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Preliminary report on magnetic susceptibility measurements on rocks within the Zaria granite batholith, Nigeria

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Low field magnetic susceptibility measurements have been carried out within the Zaria granite batholith. The result has shown that magnetic susceptibility within the batholith varies between 29 10^{-6} SI to 3506 10^{-6} SI, with an average value of 684 10^{-6} SI. The large variation in the measured values of the susceptibility is as a result of large variation of magnetic mineral content within an outcrop and the diversity of rock types within individual suite. Thin section observation of representative samples shows the major mineral to be feldspar, quartz and biotite, while magnetite, ilmenite and hematite occur as trace minerals. The frequency distribution shows a bimodal distribution, which is typical of granites due to a low-k peak for paramagnetic dominated specimens and high-k peak for magnetite/hematite dominated specimens. The occurrence of hematite and ilmenite may be due to the alteration of magnetite.

Keywords – magnetic susceptibility, paramagnetic, magnetite, Zaria, granite, batholith

1. Introduction

The magnetic properties describe the behavior of any substance under the influence of magnetic field. The magnetic properties of rocks arise from the magnetic properties of the constituent mineral grains and crystals. Typically, only a small fraction of the rock consists of magnetic minerals, and hence this small portion determines the magnetic properties and the magnetization of the rock as a whole.

The magnetic properties within a rock type can be quite variable (Carmichael, 1989) depending on chemical inhomogenity, depositional and/or crystallization, and post-deformational conditions. The mineral contribution to the magnetic susceptibility of a rock has been widely given in literature (e.g. Thompson and Oldfield, 1986; Lowrie, 1990; Schön, 1996). The values of magnetic susceptibility depend on the grain size, the presence of minute crystal lattice, such as dislocations, lattice vacancies, impurities, etc., and an amount of iron ore in a sample. Magnetic susceptibility analyses found various applications in different fields of geophysics including geophysical prospecting, mineral exploration, palaeomagnetism, archaeology, rock magnetism and environmental magnetism.

Therefore the aim of this research work is to determine the magnetic susceptibility of rocks within the study area, and to identify magnetic minerals present in the samples contributing to the magnetic susceptibility. The data base for magnetic susceptibility values for various types of rocks found in the Zaria granite batholith will be made available through the Advanced Geophysical Research Laboratories, Department of Physics, Ahmadu Bello University, Zaria. These data will mainly be used as supportive information for the interpretation of airborne aeromagnetic geophysical data within the studied area.

2. Geological settings, rock types and structures

The study area (Figure 1) lies between latitude 11 00’ N and 11 15’ N and longitudes 7 38’ E and 7 46’ E covering some parts of the Zaria granite batholith. The Zaria Granite Batholith belongs to a suite of syn to late tectonic granites and granodiorites that marked the intrusive phase of the late Pre-Cambrian to early Paleozoic Pan African orogeny in Nigeria (McCurry, 1973). These granites intruded low grade metasediments and gneisses and were collectively called »Older Granite« to distinguish them from Mesozoic »Younger Granites« (Falconer, 1911) of the Jos Plateau and surrounding areas.

The Pan African orogeny was dated 850 to 467 Ma and the Older Granites 618 to 467 Ma (Grant, 1969) using the Rb-Sr method. Ogezi (1977) used the same method to date a suite of aplite/pegmatite, medium to fine grained, and pophyritic rocks where he obtained an age of 500 Ma and the porphyritic main rock as the host to other rocks 790 Ma. Ogezi (1977) concluded that the intrusion of the older granites must have started much earlier than generally thought.

The main rock unit of the batholith is coarse porphyritic biotite granite which is distinctly foliated in the field. The foliation is broadly oriented north-south and marked by sub parallel alignment of elongated and closely packed feldspar phenocryst, mainly microcline and a corresponding preferred orientation of biotite mica. Xenolith of gneisses and micro- as well as mafic clots in various stages of digestion also occur in the rock. These bodies conform in orientation to the general foliation trend. One variant of the granite can be found exhibiting a less distinct foliation most probably due to sparse distribution of the feldspar phenocryst.

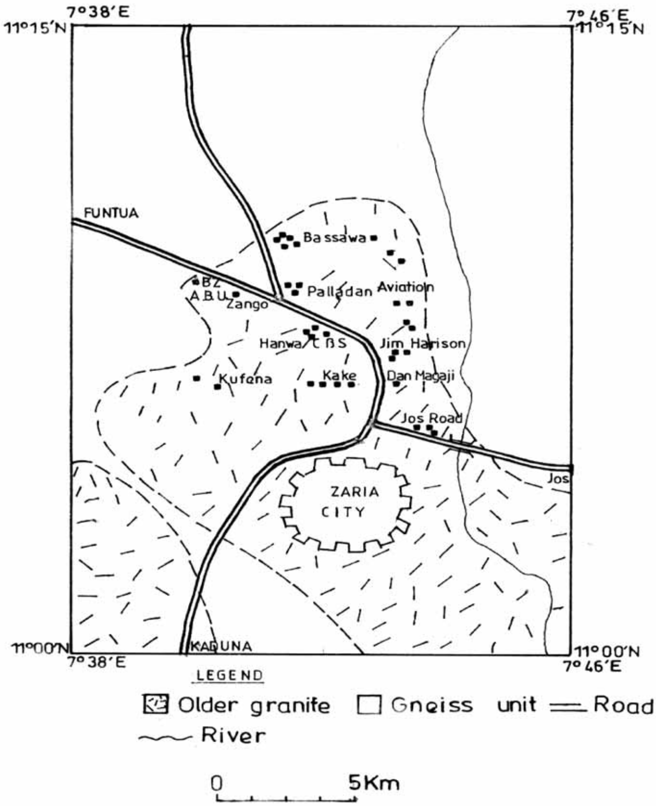

Figure 1. Geological map of the Zaria granite batholith showing the rock exposures studied.

Close to the margin of the batholith, the granite tends to become rather granodioritic. The type locality is the River Kubani valley exposure of the western boundary of the batholith near Ahmadu Bello University (ABU) main campus. At this point, the batholith is in contact with local basement schist and there is an interbanding between the granite and the host schist. These interbanded rocks dip uniformly at 56° to the west. A similar phenomenon was reported by Webb (1972) in another contact area in the north near Wurara.

3. Microscopic description and trace minerals identification

The petrogenesis of the Zaria biotite granite had been reported by Ike (1974). The porphyritic biotite granites were intruded under the control of preexisting structures in the gneissic basement, already dictated by the prevailing Pan African orogeny (618–480 m.y.) whose culmination and warning was marked by the intrusion of the Older Granites. Therefore, according to Ike (1974), their concordance with the basement structures does not make the older granites products of »*in situ*« processes.

Petrographic studies of each of the rock units were carried out during the course of this research. This was done by observing the thin sections of some of the representative samples under reflected light. The study revealed that porphyritic biotite granite contains essentially microcline, plagioclase, quartz, biotite and orthoclase feldspar with microcline and quartz predominating. The microcline crystals are clear and have grain sizes of 2–20 mm 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 2 mm 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. Few brown flakes of chlorite formed due to alteration of biotite caused by insipient weathering were seen.

The medium to coarse grained biotite granite consists of crystals of feldspars, microcline, orthoclase, oligoclase together with quartz and biotite. Accessory minerals include zircon, apatite, allanite and magnetite. Secondary minerals include hematite, chlorite and clay minerals.

Table 1: Description of samples and trace minerals extracted from decomposed granites of the Zaria batholith.

Sampling locality	Sample identification	Rock unit description	Heavy mineral assemblage recovered
Jim Harrison granite pavement	A	coarse-graind porphyritic biotite granite	magnetite, trace ilmenite, zircon and biotite
Dan Magaji quarry	B	coarse grained – grained foliated biotite granite	magnetite, zircon, ilmenite
Zango granite exposure	C	medium grained foliated biotite granite	ilmenite, magnetite, hematite, biotite, trace tourmaline
Aviation site II quarry	D	coarse grained biotite granite	magnetite, ilmenite, biotite, zircon, hematite
Kufena Hill	E	foliated medium grained granite	ilmenite, magnetite, garnet, biotite and hematite
Jos road (Panzazzau granite)	F	coarse grained pink feldspar granite	magnetite, hematite, ilmenite, zircon and biotite
Hanwa granite	G	coarse grained granite	magnetite, biotite, ilmenite, zircon, hematite
Basawa road granite pavement	H	coarse grained foliated biotite granite	ilmenite, magnetite, biotite and tourmaline

Microscopically, the microgranite essentially contains quartz, plagioclase and biotite.

Trace mineral analysis was carried out on eight samples of decomposed granite collected at different locations across the Zaria granite batholith for the purpose of the above study. One kilogram of the decomposed granite was collected from each site and the trace minerals were separated using hand panning technique. The disaggregated samples were placed inside a prospector's pan and then washed with stream water. During the washing process light minerals such as quartz, decomposed feldspars, some biotite and chlorite were reduced considerably. The residue was mainly an assemblage of heavy trace minerals with some grains of quartz and feldspars as impurities. The residue was hand picked under the binocular microscope.

The method for the identification of the trace minerals was by observing the properties of each mineral such as color, crystal shape and cleavages using the binocular microscope and hand lens. The samples and the heavy minerals separated are described in Table 1.

4. Principle and measurement of magnetic susceptibility

Magnetic susceptibility is the degree of magnetization of a material in response to an applied magnetic field. The volume magnetic susceptibility, represented by the symbol K is defined by the relationship

$$\boldsymbol{M} = K\,\boldsymbol{H}$$

where,

$\boldsymbol{M}$ is the magnetization of the material (the magnetic dipole moment per unit volume), measured in amperes per meter, and

$\boldsymbol{H}$ is the applied field, also measured in amperes per meter.

Both quantities are measured in SI units

The magnetic induction $\boldsymbol{B}$ is related to $\boldsymbol{H}$ by the relationship

$$\boldsymbol{B} = \mu_0(\boldsymbol{H} + \boldsymbol{M}) = \mu_0(1 + K)\boldsymbol{H} = \mu\boldsymbol{H}$$

where μ_0 is the permeability of free space (4π 10^{-7} Henry/m), and is the relative permeability of the material.

If K is positive, then $(1+K)$ greater than 1 and the material is called paramagnetic. In this case, the magnetic field is strengthened by the presence of the material. Alternatively, if K is negative, then $(1+K)$ less than 1, and the material is diamagnetic. As a result, the magnetic field is weakened in the presence of the material.

The contributions at low field to magnetic susceptibility are summed up as shown (Rochette, 1994).

$$K_{lf} = K_d + K_p + K_{af} + K_f$$

where the successive right-hand terms are the diamagnetic, paramagnetic, antiferromagnetic and ferromagnetic response of the sample. This approach is appropriate where one can measure each of the magnetic response directly, and requires the application of high fields (Borradaile and Henry, 1997). However, one cannot associate each term directly with a particular mineral, which is paramount in petrofabric interpretation. This is because all minerals provide a minuscule diamagnetic response and paramagnetic silicates will usually yield significant ferromagnetic response from their inclusions.

5. Methodology

Ten outcrops (site) located within the study area were considered for the study. Cylindrical samples were collected from each site, in conformity with the normal procedure of sample collection in paleomagnetic studies. Depending on the size of the outcrop at-least ten (10) samples were cored randomly to cover the site. 110 sampled points were obtained, each sample were then cut into two specimens giving a total of 220 specimens. Out of this, only 200 were found suitable for further work. The magnetic susceptibility for each of the 200 specimens was measured using the Bartington MS2B sensor, operated at low frequency, and connected to MS2 meter linked to a computer operated using the Multisus2 for windows software.

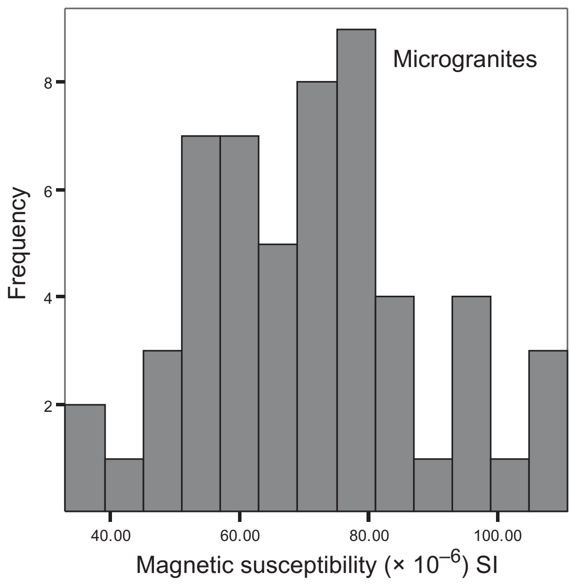

Figure 2. Frequency distribution plot for microgranites.

6. Results

The result shows that the magnetic susceptibility measured within the study area ranges from 29 10^{-6} SI to 3506 10^{-6} [SI], with an average value of 684 10^{-6} [SI]. From the thin section observations 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 (micrograaite). The coarse pophyritic biotite shows high magnetic susceptibility values ranging between 716 10^{-6} to 3506 10^{-6} [SI]. In the medium grained biotite 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 micrograuite samples, ranging between 33 10^{-6} and 111 10^{-6} [SI]. The frequency distribution for each of the rock types are given in Figures 2, 3 and 4.

7. Discussion

Thin section study of the rock representative samples in the study area reveal three major minerals, these are; feldspar, quartz and biotite as the only opaque mineral. The trace minerals recovered from the decomposed granite shows that magnetite, ilmenite, hematite and biotite occur in all the investigated sites as trace minerals. Rock magnetic susceptibility studies combine magnetic contributions of the mineral which constitute the rock unit, there-

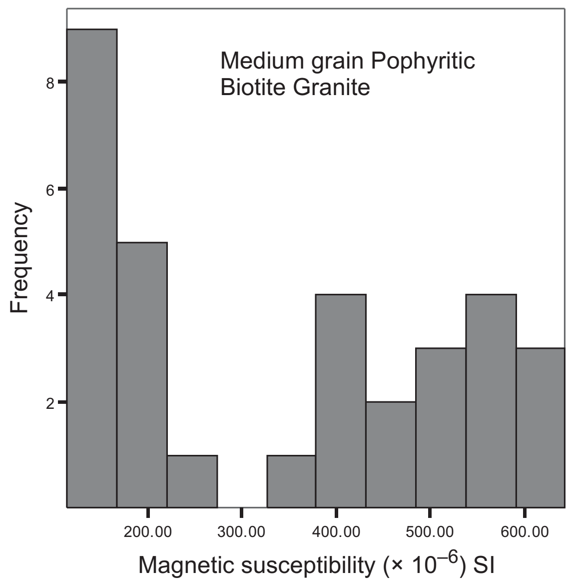

Figure 3. Frequency distribution plot for medium grain biotite granites.

fore, the contributions to the magnetic susceptibility and magnetic anisotropy are due to the occurrence of these minerals.

The diamagnetic contribution originates from feldspar and quartz. The quartz has an intrinsic magnetic susceptibility of –13.4 10^{-6} [SI] (Hrouda, 1986) and –2.76 10^{-6} [SI] for feldspar (Borradaile et al., 1987). These values are normally negligible in tectonic studies (Borradaile and Henry, 1997). Hence the magnetic contributions to the magnetic susceptibility within the study area are due to the paramagnetic mineral, biotite, a major mineral in the study area and the trace ferromagnesian minerals; magnetite, hematite and ilmenite. The magnetic susceptibility K, values obtained for the coarse porphyritic biotite is reasonable because the magnetite which occurs as a trace mineral is well captured in the sample. Some of the specimens also show some degree of contamination by hematite. This contamination may be due to the oxidation of magnetite to hematite and may have been responsible for the brownish colourations observed in some of the specimens.

The magnetic susceptibility of the different rock types identified within the study area is indicated on the histograms (Figures 2, 3 and 4). The frequency distribution of each of the rock types forming the crystalline basement is a variable modal, reflecting the combined effect of three factors which are not easily distinguishable i.e., random error of measurements, variation of mineral content within an outcrop and the diversity of rock types within each individual group of rocks. According to Ajakaiye, (1989), this heterogeneity of the basement complex is a result of various orogenic activity of the past.

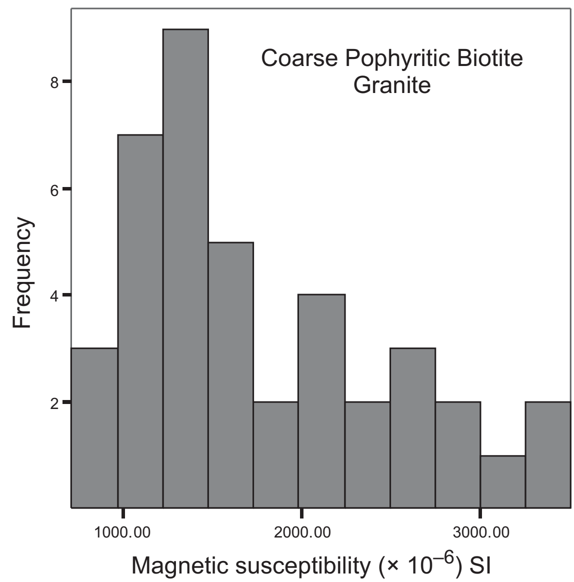

Figure 4. Frequency distribution plot for coarse pophyritic biotite granites.

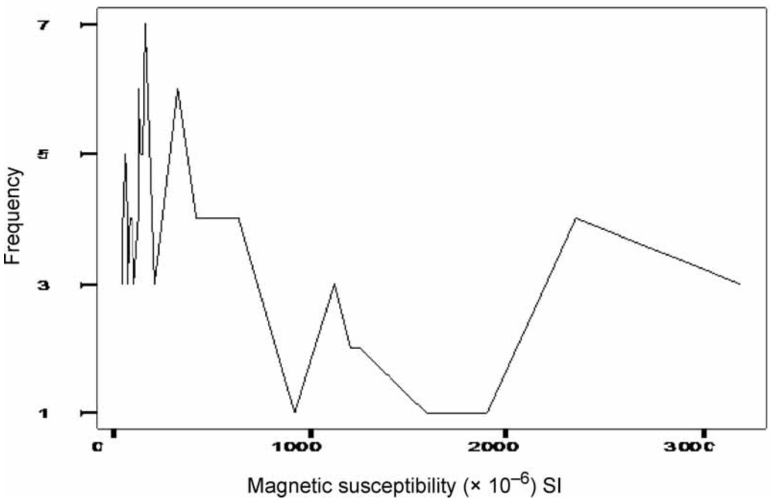

Figure 5. Frequency distribution of mean magnetic susceptibility.

The behavour in Figure 5 of the plot of frequency versus mean magnetic susceptibility for all the specimen of rocks also shows a non uniform composition of magnetic minerals within the study area. The bimodal nature of the distribution is typical of granite, which is due to a low magnetic susceptibility peak (low-*k*) for paramagnetic dominated specimens and high susceptibility (high-*k*) for magnetite/hematite dominated specimens. The mean susceptibility value of 684×10^{-6} [SI] is an indication that the magnetic susceptibility is controlled by paramagnetic minerals.

8. Conclusion

This research work has revealed that the volume susceptibilities K from the investigated samples range from 29 10^{-6} SI to 3506 10^{-6} [SI], with an average value of 684 10^{-6} [SI]. The research has shown that the magnetic susceptibility within the study area is controlled mainly by paramagnetic mineral. It also shows that 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).

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SAŽETAK

Preliminarno izvješće o mjerenjima magnetske susceptibilnosti granit-batolit stijena na području Zarie u Nigeriji

S. A. Oniku, I. B. Osazuwa i O. C. Meludu

Mjerenja susceptibilnosti u slabom magnetskom polju provedena su na granit-batolit stijenama u Zariji. Rezultat je pokazao da se magnetska susceptibilnost batolita mijenja između 29 10^{-6} SI i 3506 10^{-6} SI, sa srednjom vrijednošću od 684 10^{-6} SI. Široki interval mjerenih vrijednosti susceptibilnosti posljedica je velike raznolikosti magnetskih minerala unutar izdanka i raznovrsnosti tipova stijena. Proučavanje reprezentativnih uzoraka tankog presjeka pokazuje da su glavni minerali feldspat, biotit i

kvarc, dok su magnetit, ilmenit i hematit minerali u tragovima. Raspodjela učestalosti je bimodalna, koja je tipična za granite zbog niskog k-šiljka kod dominirajućih paramagnetskih uzoraka i visokog k-šiljka kod magnetita/hematita.
Hematit i ilmenit mogu se pojaviti zbog trošenja magnetita.

Ključne riječi: magnetska susceptibilnost, paramagnetičnost, magnetit, Zaria, granit, batolit

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