Abstract: Evaluation of the length and orientation of the lineaments within Idanre area indicated that the dominant trend is ENE-WSW (80°–90°) – oblique to the long-axis of the batholith; while another is at NNW-SSE (170°–180°) and NNE-SSW (0°–10°) – parallel to the long-axis of the batholith. The ENE-WSW fractures represent those that developed due to shrinkage within the cooling batholith as the magma rose, while the other group (NNW-SSE and NNE-SSW) represents zones of weaknesses within the country rock at the time of intrusion of the magma. The results showed high density fracturing on the batholith, which is possibly related not only to its depth of emplacement but also to shrinkage effects due to compressive forces acting on the intrusive body at the time of its ascent. Also, the parallelism of some of the fractures with the long-axis of the batholith seems to indicate the influence of pre-existing zones of weaknesses in determining the tectonic grains of the batholith. The intrusion is fault-bounded and its fractures are very deep and they cut the batholith into massive, steep sided and dome-shaped inselbergs. They are conduits through which ore-bearing fluids can be channeled to the surface. It can therefore be concluded that a need for detailed exploration particularly along the fractures is necessary.

Keywords: Lineaments, Mineral exploration, Remote sensing, Tectonism, Hydrogeology.

1. Introduction

Crystalline rocks of the basement complex (Precambrian to Lower Paleozoic) outcrop over a large area of Nigeria in three broad shields and are separated by Mesozoic and Cenozoic sedimentary basins. The basement complex rocks include migmatites, gneisses, schists, quartzites, amphibolites, charnockites, aplites, calc-silicates and diorite assemblages. These rocks are associated with intrusive phases of orogenic granites, aplites, pegmatites, charnockites and diorites in several places (Rahaman, 1976).

The Idanre area, which is in focus, is located in Southwestern Nigeria (Figure 1). West Africa and Odeyemi et al. (1999) described its geologic setting to be underlain by rocks of the Precambrian Basement complex, consisting of the migmatite-gneiss complex, Neoproterozoic metasediments and intrusive Older Granites (Figure 2). The migmatite-gneisses, being the oldest rocks in this and other parts of the country, are both litho- and tectonotratigraphically basal to all subsequent suprajacent lithologies and orogenic events. It consists of migmatites and gneisses, and it exhibits complex deformation styles which underlie its poly cyclic nature. The term ‘Older Granites’ was first coined by Falconer (1911) as a descriptive label to encompass a Precambrian suite of plutonic gneissose granites, coarse, porphyritic/porphyroblastic granites, fine-grained granites, adamellites, granodiorites, quartz-diorites and charnockites which occur as prominent batholithic masses in many parts of the Nigerian Basement Complex.

Idanre batholith, which is of the Older Granite suite of Pan-African (550±100Ma) age, is emplaced discordantly to semi-concordantly within both the migmatite-gneiss complex and its superjacent metasedimentary cover. The batholith comprises porphyritic or porphyroblastic, one–mica granitoid with compositions ranging from granites through adamellite to granodiorite (Rahaman, 1976).

Satellite images and aerial photographs are extensively used to extract lineaments for different purposes (Drury, 2001). Since satellite images are obtained from varying wavelength intervals of the electromagnetic spectrum, they are considered to be a better tool to discriminate the lineaments and to produce better information than conventional aerial photographs (Casas et al., 2000).

The purpose of this study is to apply remote sensing techniques in lineament detection and analysis over Idanre area of Ondo State, in order to contribute to the understanding of the megascopic geologic features in the area.
2. Materials and Methods

The scope includes the processing, manual analysis and preparation of lineament map (manual interpretation) from a Landsat ETM+ satellite imagery of the study area (1,669.68 km²) bounded by Longitudes 4°52'E, 5°19'E and Latitudes 6°51'N, 7°10'N (Figure 3). The Landsat ETM+ imagery was processed to produce a false colour composite image (543 in RGB), as well as an edge-enhanced image (linear AVG3x3 filter on band5) of the study area. The digitization of the interpreted image was then carried out for the purpose of presentation. Both image processing and digitization were done using ILWIS (Version 3.3) software. As a complementary method, a geologic map of the area (GSN Sheet 61) was also included to serve as a check for the interpreted imagery. Field work involved ground truthing of the features delineated from the interpretation of the image, and traversing of the area was done by using motorcycle and by trekking across the trend of the rocks. Finally, a rose diagram of the length and orientation of lineaments in the study area was produced, alongside with lineament-density as well as lineament intersection-density maps.

3. Results

A total number of 992 lineaments were extracted by manual interpretation of both 543-RGB false colour composite and edge-enhanced images of the study area. The resultant lineament map (Figure 4) clearly shows that the study area exhibit high density fracturing in which the batholith possesses the greatest density of fractures. There is a high degree of interconnectivity of fractures on the batholith in which some of the fractures can be seen cutting across the lithologic boundaries. The rivers draining the study area seem to assume the trend of the fractures in many places.
Emplacement Tectonics of Idanre Batholith

Fig. 5. Rose diagram showing length and frequency of lineaments in Idanre area.

Fig. 5. Diagrama em rosa mostrando o comprimento e a frequência dos lineamentos da área de Idanre.

4. Discussion

Idanre batholith, which is a member of the Older Granite suite of the Nigerian Basement Complex rocks, covers an area of about 400km², with numerous stocks dotting the entire landscape surrounding the batholith, among which are the plutons at Aiyetoro and Kajola-Igbaro districts of the study area. The batholith, on satellite image, appears to stand out, exhibiting higher resistance to denudation than the great expanse of country rocks surrounding it, with stocks also “standing out” at different areas.

On satellite imagery, the batholith has its long axis trending in a N-S direction while the major rivers in the study area, such as River Owena, River Iru, River Otan and River Ahun take a general N–S orientation of flow; also the rose diagram of lineaments within the study area has one of its peaks trending along NNE-SSW (0°–10°). Ground truthing confirmed the intrusion to be of porphyritic granite composition while the enclosing country rocks are the migmatite-gneiss and quartzite complex. A general N-S orientation of the long axis of the feldspar phenocrysts in the granite batholith was also observed; this coincides with the foliation trend of the enclosing country rock. The feldspar crystals vary in length from about 2.5cm to 3cm, with orientations ranging from 028° and 036°. According to Rahaman (1976), the general N-S foliation which is defined by the parallelism of the large feldspars and an alignment of the mafic minerals can be attributed to Pan-African Orogeny (550±100Ma). Also, the major rivers in the study area take a general N–S orientation of flow, which is parallel to the foliation of the country rocks.

The elongate shape of the batholith as shown by the satellite image, suggests that it intruded a migmatite-gneiss complex (less ductile) rather than a more ductile schistose country rock. This has also been confirmed by ground truthing. The batholith seems to have intruded N-S trending fractures in a brittle country rock (migmatite gneiss); this influenced the orientation of the long axis of the batholith and the orientation of its feldspar phenocrysts along a N–S direction (Figure 6). This corresponds to the foliation trend of the country rock (Figure 7). A xenolith of country rock material found within the batholith at Old Oke-Idanre (Figure 8) has its grains trending in a direction parallel to the orientation of the long axis of the batholith. Also, migmatite-gneiss xenolith exposures between Odoku and Bekin villages on the batholith have their foliation planes preserved along the N-S direction.

Fig. 6. Porphyritic granite of the Idanre Batholith.

Fig. 6. Granito porfirítico do batólito de Idanre.

Fig. 7. Migmatite gneiss outcrop at Onipepeye, showing intense folding, northward trend and steep dip to the West.

Fig. 7. Afloramento de gnaisse migmatítico em Onipepeye, mostrando intenso dobramento, tendente para Norte e com inclinação ingreme para Oeste.

The fracture distribution within the study area shows a bimodal pattern with the highest peak at ENE-WSW (80°–90°). These dominant fractures are found to be more or less normal to the long axis of the batholith, and they cut the batholith into massive, steep-sided and dome-shaped inselbergs. The fractures are very deep and they constitute the sources of numerous springs, streams and rivers within the area such as River Arun, River Apun-Edun, River Oto and River Esun. The rose diagram also showed that they are the longest fractures within the study
area. These fractures in some parts transcend into the country rock, further controlling the trend of the rivers outside the batholith. The Owena River exhibits kinks which are fracture controlled. The fractures are mainly westward propagations of the ENE-WSW trending fractures cutting the batholith obliquely, into the country rock. Para-tectonic collisions generated by crustal thickening due to compressional forces would result in anatexis at the base of the crust (Read & Watson, 1962). The resulting melt would then be pushed up through suprajacent layers, assisted greatly by pre-existing planes of weakness within the host rocks. The plutonic body which is cooling slowly at depth reaches a certain stage of rigidity and develops joints through shrinkage, in definite patterns related to the form of the intrusion (Drury, 2001; Read & Watson, 1962). The diagonal fractures observed on the batholith (ENE-WSW) are thus related to slow cooling at depth and shrinkage due to compressive force. It can also be opined that during magma ascent, the walls of intruded fractures (in the brittle country rock) will naturally exert a measure of compressional force on the rising magma, that is at least equal in amount to the outward force being exerted by the rising magma itself as it forces its way through the fractures (to every action, there is an equal and opposite reaction). However, there are evidences that some of these ENE-WSW-trending fractures probably pre-dates the intrusion of the batholith. The porphyritic texture of the granite intrusion is also indicative of the fact that its emplacement took place at great depths within the subsurface.

As indicated by the overall axial direction of the intrusion, Idanre batholith seems to have been subjected to compression in an EW direction which represents the direction of major/maximum principal compressive stress ($\sigma_1$). This can also be due to Pan-African orogeny’s (550±100Ma) influence as the overall strike of foliations in Nigerian basement terrains trend relatively N-S (Rahaman, 1976). $\sigma_3$ represents the direction of minor/minimum principal compressive stress, while $\sigma_2$ represents the direction of intermediate principal compressive stress and corresponds to the vertical direction during ascent. According to (Meijerink, 2007), fractures which developed parallel to $\sigma_1$ (direction of maximum horizontal compression) tend to be more open. Both $\sigma_1$ and $\sigma_3$ stress directions correspond to the two significant fracture sets observed on the rose diagram (Figure 10).

The structure of an igneous intrusion and its envelope of country rocks reflect the history of the invasion and cooling of the magma. The earliest recognizable structures in the igneous body itself are those formed during the period of
crystallization which includes planar and linear flow-structures produced by the alignment of minerals and xenoliths. As a rule, these structures are aligned parallel to the roof and walls of the intrusion (Figure 10); they are believed to lie roughly at right angles to the direction of upward and outward movement of the magma, the flow lines (S-joints/longitudinal-joints corresponding to the NNW-SSE, NNE-SSW fracture sets) marking the direction of extension due to this magmatic pressure (Read & Watson, 1962). Cross-joints (Q-joints), which are those which formed at right angles to the flow lines, also correspond to the ENE-WSW fracture set.

Closer study of the satellite image showed a distinct tonal variation in the properties of a portion of the envelope country rock bounded by Owena River on the west and the road leading from Legbira to Omifunfun on the east. This variation is most noticeable in the southern part of the batholith’s envelope, and may suggest the influence of Precambrian fractures on the emplacement of the granite. Ground truthing further confirmed this by revealing a sharp change in the grade of migmatization of the rocks on the opposite banks of Owena River, thereby suggesting the presence of a major fault along the river channel. A model (Figure 9) has been used to explain the process of development of pre- or syn-tectonic faults which are associated with the intrusion of the magma. Note that the Owena River channel only took advantage of the pre-existing fracture. The model also shows that Idanre batholith itself is fault-bounded. An isolation of the longest fractures in the study area, which were also observed to have cut both the batholith and the country rocks, suggests that the batholith might have intruded a network of pre-existing fault blocks in the country rock (Figure 11).

Lineament contour maps (Figure 12) show a very high concentration of lineaments on the batholiths (A), while the lineament intersection also shows higher density (B) at mid and northern parts of the batholith. Fractures being a source of secondary porosity in basement rocks, it can therefore be said that the batholith constitutes a zone of possibly high water-storage capacity within the study area.

5. Conclusions
From the remote sensing and field observations in Idanre area, results show high density fracturing on the batholith, which is possibly related not only to its depth of emplacement but also to
shrinkage effects due to compressive forces acting on the intrusive body at the time of its ascent. Idanre batholith is a fault-bounded intrusion with the parallelism of some of the fractures with the long-axis of the batholith indicating the influence of pre-existing zones of weaknesses which determine the tectonic grain of the batholith.

The batholith possesses the highest density of lineament intersection in the area, and as a result it constitutes the zone of highest water-storage capacity. Areas of highest lineament-intersections on the batholith can therefore be focused on for hydrogeological exploration within the study area.

The drainage in the study area is fracture controlled. The intrusion of the batholith also caused intense deformation of the envelope rocks enclosing it; an effect which diminishes with distance away from the batholith. Since very deep and long fractures usually constitute conduits through which ore-bearing fluids can be channeled, there is a need for detailed exploration particularly along such fractures in the study area.

References