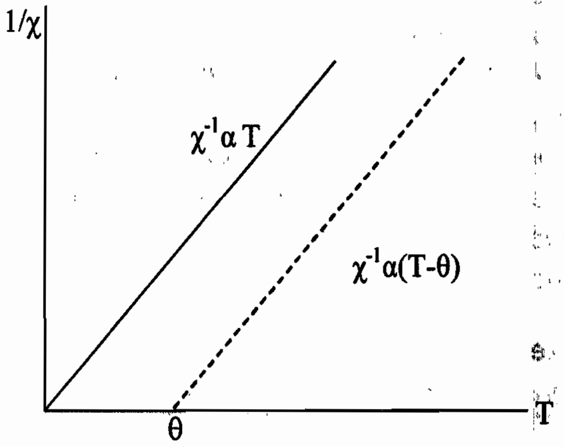

Fig.3: The linear plot of the inverse of paramagnetic susceptibility against temperature

At temperatures above the Neel temperature (T_N) and Curie temperature (T_c) respectively, both antiferromagnets and ferromagnets behave as paramagnets with 1/χ linearly proportional to temperature. They can be distinguished by their intercept on the temperature axis, T = θ. Ferromagnetics have a large, positive θ, indicative of their strong interactions. For paramagnetics θ ≈ 0 and antiferromagnetics have a negative θ. The objective of this research is to investigate the characteristic curve of magnetic susceptibility versus temperature for representative rocks samples selected from within the Zaria granite. This will be used to determine the Curie point temperature and to identify the magnetic minerals present.

Rock Units and Petrography Within the Study Area

The Basement complex of Nigeria is polycyclic and retains memories of events dating back to about 3000 m. y. As in other parts of Africa, it suffered its most pronounced deformation and remobilisation during the Pan African Orogeny (about 650-450 m. y. ago). During this period the tectonics associated with this Orogeny imparted a platy foliation now observed in the syntectonic Older Granite as well as other textural features that can be related to it. A review of the geology of this terrain (Odeyemi, 2005) has shown that the basement may have belonged to the 1300-900 m. y. Kibaran Orogeny.

The Zaria granite batholith (Fig.4) belongs to a suite of syn and late tectonic granites that marked the intrusive phase of the late Pre-Cambrian to early Paleozoic Pan African orogeny in Nigeria (Mccurry, 1973). These granites and granodiorites intruded low grade meta-sediments and gneisses and were collectively called the 'Older Granites' to distinguish them from the Mesozoic 'Younger Granite' (Falconer, 1911) of the Jos Plateau. The main rock types are:

(1)Porphyritic biotite granites

(2) Medium to coarse biotite granites

(3) Biotite microgranites

Petrographic studies carried out during the cause of this work indicate that the rock contains essentially microcline, plagioclase, quartz, biotite and orthoclase feldspar with microcline and quartz predominating. The microcline crystals are clear and have grain sizes of 2-20mm in length. Inclusions of plagioclase are common in the microcline. Quartz occurs both as phenocryst and aggregates in the ground mass. The crystals rarely exceed 2mm in diameter. There are two varieties of plagioclase phenocrysts: those that occur interstitial to quartz and biotite and those that are enclosed by microcline. The biotites occur as brown laths oriented in one direction accounting for the foliation observed within the rock. Orthoclase crystals are few and they occur as inclusion within the microcline phenocrysts, also a few brown flakes of chlorite are formed due to alteration of biotite caused by insipient weathering.

Data Collection and Experimentation

The rock samples used in this research were those collected for anisotropy of magnetic susceptibility studies.

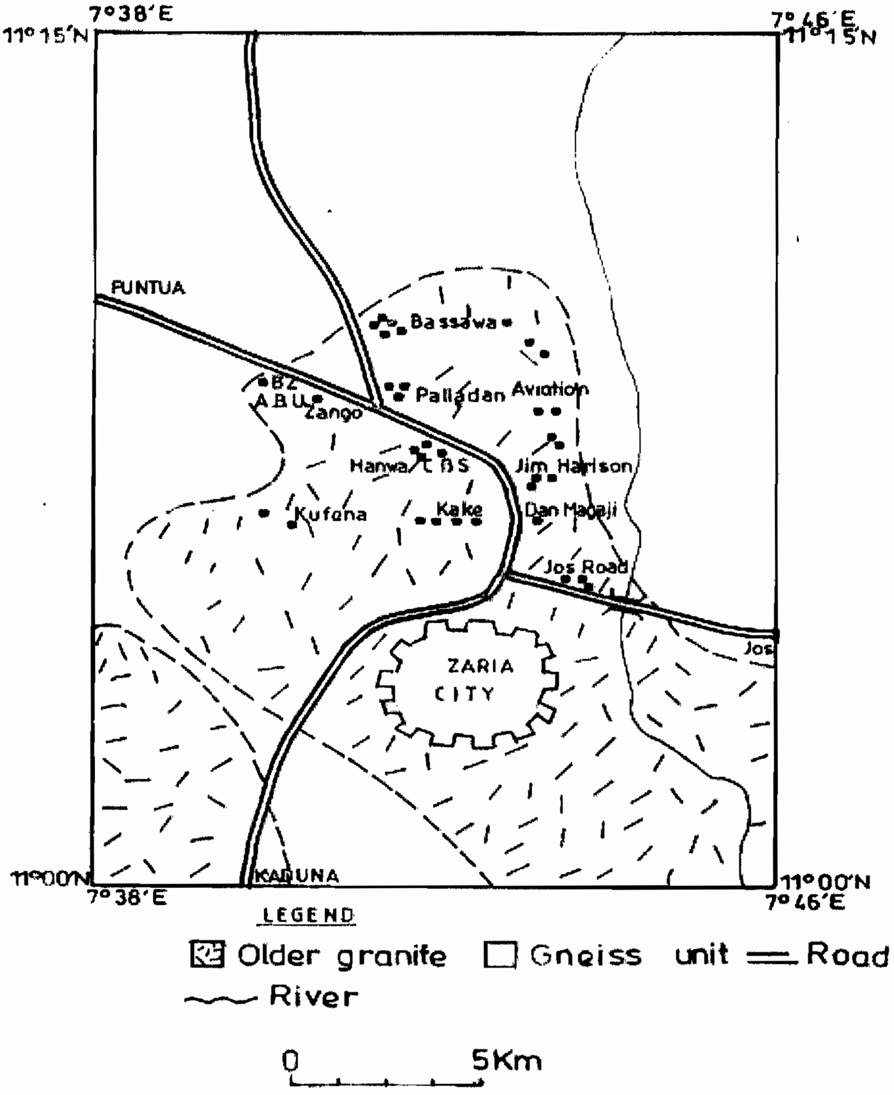

Fig.4: Geology map of the study area showing the sampled points

. They are cylindrical in shape and having dimensions 25 mm by 22 mm. The magnetic susceptibility of the samples was determined using the Bartington MS2B sensor operating at low frequency. The temperature dependence of magnetic susceptibility experiment was carried out on representative samples using the Bartington MS2X/T system (Fig.2). The samples were frozen in the refrigerator to nearly 0°C and then quickly transferred to the water (MS2W) sensor connected to the MS2WF furnace and linked via a MS2 meter to a computer operating with GEOSOFT software. The furnace was set to read temperature from 0°C to 700°C at a changing rate of 10°C/min and then cooled back to room temperature at the same rate. The GEOSOFT prompt the operator to select the correct thermocouple, set the power supply to a rising or falling ramp and collects the magnetic susceptibility measurements as a function of temperature.

Magnetic Susceptibility

The magnetic susceptibility values ranges from 29×10^{-6} SI to 3506×10^{-6} [SI], with an average value of 684×10^{-6} [SI]. The study area consisted basically of three types of rocks; the coarse pophyritic biotite granite, the medium grained biotite granite and the fine grained biotite granite (microgranite). The magnetic susceptibility was found to depend on the amount of magnetite captured in each sample. The coarse pophyritic biotite in which magnetite is well captured as revealed in the thin section observation shows high magnetic susceptibility values ranging between 716×10^{-6} to 3506×10^{-6} [SI]. In the medium grained granite the magnetic susceptibility values are moderate, ranging between 127×10^{-6} and 525×10^{-6} [SI]. The least values of magnetic susceptibility occur in the microgranite samples, ranging between 29×10^{-6} and 111×10^{-6} [SI].

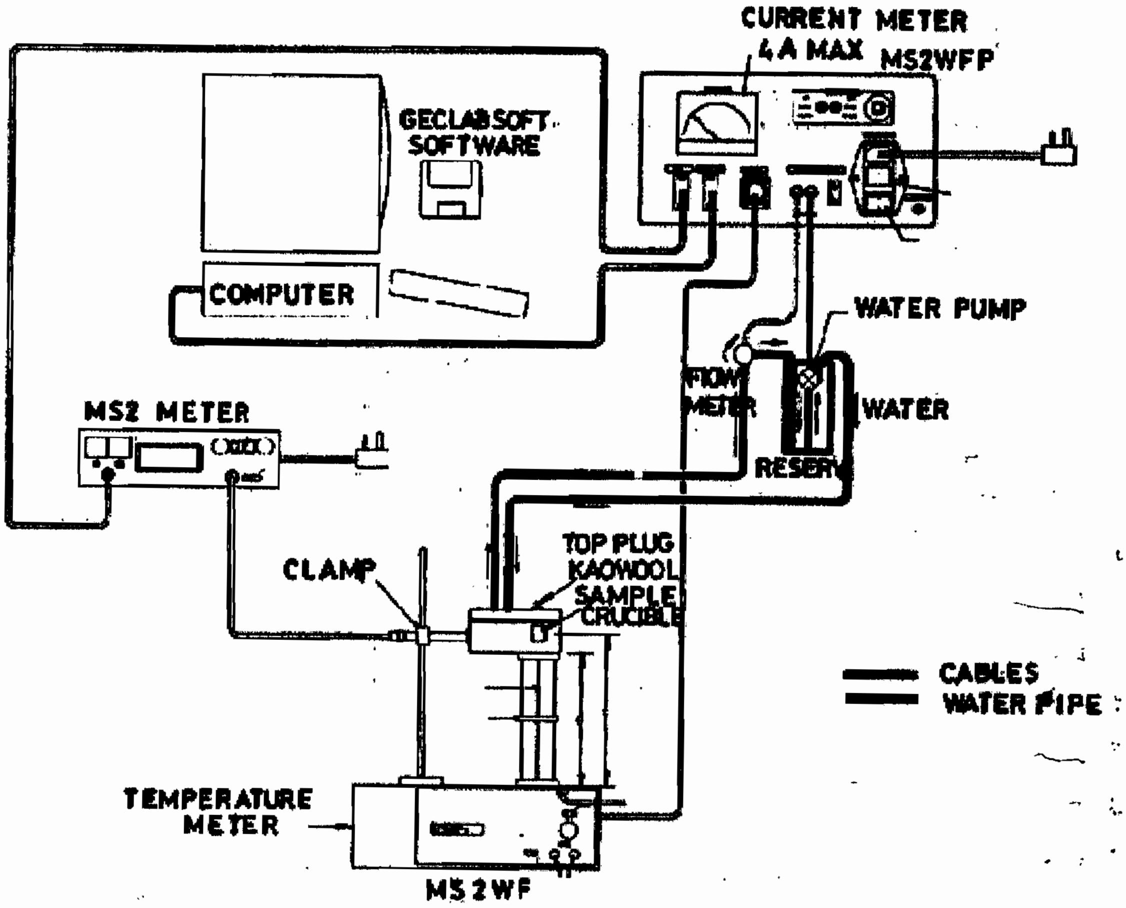

Fig.5: (MS2X/T) Susceptibility/temperature interconnection diagram (MS2 manual)

Thermomagnetic Experiment

The measurement of magnetic susceptibility reveals that its value is dependent on concentration of magnetic minerals; therefore three samples, one each from the rock types were considered for the temperature dependence studies. The three samples considered are sample KUF03 with magnetic susceptibility value 803 x 10^{-6} SI, DAN02, 1388 x 10^{-6} SI and HAN10 having magnetic susceptibility of 58 x 10^{-6} SI. The result is shown in figs. 6, 7 and 8.

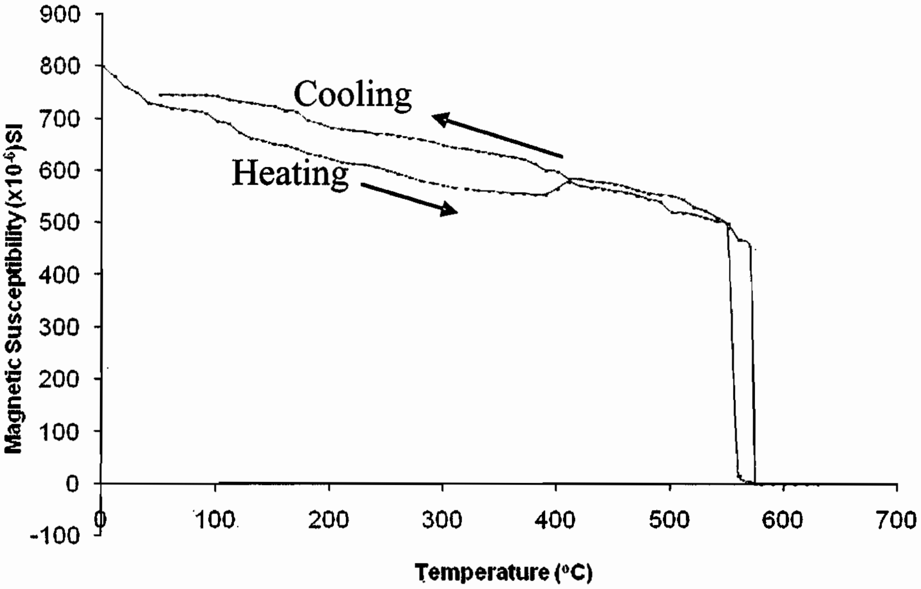

Fig.6: Variation of magnetic susceptibility against temperature for Sample KUF03.

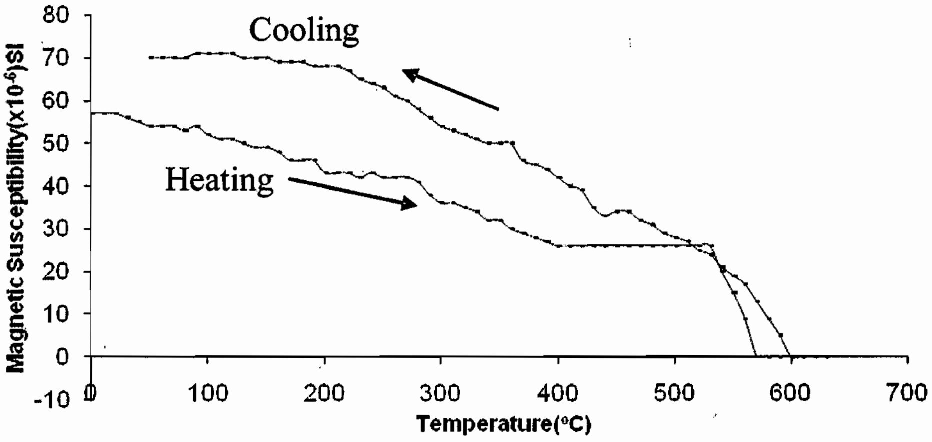

Fig.7: Variation of magnetic susceptibility with temperature for sample HAN10

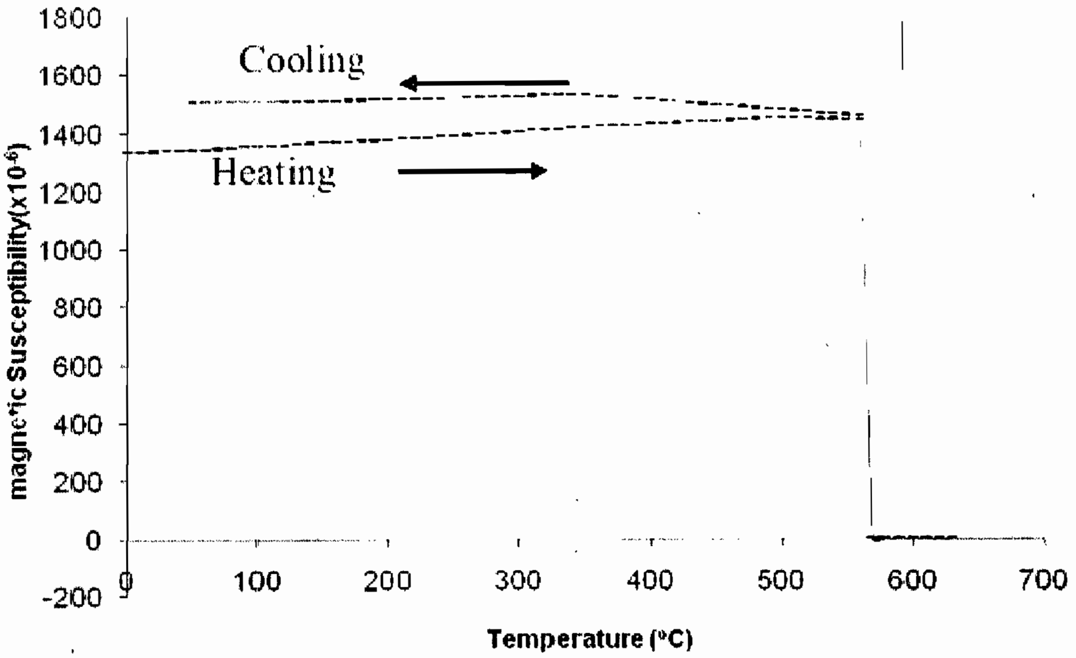

Fig.8: Variation of magnetic susceptibility with temperature for sample DAN02.

Discussion

Figures 6, 7 and 8 show the results of the thermomagnetic experiments. The three samples represents the general behavior of almost all the rocks sampled, hence the adoption of the curves for the general trends. .In Fig.6 and Fig.7 the magnetic susceptibility decreases as the temperature increases and then suddenly drops to zero at a temperature of about 575 ± 5°C. The decrease of magnetic susceptibility as the temperature is increased is an indication that the magnetic susceptibility in the sample is controlled mainly by paramagnetic mineral (Ferré *et al.*, 1999; Siegesmund and Becker, 2000, and Zananiri *et al.*, 2004,) biotite which occur as a major mineral in the study area. The sudden decrease of magnetic susceptibility to zero at 575± 5°C, a Curie temperature typical of magnetite reveals the contribution of a trace amount of a ferromagnetic phase to the magnetic susceptibility. The Curie temperature of this phase suggests that it is magnetite, most likely may have occurred as micro-inclusion within biotite crystals. The cooling also follow the same path but with an increased value of magnetic susceptibility which is as a result of oxidation of magnetite to most likely haematite (Ferre *et al.*, 1999). Figures 8 is characerised by a fairly constant magnetic susceptibility until the Curie point at about 575 ± 5°C after which it drops. This behavior reflects that the magnetic susceptibility in this sample is controlled by the presence of ferromagnetic mineral.

Conclusion

The research has shown that the main magnetic carrier responsible for the magnetic susceptibility is paramagnetic minerals. From Petrographic and trace mineral studies carried out during the course of this work, the major paramagnetic mineral occurring within the study area is biotite, hence may have controlled the magnetic susceptibility. The sudden decease to zero of magnetic susceptibility at a Curie temperature typical of magnetite 575±5°C which indicates that magnetite, most likely as an inclusion within the biotite crystal, occurs as a trace ferromagnetic mineral.

Acknowledgment

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