DETERMINATION OF EMPLACEMENT DIRECTION OF ZARIA GRANITE BATHOLITH USING THE ANISOTROPY OF MAGNETIC SUSCEPTIBILITY (AMS) METHOD

[1]A.S. Oniku, [2]I.B. Osazuwa and [1]O.C. Meludu
[1]Dept of Physics, Federal University of Technology, Yola, Nigeria
[2]Dept of Physics, Ahmadu Bello University, Zaria, Nigeria
E-mail: adetolaoniku@yahoo.co.uk

(Submitted: 12 February, 2008;Accepted:24 May,2008)

Abstract

The anisotropy of Magnetic Susceptibility (AMS) has been used as a proxy in the determination of the emplacement direction of the Zaria granite batholith. The study has been able to establish the North-South trend of the batholith with the principal susceptibility tensors (K_{max}, K_{int}, K_{min}) corresponding to the tectonic axes. The K_{max} axes indicate a north-south trend corresponding to the geologically observed mineral alignment and hence to the direction of minimum stress which occurred during the Pan-African Orogeny (618±480 Ma) and the K_{min} reflects the direction of maximum stress.

Keywords: *Anisotropy of magnetic susceptibility, emplacement direction, granite batholith, mineral alignmen and tectonic axis*

Introduction

The granitic rocks occurring in form of inselbergs, whalebacks, granite pavements and isolated blocky hills found in Zaria and surrounding regions are regarded as a single batholith (Fig.1). This batholith initially known as the "Zaria Granite' is one of the elongate north-south oriented granite bodies concordantly emplaced in the preexisting gneisses of the Degree Sheet 21, Zaria (McCurry,1970,1973). The currently used term 'Zaria Granite Batholith' was proposed by Webb (1972).

The recognized extent of the batholith indicates that it is at least 90 km long and up to 22 km wide. It extends southward from the northern part of Zaria up to Katabu in the vicinity of Kaduna. The intense regional tectonism and resultant deformation that accompanied the emplacement of the Older Granite during the Pan-African orogeny produced a well defined and extensive N-S trend in north central Nigeria including the Zaria area (Russ, 1959; Truswell and Cope, 1963; Grant, 1969; McCurry, 1973 and

Ogezi, 1977).

The purpose of this study is therefore to provide a complimentary explanation to the geologically observed structural trend associated with the Zaria Granite Batholith using the anisotropy of magnetic susceptibility (AMS) with the aim of establishing the emplacement direction which occurred during the Pan-African Orogeny.

Magnetic susceptibility (K) is the measure of magnetic response of a material to an external magnetic field. Anisotropy of Magnetic Susceptibility arises from the orientation of the crystallographic axes of minerals, which often control shapes of grains (Rochette *et al.*, 1992). Studies by Khan (1962) have shown that crystallographic axes correspond to the principal axes of the AMS ellipsoid. AMS has been widely used as a proxy for deducing the emplacement direction of dikes, basaltic and granitic bodies (Rochette *et al.*, 1992; Borradaile and Henry, 1997; Bouchez, 1997; Eric *et al.*, 1999; Siegesmund and Becker, 2000 and Eric *et al.*, 2002). It has also been used to determine flow directions in rhyolite flows (Dhiren, 2006).

Geological Settings of the Study Area

The Zaria Granite Batholith 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 referred to as the 'Older Granites' to distinguish them from the Mesozoic 'Younger Granite' (Falconer, 1911) found in the Jos Plateau. The Pan-African Orogeny was dated at 618 to 480 M.a. (Grant, 1969) using the Rb-Sr dating technique. Figure 1 is the geological map of part of Zaria batholith showing the various outcrops where samples were collected.

The petrogenesis of the Zaria biotite granite was studied 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.

Russ (1959), Truswell and Cope (1963) and McCurry (1973), carried out structural and tectonics studies of the region and concluded that the intense regional metamorphism preceded and accompanied the emplacement of the older granites which resulted in a pronounced and widespread North-South trend in the North Central Nigeria including Zaria and Niger Provinces.

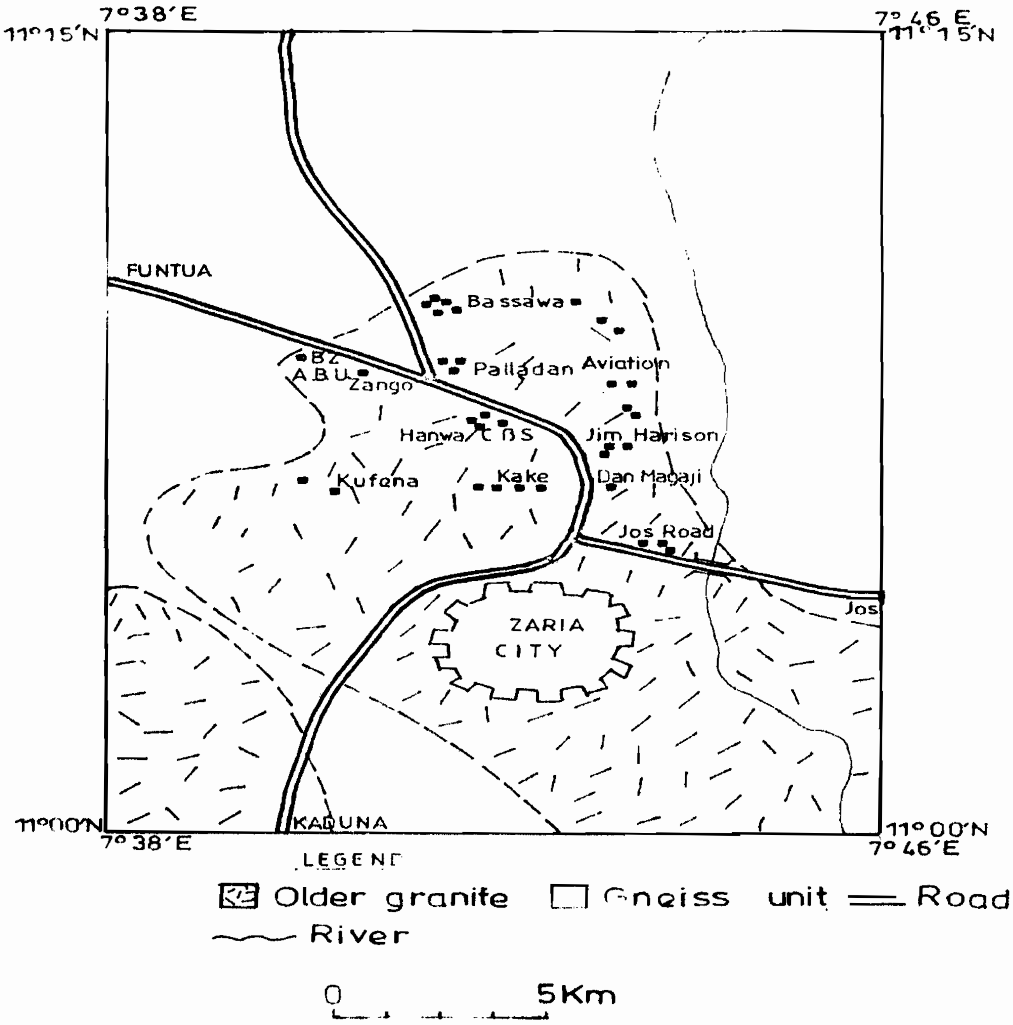


Fig.1: Geological map of the Zaria granite batholith showing the rock exposures studied.

Methods

Oriented core samples were collected from 10 different outcrops located within the study area. At each outcrop, cores were drilled at different points scattered randomly on the outcrop. At each point, core with diameter 30 mm, long enough to yield two specimens were obtained using the gasoline powered, water cooled portable acker drill equipment model Packsack Diamond core drill. The cores of 30 mm diameter were trimmed to 25 mm diameter, and cut to a length of 22 mm to conform to the length/diameter ratio of 0.85 of Noltimier (1971). A total of 200 cylindrical samples close enough to perfect cylindrical shape of 25 mm x 22 mm (standard paleomagnetic samples) were obtained.

The anisotropy of magnetic susceptibility (AMS) measurements was carried out at the Advanced Geophysical laboratories, Department of Physics, Ahmadu Bello University, Zaria using the Bartington MS2 meter connected to MS2B sensor and connected to a computer running with the AMSWIN-BAR software. The MS2B sensor was used along with sample adaptors provided with the software. For the measurements of anisotropy, each sample placed in the adaptor was rotated about the three diagonal axes, and magnetic susceptibility measured in each of the three measurement planes. The output is a trend and plunge for each of the principal susceptibility tensors (i.e K_{max}, K_{int}, K_{min}), mean susceptibility, and the three axial ratios given as

$$Lineation = L = K_{max}/K_{int} \quad (1)$$

$$Foliation = F = K_{int}/K_{min} \quad (2)$$

$$Degree\ of\ anisotropy = P = K_{max}/K_{min} \quad (3)$$

Stereoplots of the principal tensors, K_{max} and K_{min} are plotted on lower hemisphere stereonet projections using the "Stereonet" software developed by Allmendinger (2002).

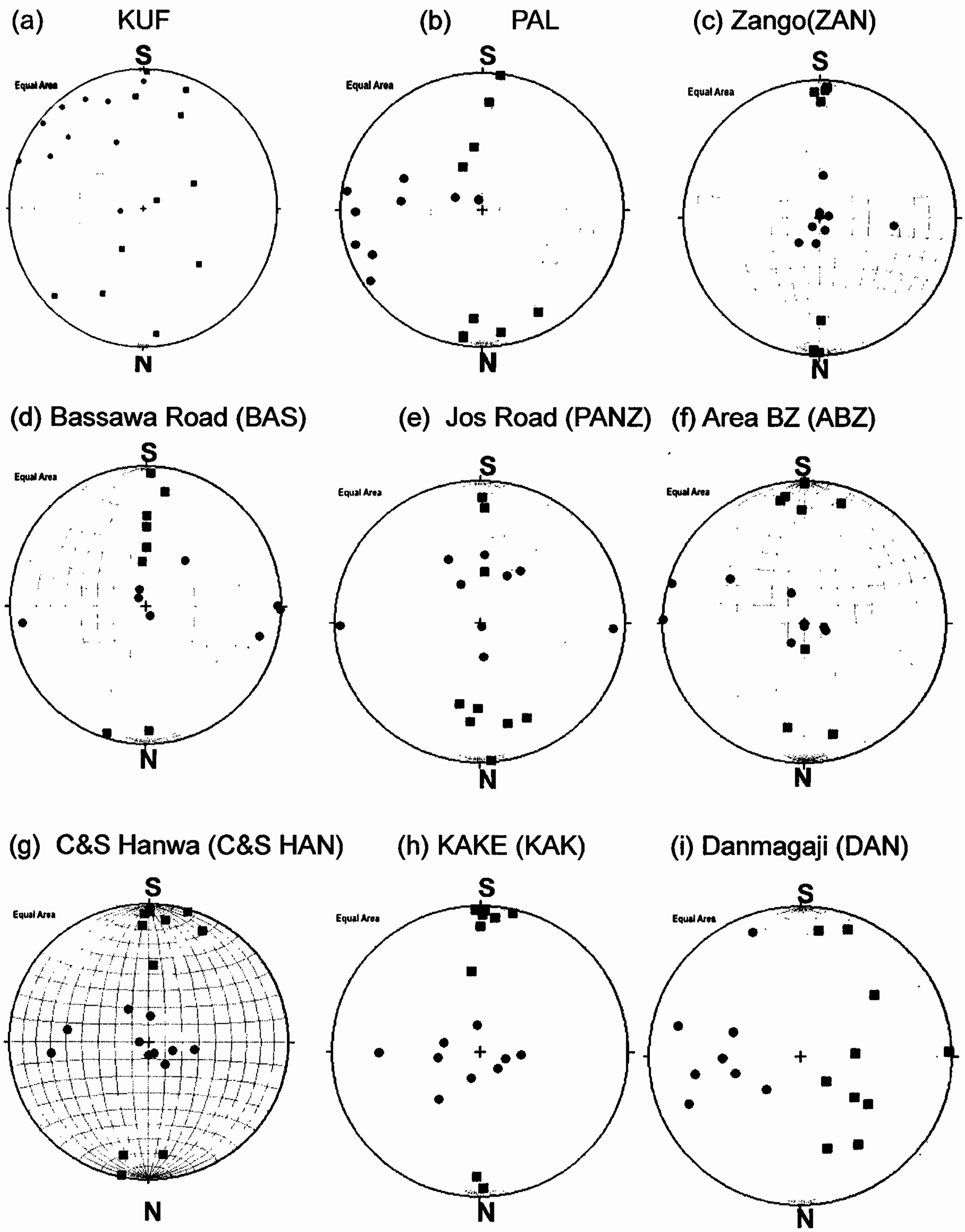
Results

The ideal result of AMS measurements would be an orthorhombic ellipsoid represented by orthogonal clusters of the principal tensors on a stereonet plot. Lower hemisphere projections for K_{max} and K_{min} for each of the ten outcrops investigated within the Zaria granite batholith are shown in Figures 2(a-j) respectively. All the ten outcrops consist of varying amounts of scatter in orientation of tensors. Apart from Figs 2(a) and 2(j), all others show noticeable north-south trend for most K_{max} axes. The K_{min} axes are least scatter showing clustering around the center of the stereonet in Figs 2.c, d, f and h. Figure 3 shows the stereonet for all the K_{max} and K_{min} axes for all the investigated outcrops.

Discussion

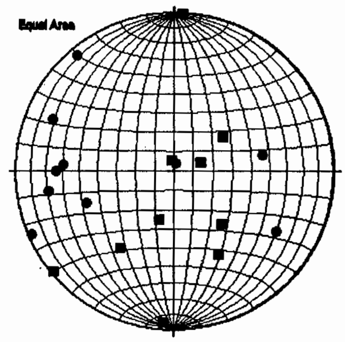
Khan (1962) has shown that K_{max} in flows is parallel to direction of flow. Therefore consistency in alignment of K_{max} is a good proxy for determining magmatic flow directions. Large scatter in AMS directions obtained from Figs. 2(I and X) makes it difficult to interpret a primary flow direction. The brittle nature of some of the samples could have also led to scatter, since some samples contained cracks, and chipped edges, formed during sample preparation. It is likely one or a combination of these factors contributed in the large observed scatter

(Dhiren, 2006). Also, the AMS ellipsoid combines contributions from several minerals whose individual AMS ellipsoids are of different shape, therefore, small variations in the proportions of the magnetic minerals change the shape of the rock's AMS ellipsoid even if the alignment process were of constant intensity (Borradaile and Henry, 1997).



(J) Jim Harrison

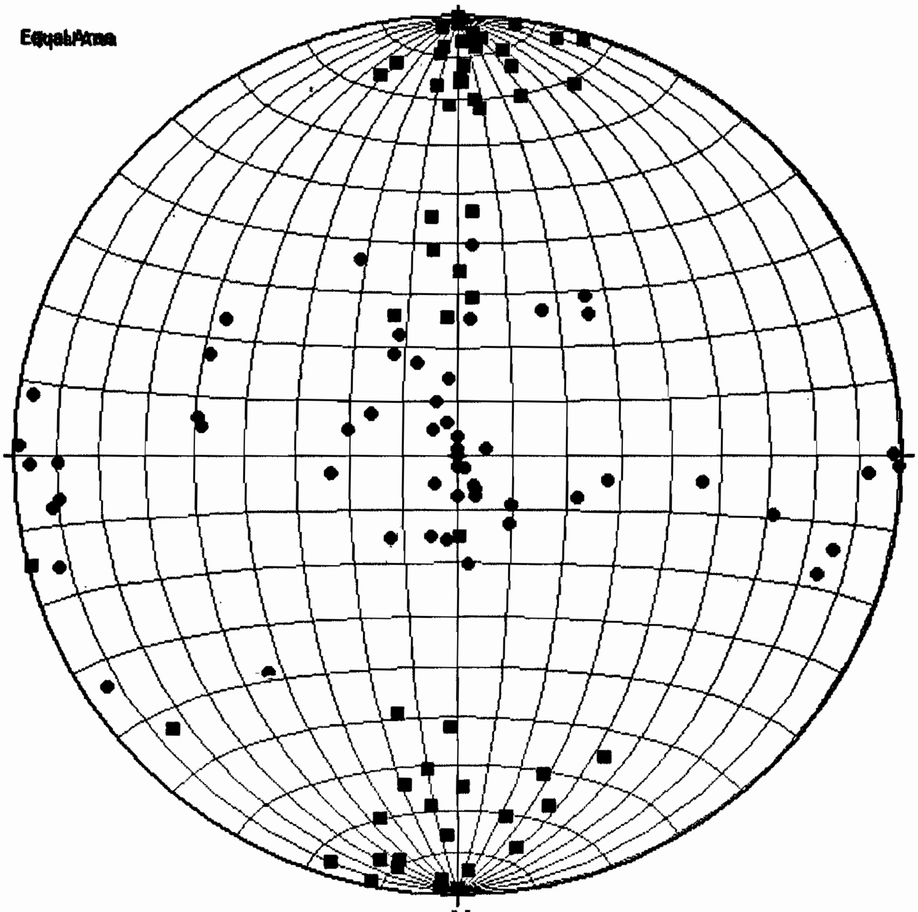
S



N

Figs.2: represents the stereonet for each of the outcrop (solid squares represent K_{max} while solid circles represent K_{min}).

S



N

Fig.3: Equal-area projection of the mean direction for K_{max} (solid squares) and K_{min} (solid circles) K_{max} shows the North-South trend of the Zaria Batholith and K_{min} the stress direction during the Pan-African.

However, the remaining Figs show a well defined pattern of arrangements of both K_{max} and K_{min} axes. The K_{max} axes which indicate the direction of movement of the fold of the batholith indicates a North-South trend corresponding to the geologically observed mineral alignment. According to Ike (1974), minerallogically defined foliation within the batholith may have resulted with the initiation from regional compression stress having an edge over that due to simple cooling history. The directions of the foliation were related to the orientation of the tectonic axes. The tectonic axes correspond to our principal susceptibility tensors (*i.e* K_{max}, K_{int}, K_{min}) and hence K_{max} correspond to the direction of minimum stress (flow direction) which occurred during the Pan African Orogeny and K_{min} reflects the direction of maximum stress. Fig. 3 combines all the plots in Fig.2, and shows the North-South direction, constrained for movement of magma indicated by K_{max}, while the East-West stress direction corresponding to the stress direction exerted by Pan African Orogeny on the batholith is indicated by K_{min} direction.

Conclusion

This study has shown that anisotropy of magnetic susceptibility could be a useful tool in the determination of the emplacement direction in granitic bodies. The study has been able to establish the North-South trend of the Zaria granite batholith with the principal susceptibility tensors (K_{max}, K_{int}, K_{min}) corresponding to the tectonic axes as suggested by Ike (1974). Thus, the study has shown that AMS principal directions can record flow-direction from magma, finite-strain directions and stress-directions from tectonized rocks. The study therefore agrees with the observed field direction of the batholith.

Reference

Allmendinger, R.W., (1992): Stereonet, V. 4.52. Program for the Macintosh Computer.

Borradaile, G.J., Henry, B., (1997): Tectonic Applications of the Magnetic Susceptibility and its Anisotropy. Earth Sci. Rev. 42, 49-93.

Bouchez, J.L., (1997): Granite is Never Isotropic: An Introduction to AMS Studies of Granitic Rocks. In: Bouchez, J.L., Hutton, D.H.W., Stephens, W.E. (Eds.), Granite: From Segregation of Melt to Emplacement Fabrics. Petrology and Structural Geology. Kluwer, Dordrecht, 95-112

Dhiren, R. P. (2006): Using Anisotropy of Magnetic Susceptibility to Determine Flow Directions of the Devil Track and Kinball Creek Rhyolites. 19th Annual Keck Symposium; http://keck.wooster.

Edu/publications

Ellwood, B. B., (1978): Flow and EmplacementDirection Determined for Selected Basalt Bodies using AMS Measurements: Earth & Planetary Science Letters, v. 41, p. 254-264.

Eric, F.C.,Jeff, W. and Gerard, G.,(1999): Magnetic Susceptibility of the Bushveld Alkaline Granites, South Africa. Tectonophysics. 307, 113-133.

Eric, F.C.,Cecile, B. and Julian S.M., (2002): Magma Flow Inferred from AMS Fabrics in a Layered Mafic Sill, South Africa. Tectonophysics. 354, 1-23.

Falconer, J. D. (1911): The Geography and Geology of Northern Nigeria. Macmillan, London.

Grant, N. K. (1969): The Late Precambrian to Early Paleozoic Pan-African Orogeny in Ghana, Togo, Dahomey and Nigeria. Bulletin geological society of America. 8.

Ike, E. (1974): The Structure, Petrology and Economic Geology of Part of the Zaria Granite Batholith: Unpublished B.Sc Thesis, Ahmadu Bello University, Zaria.

Khan, M. A., (1962): Anisotropy of Magnetic Susceptibility of Some Igneous and MetamorphicRocks: Journal of Geophysical Research, v. 55, p. 2873-2885.

McCurry, P.(1970): The Geology of the Degree Sheet 21,Unpublished M.Sc.thesis, Ahmadu Bello University,Zaria.

McCurry, F. (1973): Geology of Degree Sheet 21, Zaria Nigeria. Overseas Geology and Mineral esources.45.

Noltimier,H.C.,(1971):Determining Magnetic Anisotropy of Rocks with a Spinner Magnetometer giving in-phase and quadrature Data Output. J. geophys. Res 76, 4849-4854.

Ogezi,A.E.O, (1977): Geochemistry and Geochronology of Basement Rocks from North-Western Nigeria. Unpublished. Ph.D Thesis, University of Leeds.

Rochette, P., Jackson, M., Aubourg, C., (1992): Rock Magnetism and the Interpretation of Anisotropy of Magnetic Susceptibility: Reviews of Geophysics, v. 30, p. 209-226.

Russ, W. (1959): The Geology of parts of Niger, Zaria and Sokoto Provinces. Bulletin Geological Survey, Nigeria.27.

Siegesmund, S., and Berker, J.K., (2000):Emplacement of the Ardara pluton (Ireland): New constraints from magnetic fabrics and age dating. Int. J Earth Sci. 89, 307-327.

Truswell, J.F. & Cope, R.N. (1963): The Geology of Parts of Niger and Zaria Provinces, Northern. Bulletin Geological Survey of Nigeria.29

Webb, P.K., (1972): Recent research on the geology between Zaria and Kaduna. Savannah, Vol. 2 241-243.