GLOBAL JOURNAL OF GEOLOGICAL SCIENCES VOL, 10, NO.1, 2012 59-69
COPYRIGHT© BACHUDO SCIENCE CO. LTD PRINTED IN NIGERIA. ISSN 1596-6798
www.globaljournalseries.com, Email: info@globaljournalseries.com

A STUDY OF BASEMENT FRACTURE PATTERN AROUND AKOKO AREA OF SOUTHWESTERN NIGERIA FOR GROUNDWATER POTENTIAL USING HIGH-RESOLUTION SATELLITE IMAGERY AND ELECTRICAL RESISTIVITY

ADELOLA ADESIDA, ADELEYE Y. B. ANIFOWOSE AND JOHN S. OJO

(Received 20 May 2009; Revision Accepted 1 September 2011)

ABSTRACT

The basement complex of southwestern Nigeria has undergone severe tectonic deformation over the geologic past, resulting in various degrees of fracturing and folding, even to the extent of complete obliteration of primary structures except for some places. This study focuses on Akoko area which is dominated by hills of crystalline rocks that have made groundwater resource exploration difficult, thereby affecting the socio-economic activities of the inhabitants. High-resolution multispectral ASTER imagery acquired at the peak of the dry season was used to delineate fractures. Additional characterization employed electrical resistivity soundings.

Results indicate the existence of four sets of fractures mostly occurring within the central and north-eastern parts. More fracture intersections occupy the central part. Ground truthing shows that the fractures mostly occur in gneisses, granites and quartzites, while geophysical data interpretation revealed fracture depths typically ranging between 32 and 65 metres. In this hard rock terrain with only a veneer of weathered materials, these fractures are the targets of most groundwater exploration activities. This study further asserts the effectiveness of integrated approach to fracture characterization and its usefulness in groundwater exploration especially in a terrain that had hitherto been hydrogeologically classified as difficult.

KEYWORDS: Crystalline rocks, Fractured rocks, Geophysical methods, Groundwater exploration, Remote sensing

INTRODUCTION

Basement complex rocks in Nigeria part of the mobile belt between the West African craton and the Congo craton. Several workers have studied the various components of the basement complex particularly in terms of their structure, petrology, geochemistry and geochronology (Hubbard, 1975; Oversby, 1975; Grant, 1978; Odeyemi, 1981; Elueze, 1988; Rahaman, 1988; Adekoya, 1993). The terrain has undergone multiple tectonic episodes resulting in various folding and fracturing events. With severe and penetrative multiple generations of foliations, evidence of primary structures has been completely obliterated in the rocks, except for a few pockets where cross-stratification in quartzites survived deformation (Okonkwo, 1992). The dominant foliation direction is along the N-S, with some variations in the NE-SW and NW-SE directions. The rejuvenation of some basement fractures during the Jurassic Period led to the emplacement of Younger Granites in the Jos Plateau area of northern Nigeria.

Since ancient times, groundwater has been a major factor influencing the establishment of human settlement. With the advancement of humanity, the demand for groundwater for domestic, agricultural and industrial purposes has been on the increase. Akoko area of southwestern Nigeria is a hilly and rocky terrain with imposing outcrops dominating the landscape. While the hills serve as catchment and sources of streams that drain the area, inhabitants depend mostly on rainwater harvesting which effectively serves them only during the rainy seasons. Due to thin overburden, shallow wells run dry in the early part of the dry seasons. This scenario has subjected the inhabitants of the area to perennial water shortage which has in turn affected their socio-economic activities, and has often led to the outbreaks of water-related diseases. The existence of topographic lows is not adequate in the location of groundwater resources, hence the necessity to study this area in a diverse way in order to locate potential aquiferous zones based on the existence of basement fractures and the weathered profile as sources of secondary porosity.

Lineaments, particularly fractures, are very important in groundwater exploration especially in hard rock terrains. Their identification from various kinds of remotely sensed data has been extensively studied and applied in geological investigations over the years (El-Etr et al., 1979; Gelnett and Gardner, 1979; Koopmans, 1982; Odeyemi et al., 1985; Ananaba, 1991; Bala et al., 2000; Mabee et al., 2002). In hydrogeology, while lineaments play a major role in the location of groundwater potential zones, it is not sufficient in itself. Rather, it is better to use multi-level approach; hence the need to understand the general geological framework as well as the geophysical parameters that point to areas of favourable groundwater potentials (Chandra et al., 2006).

Over the years, geophysical methods have been used for structural investigations within the basement complex (Olasehinde, 1989; Adesida and Omosuyi, 2005). However, data acquisition techniques of such methods are often costly and time-consuming (Olayinka, 1996). Moreover, direct investigation can only be carried out over a certain period of time.

Adelola Adesida, Department of Applied Geophysics, Federal University of Technology, P.M.B. 704, Akure, Nigeria.
Adeleye Y. B. Anifowose, Department of Applied Geology, Federal University of Technology, P.M.B. 704, Akure, Nigeria.
John S. Ojo, Department of Applied Geophysics, Federal University of Technology, P.M.B. 704, Akure, Nigeria.

Faults, joints, folds and other geological features are often expressed as lineaments on satellite imagery. Several workers have utilised remotely-sensed imagery in fracture pattern analysis in different facets of geological sciences (Edet, et al., 1994; Onyedim, 1996; Chivasa, 1999; Odeyemi et al., 1999; Anifowose, 2004). Nevertheless, the resolution of such imageries and the processing/analytical techniques often determine their successful applications.

The Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER), one of the payloads on the Japan/USA Earth Observation Satellite, comprises a highly efficient optical sensor that acquires high quality multispectral data over a 60-km swath width in 14 spectral bands ranging from the visible to thermal infrared on a single path. Its products have a spectral resolution of 15m in the visible and near infrared region, 30m in the short-wave infrared region, and 90m in the thermal infrared region (Table 1). These superior characteristics make the products a versatile tool for terrain analysis, hence their adoption for this study.

Table 1: ASTER Spectral Pass bands

Subsystem	Band No	Spectral range (µm)	Radiometric resolution	Spatial resolution (m)
VNIR	1 2 3	0.52-0.60 0.63-0.69 0.76-0.86	≤0.5%	15
SWIR	4 5 6 7 8 9	1.600-1.700 2.145-2.185 2.185-2.225 2.235-2.285 2.295-2.365 2.360-2.430	≤0.5% ≤1.3% ≤1.3% ≤1.3% ≤1.0% ≤1.3%	30
TIR	10 11 12 13 14	8.125-8.475 8.475-8.825 8.925-9.275 10.25-10.95 10.95-11.65	≤0.3K	90

VNIR =Visible to near Infrared; SWIR=Shortwave Infrared; TIR=Thermal Infrared

PHYSIOGRAPHY AND GEOLOGIC SETTING

The study area is located within Longitudes 5.32^0-6.07^0E and Latitudes 7.05^0-7.71^0N, spanning 3600 km^2 area (Figure 1). It lies within the tropical rain forest belt characterised by alternating wet and dry seasons. The Osse River and its seasonal tributaries drain the area with flow directions which appear to have been influenced by the basement fracture pattern. The study area, typified by very rugged terrain with an average elevation of 700 metres above mean sea level, is underlain by Precambrian rocks (Figure 2) comprising migmatites, granite gneisses, pelitic gneisses, pelitic schists, quartz schists, Older Granites of hornblende and porphyritic varieties, and thin lenses of quartzite. Geochronological evidences (Grant, 1978; Odeyemi, 1981; Rahaman, 1988) show the polycyclic nature of the Nigerian basement complex with deformation, metamorphism and remobilisation activities over the geologic past. Petrographic studies by Rahaman and Ocan (1988) show evidences of mineral parageneses that pointed to four metamorphic episodes comprising greenschist phase resulting in the development of biotite and garnet. The second metamorphism yielded a widespread amphibolite facies which locally attained a granulite facies grade with the breakdown of biotite to form hypersthene. The localised granulite grade is said to have produced quartzo-feldspathic gneisses and some xenolithic basic rocks. A lower amphibolite grade metamorphism resulted in blue-green amphibolitic rocks, while the last metamorphism is a retrograde type of greenschist facies that led to widespread development of secondary minerals like chlorite, and the disintegration of feldspar. Also within the gneisses are quartzo-feldspathic veins and dykes that show ptygmatitic fold structures.

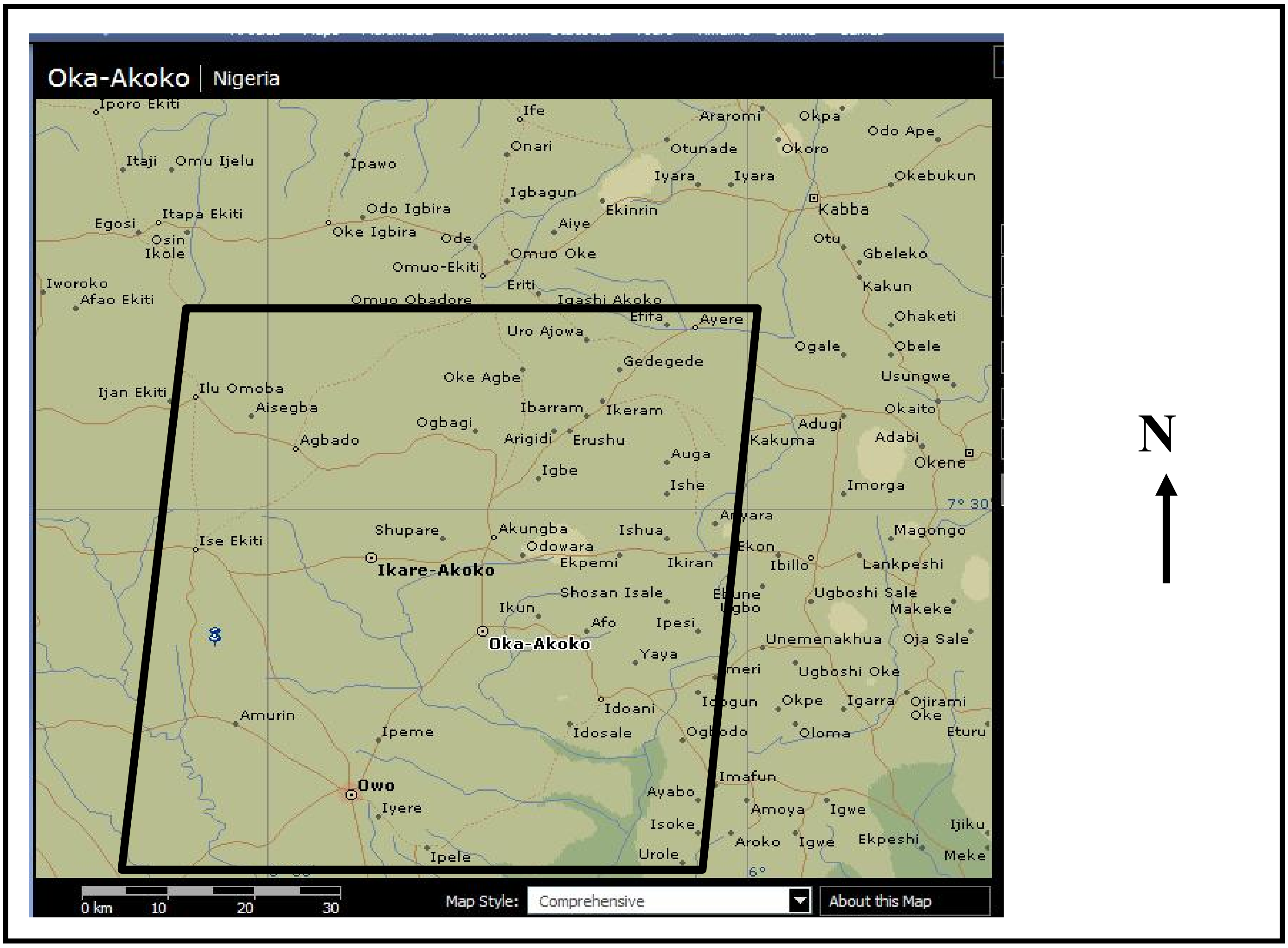


Figure 1: Location map of Akoko area, south-western Nigeria. (Source: MS Encarta 2005)

The general structural trend of rocks in the study area is mostly ENE-WSW. Although the study area is also underlain by several lithologic units, the dominant rock types are quartzite and migmatite-gneiss. The quartzite is underlain by migmatite in some places. The distribution, occurrence and thickness of the quartzite vary throughout the study area. These factors coupled with the tectonic events strongly influenced the fracture system and the observed geoelectric parameters in the study area.

MATERIALS AND METHODS

Pre-processed high-resolution level 1-B multispectral ASTER digital data acquired by the Japanese Earth Remote Sensing Data Analysis Center (ERSDAC) in February 2005 (peak of the dry season) was used for this study (Figure 3). The six bands within the SWIR spectral region (Table 1) were particularly useful in the delineation of lineaments because of their prominence and ease of identification in these bands.

In addition, several image enhancement (particularly edge enhancement) and transformation techniques comprising filtering, stretching, smoothing and Principal Component Analysis (PCA) modules in IDRISI Kilimanjaro^{TM} were used to improve the resolution and quality of the images so that the lineaments will be more legibly identified. With this, both clear and subtle lineaments were mapped (Figure 4), their azimuthal orientations determined (Table 2), and a rose diagram plotted (Figure 5). Electrical resistivity survey was carried out at some locations to determine the resistivity of the top soil and the depths to the bedrock within the study area.

Over 120 depth-sounding stations were occupied, and typical interpreted resistivity sounding data are presented in Figure 6. Under Surfer^{TM} environment, the interpreted geoelectric parameters were used to produce topsoil resistivity distribution map (Figure 7) and overburden thickness distribution map (Figure 8). Similarly, the estimated second order (Dar Zarrouk) parameters were employed in the generation of Coefficient of Anisotropy map for the study area (Figure 9).

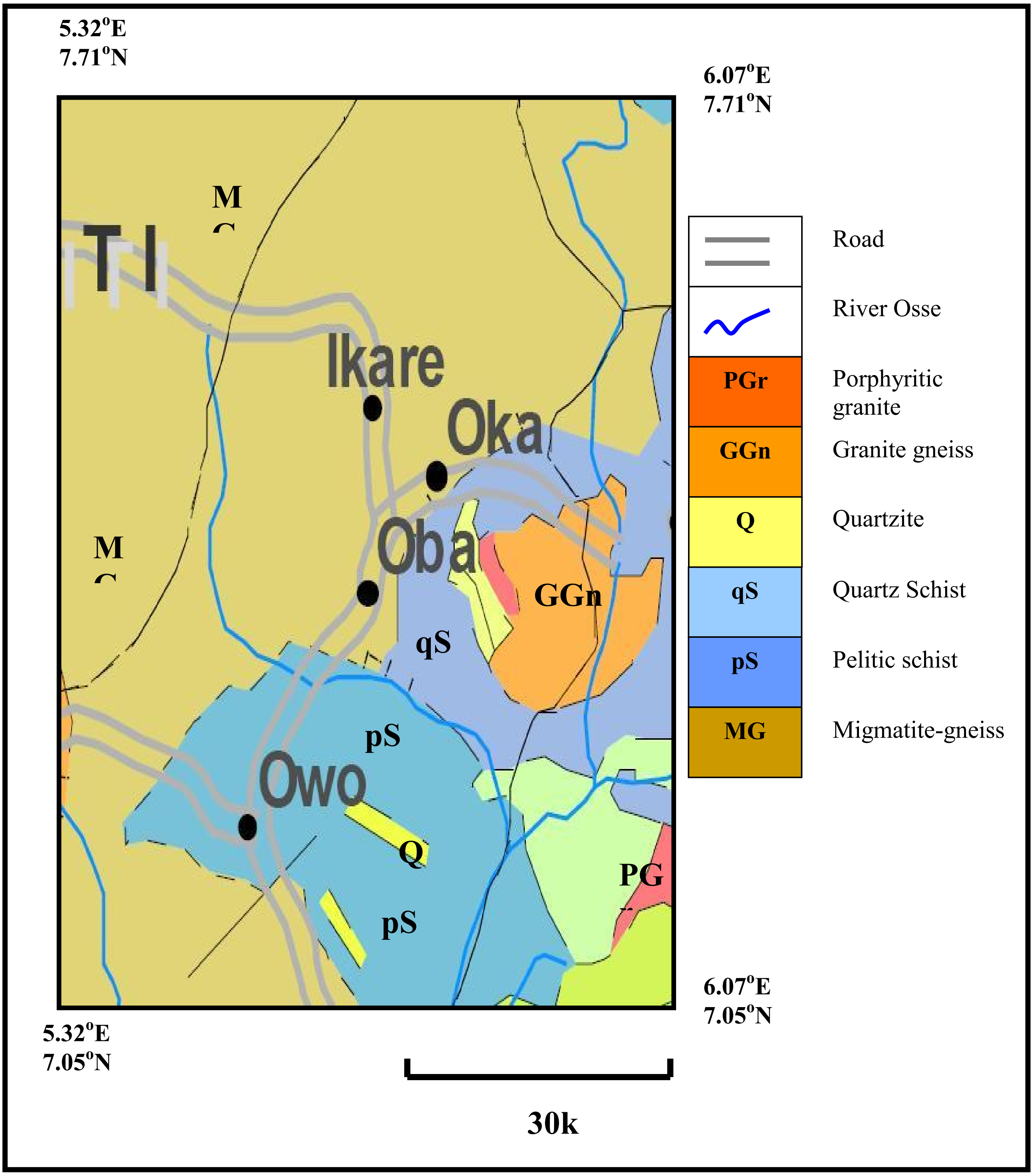


Figure 2: Geological map of the study area (Source: Nigeria Geological Survey Agency, 2006)

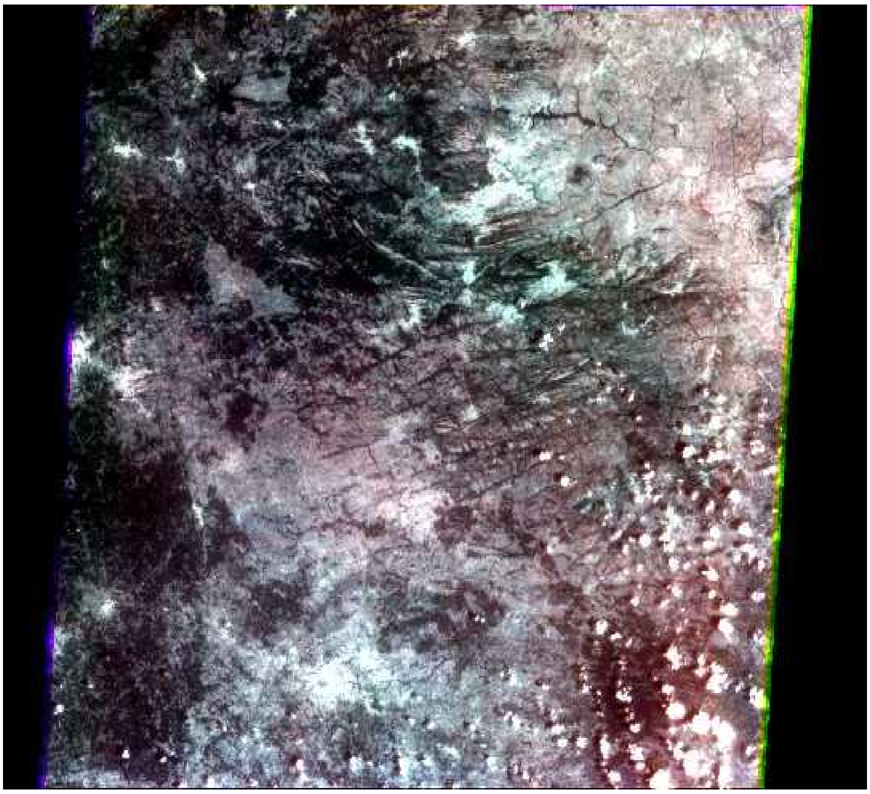


Figure 3: ASTER satellite imagery over the study area (Courtesy of ERSDAC, Japan).

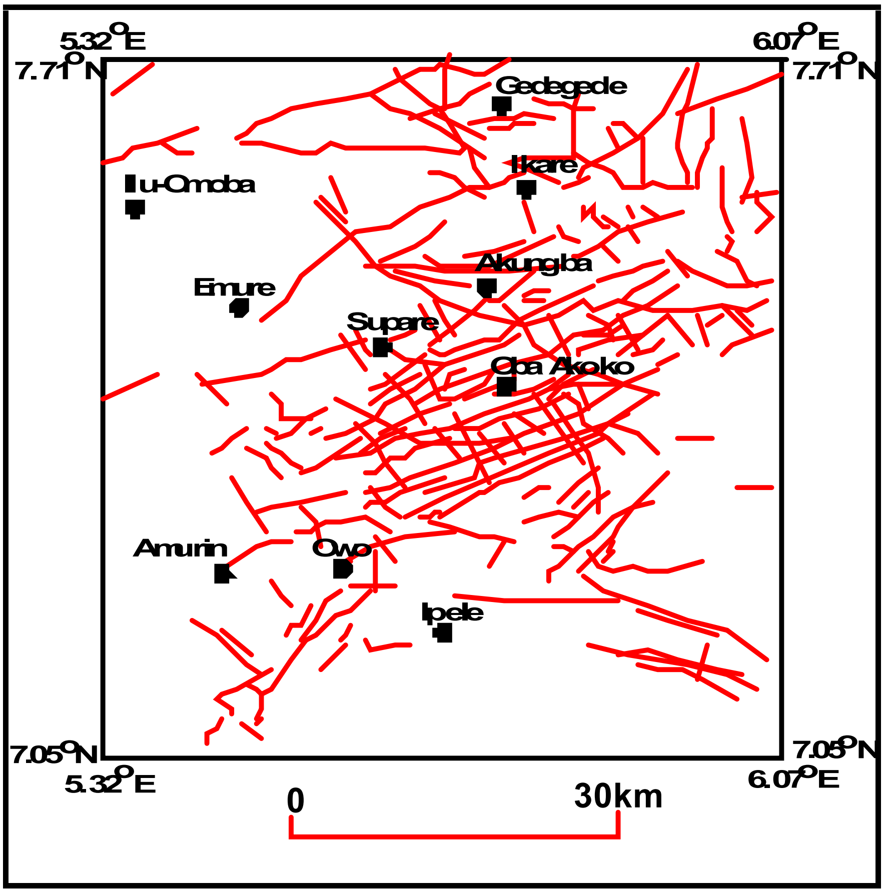


Figure 4: Lineament map of the study area

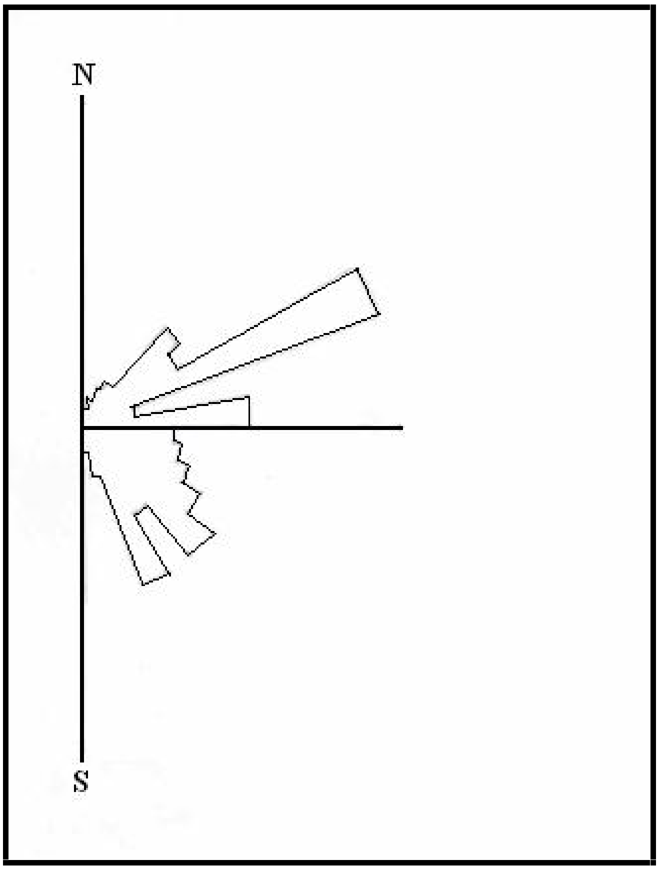
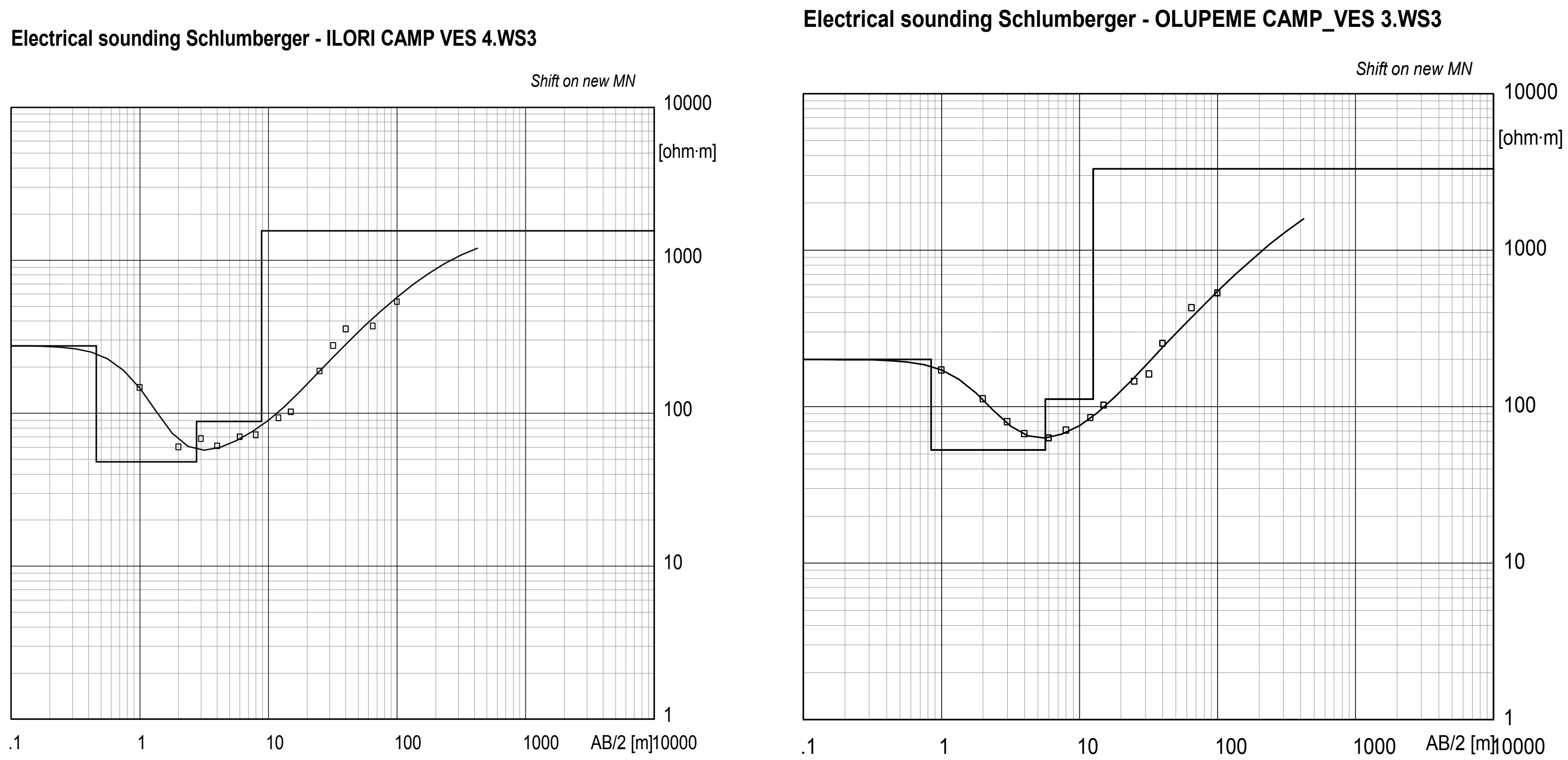


Figure 5: Rose diagram of lineaments in the study area

Table 2: Directional frequency of fractures in the study area

Orientation	Frequency (N)	N%
001-010	5	1.42
011-020	4	1.14
021-030	7	1.99
031-040	9	2.56
041-050	23	6.55
051-060	21	5.98
061-070	58	16.52
071-080	21	5.98
081-090	31	8.83
091-100	17	4.84
101-110	18	5.13
111-120	20	5.70
121-130	25	7.12
131-140	30	8.55
141-150	19	5.13
151-160	30	8.55
161-170	9	2.56
171-180	4	1.14
Total	351	99.69%



Electrical sounding Schlumberger - ILORI CAMP VES 4.WS3

Electrical sounding Schlumberger - OLUPEME CAMP_VES 3.WS3

Model Resistivity [ohm·m]	Thickness [m]	Depth [m]
276	.46	
48	2.3	.46
88	6.1	2.8
1554		8.9

Model Resistivity [ohm·m]	Thickness [m]	Depth [m]
200	.84	
53	4.8	.84
112	6.9	5.6
3303		12

Figure 6: Typical interpreted Schlumberger depth sounding curves from the study area.

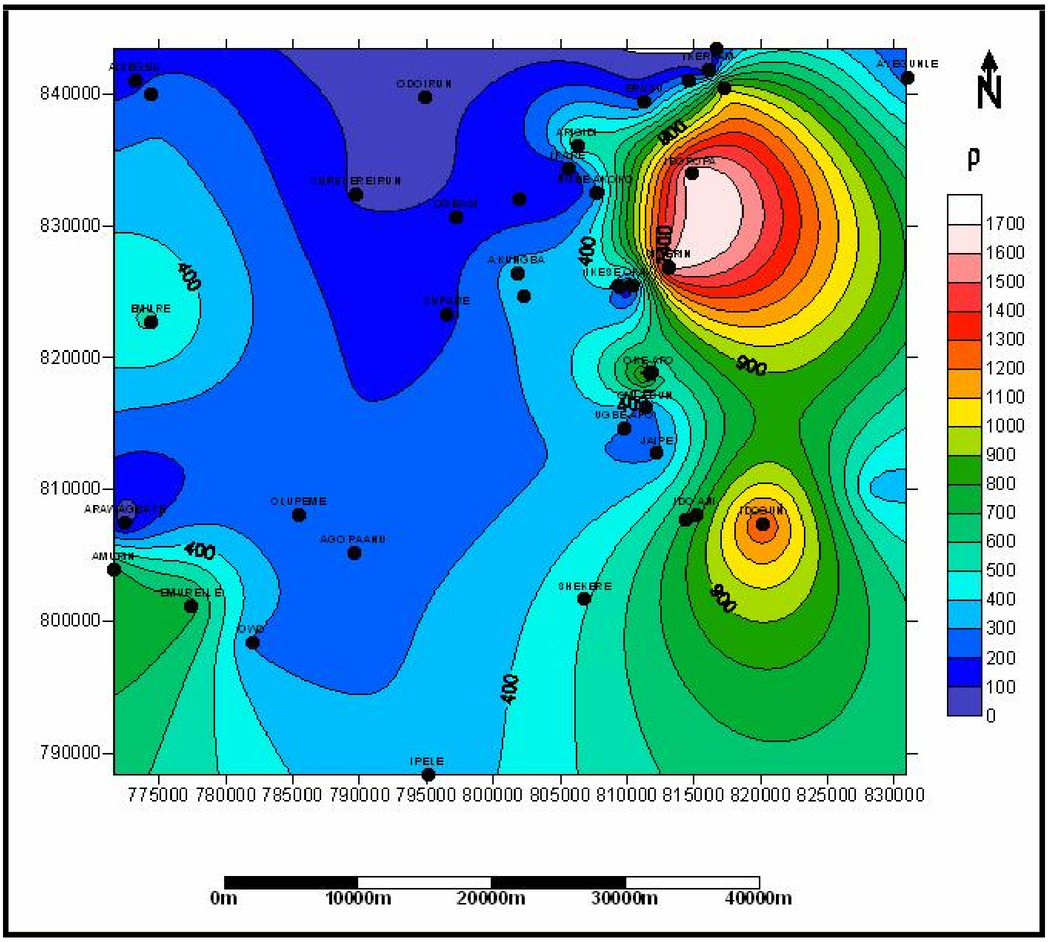


Figure 7: Overburden resistivity distribution map of the study area.

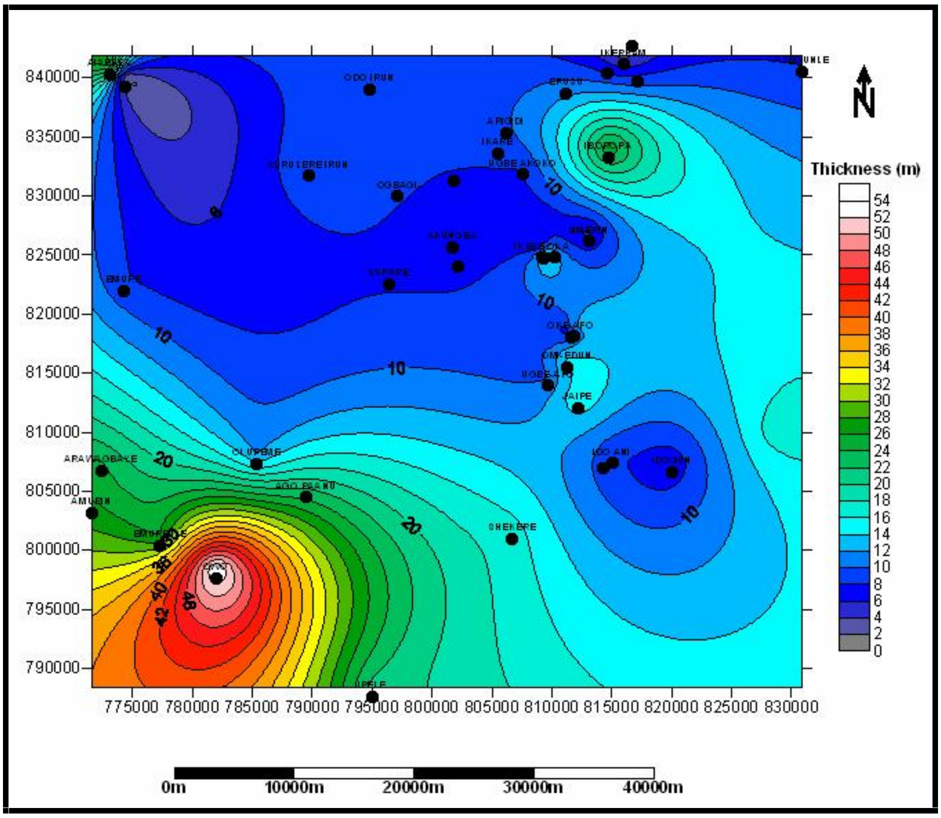


Figure 8: Overburden thickness map of the study area.

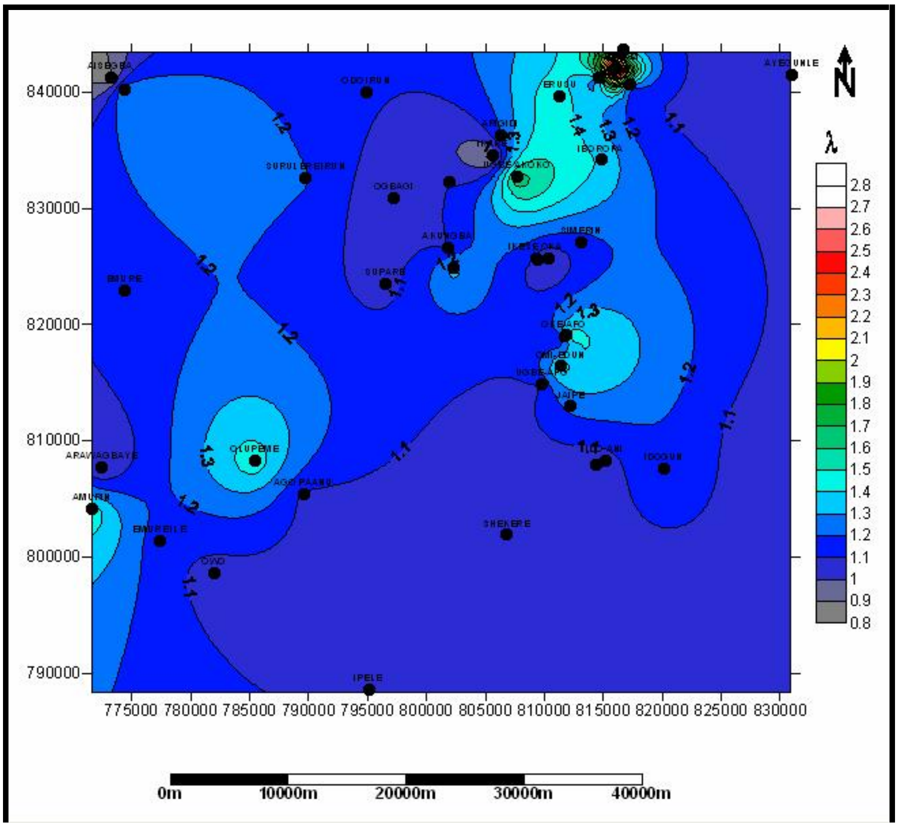


Figure 9: Coefficient of anisotropy map of the study area.

RESULTS AND DISCUSSION

Fracture Pattern

A total of 351 lineaments were extracted from the imagery. Results indicate that one major, and two minor sets of fracture patterns exist in the study area. The major set is orientated in the 061°-070° direction while the minor ones are in the 081°-090°, 131°-140° and 151°-160° directions (Figure 5). The minor fractures are numerous and mostly intersect the major ones, particularly around Oba Akoko (Figure 4). Most of the fractures are found within the central and north eastern parts of the study area. They reflect the tectonic stress directions within a terrain characterised by polycyclic tectonism. It is observed that some are curvilinear fractures. However, there are more intersections within the central part. The first sets are the longer lineaments with lengths varying from 5 to 12 km. These are directed generally ENE-WSW. The second set of lineaments are numerous, short and of various directions, almost randomly. There are more truncations within the zone, which is an indication of older fracture system. These places are typically underlain by migmatites. Locations with dense lineaments with intersections (e.g. some parts of Ikare and Akungba Akoko) are acknowledged as high groundwater potential zones because of the higher degree of secondary porosity that had been created.

Resistivity Depth Sounding

The dominant curve type observed in the study area is an H-curve. Others are HA, A, HQ, K, QA, HH and KA curve types. These curves also vividly depict the depth to fresh or fractured basement which resistivity varies from 127 to 593 ohm-m. Interpretation shows that the central portion is characterised by thin overburden despite the relatively dense fracture pattern (Figure 6). This is related to the nature of the underlying migmatite gneiss. Areas underlain by quartzite generally have thick overburden as a result of deep weathering. The thickness of the overburden is not related to the fracture pattern but to the nature of the underlying rocks.

The resistivity sounding data also show that the fractures are typically between 32 and 65 metres in depth. The resistivity values of the rocks decrease with fracturing and fracture density. This is illustrated in the remarkable correlation between the satellite imagery, resisitvity distribution and overburden thickness maps (Figures 3, 7 and 8). Areas that have dense fractures with intersections and thick overburden are acknowledged as high groundwater potential zones (e.g. some parts of Ikare and Akungba).

Relationships between Topsoil Resistivity, Overburden thickness and Coefficient of Anisotropy

Comparison of the satellite imagery and the topsoil resistivity distribution map shows that the resistivity of the topsoil decreases with lineament density. This suggests that topsoil resistivity might be a pointer to fracturing especially within the basement complex. However, other factors such as water saturation, mineralogy and lithology play important roles that cannot be overlooked.

It can also be observed that areas underlain by quartzites (e.g. Owo, Idoani, Ipele, etc) have overburden thicknesses varying from 16 to 54 m. Some places (e.g. Jaipe, Iboropa, Olupeme) have medium overburden thicknesses varying from 10 to 16 m, while some locations (e.g. Ikaram, Ibaram, Gedegede and some parts of Simerin) have overburden thicknesses typically less than 10 m, and are underlain by migmatites. This implies that lithology, rather than fracturing, influences the overburden thickness. However, areas underlain by quartzites are generally inclined to having higher overburden thickness due to deep weathering (Adesida and Omosuyi, 2005). Thick overburden is known to be essential for high groundwater potential and also for good groundwater quality, because most surface leachates would have been attenuated before getting to the water table in an unconfined aquifer.

The coefficient of anisotropy map (Figure 9) generally reflects the degree of weathering, fracturing and lithology. Areas underlain by quartzites have typical values of about 1.1; this gradually increases to 2.8 as the lithology changes from quartzite to migmatite and with decrease in the overburden thickness. The influence of fracturing on the degree of anisotropy is evident from the fact that fractured areas within the migmatites (e.g. Akungba and Supare) have lower coefficient of anisotropy of about 1.2 while areas underlain by relatively fresh migmatites (e.g. Ikaram and Ibaram) have values ranging from 1.3 to 2.8. Therefore, fracturing, overburden thickness, lithology and degree of weathering are factors that determine variation in the coefficient of anisotropy. The spatial distribution of the coefficient of anisotropy as shown on Figure 9 clearly demarcates major rock successions in the study area. For example, areas underlain by quartzites (Owo, Shekere, Idoani etc) have coefficient of anisotropy of about 1.1 while those underlain by migmatites and gneisses (Epiri-Oka, Ikese Oka, etc) have coefficient of anisotropy greater than 1.3. The highest values (> 1.7) are found around Erusu Akoko, Gedegede, Ikaram and Ibaram. These are areas underlain by migmatite gneisses, characterised by thin overburden (< 10 m) and attendant low to medium topsoil resistivity values. All these imply that the underlying basement rocks are relatively fresh and unfractured.

CONCLUSIONS

High-resolution satellite imagery has been used in the identification and delineation of fractures over the study area. In addition to geological mapping, it has been observed that degree of fracturing and overburden thickness determine the groundwater potential of crystalline basement areas, and therefore can be utilized in groundwater exploration, especially in areas that had hitherto been hydrogeologically classified as difficult.

The relevance of this study to groundwater exploration has been demonstrated in the area covered. It affirms the effectiveness of high-resolution satellite imagery in the investigation of fracture patterns especially in crystalline basement terrains, and its suitability in reconnaissance for the delineation of areas for further ground-based studies. Finally, subsequent studies are considering the integration of other geophysical (seismic and magnetic) methods and borehole yield data into Geographic Information System (GIS) towards further characterisation of these fractures vis-à-vis groundwater development in the study area. This is also expected to be the genesis of a pilot study on the hydrogeochemical characterization of groundwater on a GIS platform in southwestern Nigeria.

ACKNOWLEDGEMENT

The authors are grateful to the ASTER-ARO Office for providing the satellite imageries used in this study.

REFERENCES

Adekoya, J.A., 1993. Proterozoic Maru and Birnin Gwari banded iron-formations, Northwestern Nigeria. J. Mining and Geology 29(1): 63-76.

Adesida, A. and Omosuyi, G.O., 2005. Geoelectric investigation of bedrock structures in the mini-campus of the Federal University of Technology, Akure, Southwestern Nigeria and the geotechnical significance. J Pure and Applied Physics 4: 32-40.

Ananaba, S.E., 1991. Dam sites and crustal megalineaments in Nigeria. ITC J. 1:26-29.

Anifowose, A.Y.B., 2004. Remote sensing analysis of Ifewara-Zungeru megalineament in Nigeria. PhD thesis, Fed. Univ. Tech., Akure, Nigeria, 169p.

Bala, A.F., Batelaan, O. and de Smedt, F., 2000. Using Landsat-5 imagery in the assessment of groundwater resources in the crystalline rocks around Dutsin-ma, northwestern Nigeria. J. Mining and Geology 36(1): 85-92.

Chandra, S., Rao, V.A., Krishnamurthy, N.S., Dutta, S. and Ahmed, S., 2006. Integrated studies for characterization of lineaments used to locate groundwater potential zones in a hard rock region of Karnataka, India. Hydrogeology J. 14(5): 1042-1051.

Chivasa, M., 1999. Lineament analysis of Landsat Thematic Mapper images- study of post-Karoo fault patterns in the Hwange Coalfields, Zimbabwe. In P.O. Adeniyi (Editor) Geoinformation Technology Applications for resource and environmental management in Africa. African Association of Remote Sensing of the Environment, Lagos, Nigeria, pp. 215-224.

Edet, A.E., Teme, S.C., Okereke, C.S. and Esu, E.O., 1994. Lineament analysis for groundwater exploration in Precambrian Obudu massif and Obudu plateau, S. E. Nigeria. J. Mining and Geology 30(1): 87-95.

El-Etr, H.A., Moustafa, A.R. and El-Baz, F., 1979. Photolineaments in the ASTP stereostrip of the Western Desert of Egypt. Apollo-Soyuz Test Project (ASTP) Summary Science Report Vol. II, Earth Observations and Photography, NASA SP-412: 97-105.

Elueze, A.A., 1988. Geology of the Precambrian schist belt in Ilesha area, southwestern Nigeria. In P.O. Oluyide, W.C. Mbonu, A.E. Ogezi, I.G. Egbuniwe, A.C. Ajibade, and A.C. Umeji (Editors) Precambrian Geology of Nigeria, Geological Survey of Nigeria, Kaduna, pp. 77-82.

Gelnett, R.H. and Gardner, J.V., 1979. Use of radar for groundwater exploration in Nigeria, West Africa. Proc. 13th Inter. Symposium on Remote

Sensing and the Environment, Ann Arbor, Michigan, 11p.

Grant, N.K., 1978. Geochronology of Precambrian to early Paleozoic Pan African orogeny in Ghana, Togo, Dahomey and Nigeria. Geological Society of America Bull. 80: 45-56.

Hubbard, F.H., 1975. Precambrian crustal development in western Nigeria: indications from the Iwo region. Geological Society of America Bull. 86: 548-564.

Koopmans, B.N., 1982. Some comparative aspects of SLAR and airphoto images for geomorphologic and geologic interpretation. ITC J. 3: 330-337.

Mabee, B.S., Curry, P.J. and Hardcastle, K.C., 2002. Correlation of lineaments to groundwater inflows in bedrock tunnel. Ground Water 40(1): 37-43.

Malomo, S., 2006. Geological map of Nigeria, Digital format. 1:4,402,912. Nigerian Geological Survey Agency.

Microsoft Corporation, 2005. Microsoft Encarta Premium 2006 Ver 15.0.0.0603.

Nigeria Geological Survey Agency, 2006. Geological map of Nigeria, 1:4,402,912. Published by the authority of the Federal Republic of Nigeria.

Odeyemi, I.B., 1981. Review of orogenic events in the Basement Complex of Nigeria, West Africa. Geologische Rundschau 70(3): 897-909.

Odeyemi, I.B., Anifowose, A.Y.B. and Asiwaju-Bello, Y.A., 1999. Multitechnique graphical analyses of fractures from remote sensing images of Basement regions of Nigeria. J. Mining and Geology 35(1): 9-21.

Odeyemi, I.B., Malomo, S. and Okufarasin, Y.A., 1985. Remote sensing of rock fractures and groundwater development success in parts of S.W. Nigeria. Natural Resources Forum, New York, 311-315.

Okonkwo, C.T., 1992. Structural geology of basement rocks of Jebba area, Nigeria. J. Mining and Geology 28(2): 203-209.

Olasehinde, P.I., 1989. Elucidating fracture pattern of the Nigerian basement complex using electrical resistivity method. Angew, Geowisserschaft 8: 109- 120.

Olayinka, A.I., 1996. Non-uniqueness in the interpretation of bedrock resistivity from sounding curves and its hydrogeological implications. Water Resources J. 7(1 & 2): 49-55.

Onyedim, G.C., 1996. An investigation of structural and lithologic controls of drainage patterns in part of Ilesa area using remote sensing data. J. Mining and Geology 32(1): 53-58.

Oversby, V.M., 1975. Lead isotope study of aplites from the Precambrian rocks near Ibadan, Southwestern Nigeria. Earth and Planetary Sciences Letters 27: 177-180.

Rahaman, M.A., 1988. Recent Advances in the study of the Basement Complex of Nigeria. In P.O. Oluyide, W.C. Mbonu, A.E. Ogezi, I.G. Egbuniwe, A.C. Ajibade and A.C. Umeji (Editors) Precambrian Geology of Nigeria, Geological Survey of Nigeria, Kaduna, pp. 11-43.

Rahaman, M.A. and Ocan, O., 1988. The nature of granulite facies metamorphism in Ikare area, southwestern Nigeria. In P.O. Oluyide, W.C. Mbonu, A.E. Ogezi, I.G. Egbuniwe, A.C. Ajibade and A.C. Umeji (Editors) Precambrian Geology of Nigeria, Geological Survey of Nigeria, Kaduna, pp.157-163.