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Reconnaissance Litho-structural Study of the Anka Area, Northwestern Nigeria: Implications for Mineral Exploration

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ABSTRACT
The geology of Anka area is characteristic of the Basement Complex rocks of northwest Nigerian, and it is part of a larger metasedimentary (Schist) Belts one of which is the Anka schist belt. A combined lithostructural investigation using remotely-sensed and field data was carried out with a view to ascertaining their implications for potential for mineralization. Techniques such as principal component analysis (PCA), band ratioing (BR), Minimum Noise Filter (MNF), False Colour Composition (FCC) as well as directional filtering hill shading, stream order and flow direction were applied to Landsat 8 and shuttle radar topographic mission (SRTM) imageries and combined with field data in order to establish geology and structural disposition. The Anka area is underlain by five major lithological units which are the granite-gneiss, phyllite, granite, diorite and pegmatite. The major structural trends in the study area lie principally within NE-SW, NNE-SSW and ENE-WSW for both remote sensing and field structural data. These structural trends conform to the regional structural trend of Nigeria. The significance of geological and structural trends of these rock units and their relationship to mineralization is that these fissures associated with the lithologies could serve as key migration and deposition pathways for ore-bearing fluids. Therefore, an understanding of the geology and associated structures could serve as baseline information for mineral exploration in the Anka area.

Keywords: Anka, Schist Belt, Litho-Structure, Landsat

INTRODUCTION

Anka, the type locality for one of the Nigerian metasedimentary (schist) belts, is located within Zamfara state. Geographically, the area cuts across two topographical sheets of Anka sheet 52 SE and Maru sheet 53 SW, precisely between longitude 5°48'E and 6°00'E and latitude 11°58'N and 12°15'N (Fig. 1). It is made up of five localities namely, Dareta, Bagega, Sunke, Abare and Yargalma, covering an estimated area of 178km². The Anka schist belt forms part of the Nigerian metasedimentary (schist) belts, standing at the northwestern fringe of the belt, which occupies the western half of Nigeria. It is composed almost entirely of low to medium grade metasedimentary rocks.

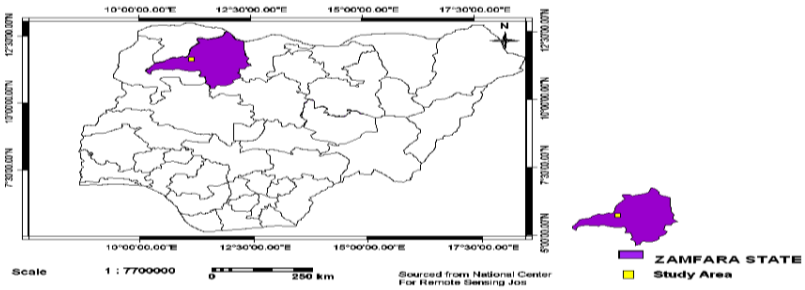


Figure 1: Map of Nigeria Showing the Study Area Located in Zamfara State

The deployment of remotely sensed data in geological applications such as lithological discrimination, mineral detection, mineral potential and hydrothermal alteration mapping at various scales have shown remarkable success (Sabins, 1999, Van der Meer *et al* 2012, Zoheir & Emam, 2014, Kumar *et al* 2015). Space borne multispectral sensors, particularly Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) launched in 1982 and 1999 with 5 and 8 spectral channels respectively have been well employed for such applications for regional mapping, structural interpretation and to aid prospection of mineral deposits, (Perry and Vincent, 2009, Richards, 2013, Rogge et al, 2007). Structural mapping is considered very important in several aspects of geosciences such as mineral exploration (Rowan and Lathram, 1980), hot spring detection, hydrogeological studies, (Sabins, 1996, Drury, 2001, Gad and Kusky, 2002), earthquake and landslide risk assessment and site selection for engineering construction of dam and bridges (Stefouli et al., 1996). Regional study of linear features such as faults, joints, folds, dikes, crustal fracturing and lithological contacts using remote sensing has made significant advances in geological research in the last few decades, (Rowan and Lathram, 1980, Sigmons, 1987, Patra et al, 2013). This is more so due to the fact that the occurrence of mineral deposit in any area depends

on the lithology and the tectonic history. Structural discontinuities in rocks are often useful features that constitute migratory pathway for ore-bearing hydrothermal fluids.

The Anka Schist Belt has been investigated using remotely-sensed data for structural interpretation and mineral-potential mapping, some of which are concerned with establishing tectonic setting and structural coincident with potential gold mineralization in the Anka area, (Salau et al. 2016, Agunleti et al. 2020 and Augie et al. 2022, etc.). This study is a further attempt at geological assessment and interpretation of structural features and their implications for potential mineral deposits using integrated Landsat 8 and Shuttle Radar Thematic Mapper (SRTM) in conjunction with field data in the Anka schist belt. This is with a view to establishing concurrence or otherwise with previous work in the area.

Regional Geological Setting

The geology of Nigeria indicates that crystalline and sedimentary rocks occur in almost equal proportion. The sedimentary rocks are scattered within the seven major depositional basins of the country (Umaru and Ibrahim 2020, Turner, 1983). The study area lies within the basement complex of north-western Nigeria (Fig. 2). Rocks in the basement complex have been categorized into three broad lithological groups: the migmatite-gneiss complex, the schist belts and the Pan-African granitoids (Rahaman, 1988). The migmatite-gneiss complex is a product of long polycyclic evolutionary processes (Woakes and Bafor, 1984, Emofurieta and Ekuajemi, 1995). Rocks in this belt display chemical variations indicating that they originated from heterogeneous progenitors (Agunleti et al 2020a, Elueze, 1981, Holt, 1982). The schist belt forms a large part of the basement complex of Nigeria and consist essentially of low-grade metasediments and metabasic rocks exposed in series of N-S trending synformal troughs infolded into the crystalline migmatite-gneiss complex. The major belts could be divided into two broad areas, separated by basement granitoids, of ‘’northwest’’ and ‘’southwest’’ belts, consisting of seven and four schist belts respectively, with the Anka and Maru belts in the extreme north (Hofmann, et al, 2025). In some parts of the country, the schist belts are associated with subordinate mafic rocks, metaconglomerate and carbonates such as in Igarra area.

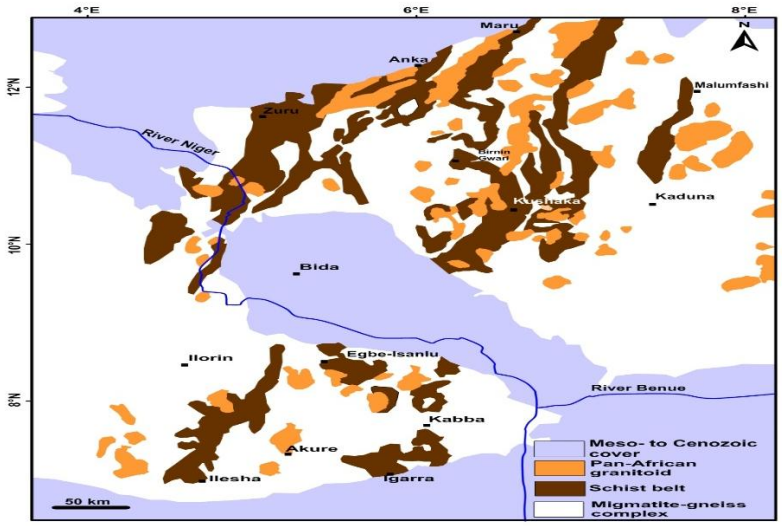


Figure 2: Map of The Western Half of Nigeria Showing the Distribution of the Nigerian Schist Belts (Modified After Bafor, 1988)

MATERIALS AND METHODS

For this study, Shuttle Radar Topographic Mission (SRTM) digital elevation model (DEM) data with spatial resolution of 30 m (1 Arc-Second) and Landsat 8 image (Path/Row-190/055) covering the study area (downloaded from http://earthexplorer.usgs.gov/) were used. The data used were projected to WGS 1984 UTM Zone 31 N. Several pre-processing techniques were applied on Landsat 8 data before further image processing procedures. The pre-processing techniques include: conversion to top of the atmosphere (ToA) reflectance, sun angle correction and layer stacking. Furthermore, image processing techniques such as principal component analysis (PCA), band ratioing (BR), minimum noise fraction (MNF) and false-colour composition (FCC) were applied to the Landsat 8 data to enable lithological discrimination. For structural interpretation, filtering and edge detection techniques were applied on DEM to delineate structural features in the study area.

Band 7 of the Landsat 8 was subjected to four types of filtration processes to increase the chances of identifying the lineaments using ENVI software. The filters include: Laplacian filter, 0^0 directional filters, 45^0 directional filter And 90^0 directional filter. The lineaments wear carefully identified on each of the filtered images using a manual identification procedure. The lineament shape file was then exported to rockworks where the rose plot was done. The false colour composite was obtained by combining the individual bands 5, 4 and 3.

Band ratioing is an image processing technique used to effectively display spectral variations (Perry and Vincent, 2009). The generated ratio images enhance the contrast between materials by dividing the brightness values (digital numbers) at peaks/maxima and troughs/minima in a reflectance curve (Ibrahim et al., 2016). It enhances spectral differences between bands while minimizing topographic effects. Many forms of BR have been developed using Landsat data (TM and ETM+) according to the purpose of their application (such as lithological or hydrothermal alteration detection). The band ratio applied here for the analysis was performed with bands 1, 3, 5 and 7 using the formula: Band ratio = (5/3) + 7/ 5) + (3/1). Minimum noise fraction (MNF) analysis was carried out using the result from the band ratio process. Principal component analysis (PCA) is one of the commonly adopted methods for dimensionality

reduction in remote sensing image processing (Richards, 2013; Rogge et al., 2007). PCA involves transformation of multivariate data into new coordinate system. Principal component analysis (PCA) was done using the MNF result as input.

The processed remotely-sensed data also serve as data input for preliminary and reconnaissance field survey carried out prior to field geological mapping. This latter exercise involves the use of topographic map as a guide to locate the outcrops present in the study area. The topographic map was divided into grids to aid mapping and accessibility to different locations. Observations made on each outcrop include megascopic identification of minerals present in the rock outcrops, mineral composition, texture, degree and pattern of weathering, color of fresh rock surface, and measurement and documentation of structural details.

RESULTS AND DISCUSSION

Remote Sensing

The clarity of the outlines of the different lithologies in the study area vary across the different layers of the remote sensing data while lineaments extracted are mostly those induced by and concentrated along lithological boundaries between the different rock types within the study area. Therefore, integration of spectral and structural information from images with geological data is expected to provide a better understanding of the spatial relationships between the litho-tectonic units. Although not all the images provide optimal discrimination between the different rock units, as is the case with some other imageries, they nevertheless highlight major structures such as drainages and lineaments. Due to the fact that different layers of the processed imageries showed comparative clarity of display of the different rock types, the use of the different components in order to give a fairly clear outline of the different rock types in the study area became necessary.

In spite of this, outline of the different lithological units in the study area are weakly defined by the different remote sensing imageries. The granite gneiss and the granite are roughly outlined green and purple in the color composite (figure 3 a & b) respectively while in the PCA and MNF (figure 3 c & d) they are roughly defined by bluish-green and light to reddish purple respectively. Phyllite is defined by yellowish-green and light brown in the color composite and light-green and yellowish-purple in the PCA and MNF. Pegmatite on the other hand is represented by yellowish-brown with a scattered tint of blue and dark brown respectively in the color composite imageries. It is outlined roughly by bluish-green and yellowish brown in the PCA and MNF respectively. Diorite does not indicate any color shade probably due to its relative small size compared to the other rock units in the study area.

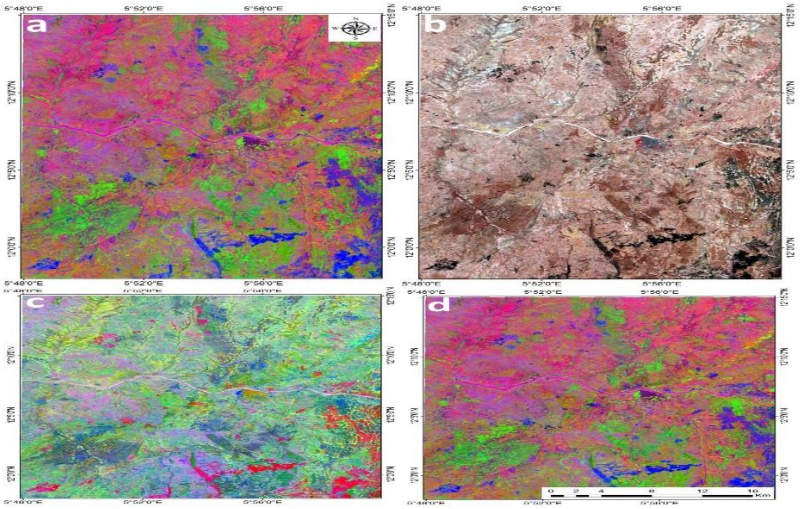
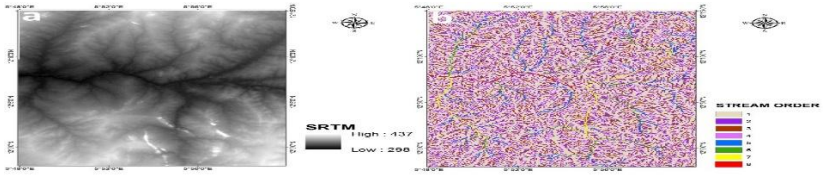


Figure 3: Landsat Image of the Study Area Displayed as: (A) Colour Composite of Red, Blue and Green (B) False Colour Composite; (C) Principal Component Analysis (PCA); (D) Minimum Noise Fraction (MNF).

Structural trends of the study area are captured well by the remotely sensed data, particularly looking at the drainage of the area, (Fig. 4). Directional filters help accentuate fractures and joints (lineaments) while Flow direction and hill shade images of the Shuttle Radar Thematic Mapper (SRTM) hillshade as well as stream order highlighted both lineament and regional structural trends. Outlines of the major rock units are not as well-defined as the drainage pattern and structures.



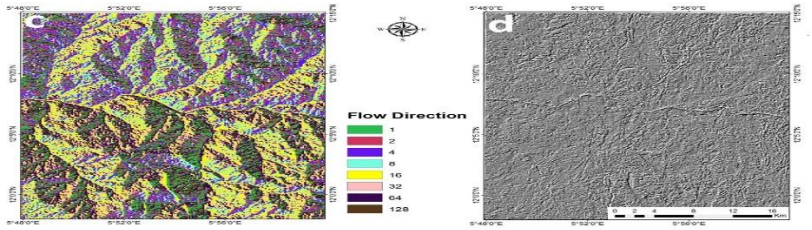


Figure 4: Remote Sensing Data Layers Used for Lineament Extraction: (A) Hillshade; (B) Stream Order (C) Flow Direction; (D) Directional Filter

The general trend of the lineaments in study area is predominantly in the NE-SW direction (Fig. 5). The extracted lineaments represent valleys, ridges and slope-breaks. N40° - N50° directions have the highest frequency of lineament which is followed by N10° - N30° and then N60° – N70°. Based on this frequency the trend of the lineaments in the study area can be described in order of frequency and starting with the highest frequency as NE-SW, NNE-SSW and ENE-WSW. Most of the lineaments trending in the NW-SE main direction constitute a very minor trend when compared with the dominant trends (Fig. 6). It is observed that the density of the extracted lineaments varies across the different lithologies in the study area. Granite-gneiss and the phyllite underlie the areas with the highest density of lineament, followed by areas underlain by the Pan-African granitoids, while the pegmatite underlies the area with the least density of lineament. An interesting peculiarity of the lineament map is the alignment of some of the lineaments parallel to lithological boundaries thereby defining the general outlines of some of the different lithologies in the study area. Furthermore, extracted lineament map superimposed on that of drainage showed a structurally controlled pattern of drainage with channels taking their sources largely from the east.

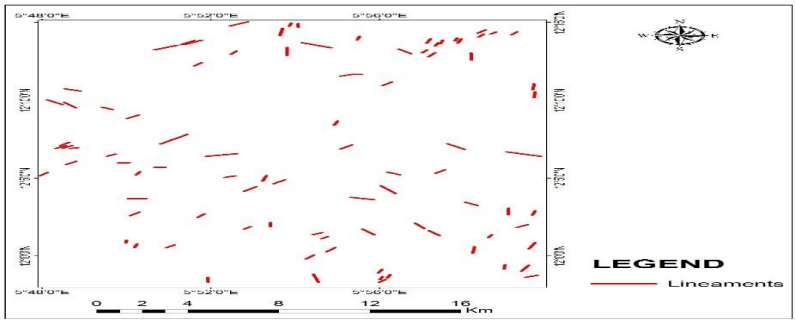


Figure 5: Lineament Map Derived from Remote Sensing Data of the Study Area

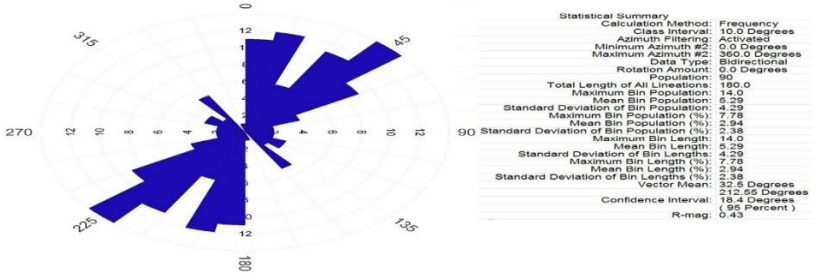


Figure 6: Rose Diagram Showing Length and Frequency of Lineament from Remote Sensing Data

Field Geology

The area is made up of different rock types such as granite gneiss, phyllite, granite, pegmatite and diorite etc. The granite-gneiss is mostly restricted to the western part of the study area. It outcrops as hills or as pavement exposures constituting the largest hill noticed is the south east of Dandabi Ridge with a relief of about 412m (above mean sea level). The texture of the granite-gneiss in the area of study varies from fine to medium grain with a well-developed foliation (Fig. 7a). It has a gradational contact with the biotite granite further north of the Dareta Ridge which can be easily distinguished by lack of foliation in the biotite granite.

The phyllite otherwise referred to as the Anka metasediment is a fine-grained schistose rock, which probably resulted from higher grade regional metamorphism of slates. The rock is soft and weathers to form flat plains. Better exposures are found along stream valleys, while those exposed on the plains, are slightly elevated and are usually silicified (Fig. 7b). It is fine to very fine grained, well cleaved and foliated, probably derived from mudstones, shale, and muddy-siltstones. The colour varies from dark grey, bluish and brown to greenish and purple. Some samples of phyllite shows compositional banding. These bands comprise alternating of dark, pellitic or micaceous layers and lighter less micaceous band. Some of the phyllite exposed along river channel is seen with quartzite intrusion with the contact between the country rocks and the granite marked at the south-eastern corner of Dareta Ridge by a silicified phyllite with an area of about 0.5 km².

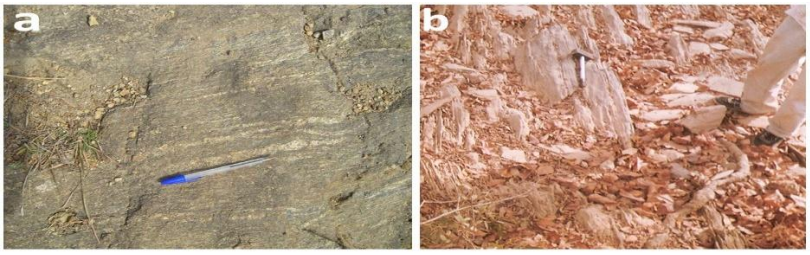


Figure 7: (A) Granite Gneiss Outcrop at Dareta Showing Mineral Alignment; (B) Altered Phyllite at Dareta

The granite consists of the biotite-granite and the hornblende granite with both outcropping at the north western portion of the study area (Fig. 8). While the former is medium to coarse grained and varies in colour from pinkish to grey the latter is very coarse-grained and porphyritic and forming part of the Maiinchi granodiorite.

While the diorite outcrop as boulders of varying shapes and sizes which may be sometimes massive and highly fractured with joint sets particularly at the Wano area the pegmatite consists of numerous ridges including intrusions into the surrounding rocks. The most prominent pegmatite ridge is at the western part of the area running for about 2 – 3 km and trending N – S; it varies from fine through medium to coarse and very coarse-grained (containing free quartz). It is pinkish in colour due to the presence of alkali feldspar.

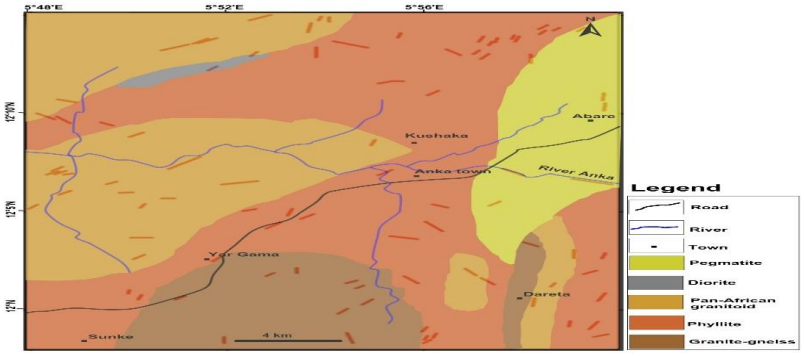


Figure 8: Geological Map of Anka Area Superimposed with Lineament Map Derived from Remote Sensing Data.

Structures

A well-developed foliation is most preserved in the phyllite and the granite-gneiss. This foliation is defined by the parallel alignment of platy minerals (micas) and quartz and mafic mineral in case of the granite gneiss. The foliation on the rock is as a result of the parallel alignment of hornblende and biotite. The dominant strike of the foliation is NE-SW but, it has different and often complex strike directions. Some portions of the granite-gneiss show segregation of minerals into mafic and felsic bands while other portions show granitic textures. Some of the granite-gneiss shows evidence of included fragments.

In some other areas, quartz veins are noticed more in the Hornblende-biotite-granite ranging in thickness from >1 to 2cm. Aplite veins occur more frequent in the biotite-alkaline-granite, rarely with veins of quartz-feldspar-pegmatites that range in thickness from 10 to 40cm. Joints are classified based on the shape, size and their relative importance which combine size and frequency of occurrence. Joints were observed on most of the rock types encountered in the study area. Their trends were measured, (Table1) and rose diagrams were plotted which indicated a NE – SW dominant trend (figure 9).

Table 1: Summery of Joint Readings On Diorite, Granite Gneiss and Phyllite

Diorite		**Granite Gneiss**		**Phyllite**	
FIELD READINGS	**FREQ UENCY**	**FIELD READINGS**	**FREQ UENCY**	**FIELD READINGS**	**FREQ UENCY**
$N80^0$	7	$N32^0$	40	$N38^0$	1
$N2^0$	3	$N20^0$	6	$N14^0$	4
$N10^0$	4	$N28^0$	4	$N24^0$	2
$N78^0$	3	$N20^0$	4	$N2^0$	2
$N62^0$	3	$N66^0$	8	$N112^0$	2
$N102^0$	3	$N2^0$	15	$N30^0$	4
$N20^0$	1	$N20^0$	15	$N20^0$	4
$N60^0$	2	$N36^0$	7	$N32^0$	8
$N120^0$	1	$N112^0$	6		
		$N98^0$	5		
TOTAL	27	TOTAL	107	TOTAL	27

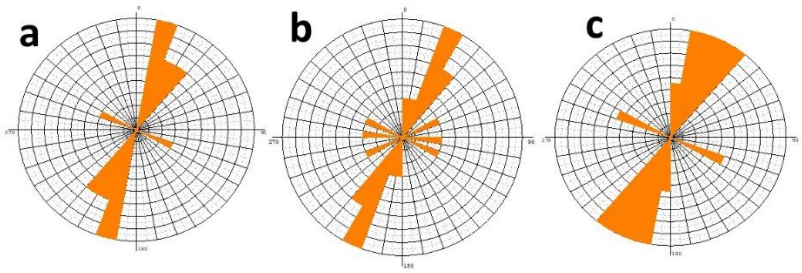


Figure 9: Rose Plot of Joint Readings On: (A) Diorite (B) Granite Gneiss and (C) Phyllite

Discussion

Geology and Tectonic Setting

Many of the Nigerian schist belts are associated with diverse mineral deposits; the distribution of the minerals is however not uniform across the different belts. The Anka belt on the other hand, is unique because it contains an appreciable amount of volcanic rocks, varying in composition from acidic to basic, which are interlayered with the clastic sedimentary rock (Adekoya, 2021, Bafor, 1988 Agunleti and Najime, 2020). This underscores the fact that some syngenetic as well as epigenetic events could have contributed to enhance the reconcentration of mineral deposits. A suite of mafic-ultramafic rocks which have been converted by regional metamorphism largely into amphibolites and metaultramafics are emplaced as lenticular to ovoid bodies within these metasediments. The process of intrusion of these bodies as well as their regional metamorphic transformations could be contributing factor to mineralization.

The dominant folds associated with the Anka schist belt are upright with axial surfaces trending NNE-SSW (Agunleti, et al, 2020b, Augie et al, 2022). Cleavages vary from slaty to phyllitic and strike NNE-SSW with vertical or near vertical dips and vary from slaty to phyllitic and strike NNE-SSW with vertical or near vertical dips (Holt, 1982, Salau, et al, 2016, Garba, 2000, Garba, 2003). Structures interpreted from remote-sensing data as well as those obtained from field data portray a generally identical trend of NE – SW. This trend finds concurrence with some of those reported by earlier workers in the present area of study. Furthermore, the relatively shallow depths of ore-bearing veins in the areas engenders an easy find for artisanal mining activities characterized by widespread abandoned mine pits that constitute sources of environmental degradations (Sani et al, 2025, Azubuike, 2011). A proper understanding of the geology and structure as intended by the present effort would engender an environmentally sustainable exploration and exploitation.

Implications for Mineral Exploration

The gold and lead-zinc-copper mineralization associated with the northwestern schist belts of Nigeria including the Anka schist belt are hosted by veins of about 1.5m wide and of an excavation depth of mine working 4m deep and set within the phyllitic country rock (Saleh, 2011, Ajibade and Wright, 1988, Adekoya, 1998). The veins follow a general structural trend of $N18^0E$ which corresponds to the major structural control exhibited by the serpentinites which have been emplaced at the margins of the Anka fault system (Adekoya, 2002, Garba and Akande, 1992, Fitches et al 1988). Many veins are currently being mined in these areas (Wano and Dareta Tungan Kudaku). The veins leave no topographic expression, but appear on the surface of the phyllites as dykes/pegmatites dykes (in the case of the lead-zinc), which usually lead to the discovery of the ore minerals.

The lead-zinc-copper in the study area is of a hydrothermal origin and is derived from the leaching of lead-zinc-copper elements from surrounding country rocks and the concentration of these elements in the cracks and fissures to form the vein deposits. The fluids responsible for this Pb-Zn-Cu mineralization are also responsible for the gold occurrence and the tourmalines reported in the area (Garba and Akande, 1992, Oke et al, 2014, Garba, 1988, Akande et al, 1988). The presence of pyrite inclusions within the lead-zinc-copper and discovery of leached capping (gossans) which is typical of sulphides) on the top of most regions of some parts of the lead –zinc-copper veins strongly proves that the Pb-Zn-Cu were probably precipitated or deposited by the same fluids with the fissures within the phyllites forming favourable sites for migration and depositions.

CONCLUSION

While the use of remote-sensing data is no substitute for good field mapping, it has the most value in areas where the surficial geology is either very poorly, or not very well known. Where poorly known, it provides a preliminary reconnaissance tool leading to the establishment of a synoptic structural pattern of an area. The use of remote sensing approaches in lithological discrimination are influenced by difference in reflectivity of different rock types in the visible to shortwave portions. Hence the need for ground-truthing.

The lead-zinc-copper in the study area is of a hydrothermal origin and is derived from the leaching of lead-zinc-copper elements from surrounding country rocks and the concentration of these elements in the cracks and fissures to form the vein deposits. The fluids responsible for this Pb-Zn-Cu mineralization are also said to be responsible for the gold occurrence and the tourmalines. The geology and structural trends of these rock units and their relationship to mineralization is of significance as fissures associated with the lithologies are key migration and deposition pathways for ore-bearing fluids. Therefore, an understanding of the geology and associated structures could serve as baseline information for mineral exploration in the Anka area.

REFERENCES

Adekoya, J. A. (2021). *Metallic and industrial minerals of Nigeria*. College press, Ibadan, Nigeria, 425.

Adekoya, J. A. (2002). Relict Sedimentary Features in Metamorphosed Proterozoic Banded Iron-Formations, Northern Nigeria, *Nigerian Journal of Science*, 36(2), 129-138.

Adekoya, J.A (1998). The geology and geochemistry of the Maru banded Iron-Formation, Northwestern Nigeria. *Journal of African Earth Sciences* 27, (2), 241–257.

Agunleti, Y.S., Najime, T., Ibrahim, A. A. & Magaji, S. S. (2020). Geology and petrographic studies of rocks in Anka

Sheet 52, Northwestern Nigeria. *Journal of Environment and Earth Science*, 10(1), 53–66. https://doi.org/10.7176/JEES/10-1-06

Agunleti, Y.S. & Najime, T. (2020). Tectonic settings and petrogenesis of Pan-African S-type granitoids in Anka Schist Belt, NW, Nigeria. *Journal of Natural Sciences Research*, 10(2), 31-45. https://doi.org/10.7176/JNSR/10-2-08

Ajibade, A. C. & Wright, J. B. (1988). Structural Relationships in the Schist Belts of Northwestern Nigeria, in: Oluyide, P. O., Mbonu, W. C., Ogezi, A. E., Egbuniwe, I. G., Ajibade, A. C. and Umeji, A. C. (Eds.), *Precambrian Geology of Nigeria*, (pp. 103-110) Publication of the Geological Survey of Nigeria, Kaduna.

Akande, S.O., Fakorede, O. & Mucke, A. (1988). Geology and genesis of gold-bearing quartz veins at Bini Yauri and Okolom in the Pan-African domain of Western Nigeria, *Geologie en Mijnbouw*, 67 (1), 41–51. https://njgjournal.nl/index.php/njg/article/view/12965.

Augie, A. I., Adamu, A., Salako, K. A., Alkali, A., Narimi, A. M., Yahaya, M. N., & Sani, A. A. (2022). Assessment for gold mineralisation potential over Anka Schist Belts, NW Nigeria, using aeromagnetic data. *FUDMA Journal of Sciences, 5*(4), 235–242. https://doi.org/10.33003/fjs-2021-0504-810

Azubike, O.C. (2011). *Update on the lead poisoning incident in Zamfara State Nigeria*. Paper presented at the regional multi-stakeholders workshop, Anglophone West Africa, sub-Regional action planning on mercury use in Artisanal and small scale gold mining

Bafor, B.E. (1988). Some geochemical consideration in the evolution of the Nigerian Basement in the Egbe area of southwestern Nigeria. In Oluyide, P.O. et al (Eds), *Precambrian Geology of Nigeria*, (pp. 277 – 288) Geological survey agency of Nigeria.

Agunleti, Y. S., Najime, T., Ibrahim, A. A. & Magaji, S. S. (2020a). The application of airborne geophysical and satellite imagery data in the delineation of rock boundaries and structural lineaments in Anka Sheet 52, Northwestern Nigeria. *Journal of Environment and Earth Science*, 10(1), 37–52. https://doi.org/10.7176/JEES/10-1-05.

Drury, S.A. (2001). *Image Interpretation in Geology*, third ed. (pp. 243) Nelson Thornes, Cheltenham, UK.

Elueze, A.A., (1981). Goechemistry and petrotectonic setting of Meta sedimentary rocks of the schist belt of Ilesha area S.W Nigeria. *Precambrian Research*, 19 167-177. https://doi.org/10.1016/0301-9268(82)90057-2.

Emofurieta, W.O. & Ekuajemi. V.O. (1995). Lime products and Economic Aspects of Igbetti, Ososo and Jakura Marble deposits in S. W Nigeria. *Journal of Mining and Geology*, 31(1), 89-97.

Fitches, W.R., Ajibade, A. C., Egbuniwe, I. G., Holt, R. W. & Wright, J. B. (1985). Late Proterozoic schist belts and plutonism in NW Nigeria. *Journal Geological Society London* 142, 319-337. https://doi.org/10.1144/gsjgs.142.2.0319.

Gad, S., & Kusky, T. (2002). Lithological mapping in the Eastern Desert of Egypt, the Barramiya area, using Landsat thematic mapper (TM). *Journal of African Earth Sciences*, 44, 196–202. https://doi.org/10.1016/j.jafrearsci.2005.10.014.

Garba, I. (2003). Geochemical characteristics of mesothermal gold mineralization in the Pan-African (600±150 Ma) basement of Nigeria. *Applied Earth Science* (Transaction of the Institution of Mining and Metallurgy, Section B), 112, 319-325. https://doi.org/10.1179/037174503225003143.

Garba, I. (2000). Origin of Pan-African mesothermal gold mineralization at Bin Yauri, Nigeria. *Journal of African Earth Sciences*, 31, 433-449. https://doi.org/10.1016/S0899-5362(00)00098-1.

Garba, I. & Akande, S.O. (1992). The Origin and Significance of non aqueous CO2 fluid inclusion in the auriferous veins of Bin-Yauri, northwestern Nigeria. *Mineral Deposita*, 27 249-255. https://doi.org/10.1007/BF00202550.

Garba, I. (1988). The variety and possible origin of the Nigerian gold mineralization: Okolom Dogondaji and Waya veins as case studies. *Journal of African Earth Sciences* 7 981-986. https://doi.org/10.1016/0899-5362(88)90011-5.

Hofmann, A., Dada, S., Olobaniyi, S. B., Ajigo, I., Elburg, M., Caxito, F. A., & Bekker, A. (2025). Schist belts of the Benin–Nigeria Shield reveal a Neoproterozoic history. *Terra Nova, 37*(4), 239–249. https://doi.org/10.1111/ter.12772

Holt, R.W. (1982). *The Geotectonic evolution of Anka Belt in the Precambrian Basement Complex of NW Nigeria*. (Unpublished Ph.D. Thesis, the Open University).

Ibrahim, W.S., Watanabe, K., Yonezu, K. (2016): Structural and litho-tectonic controls on Neoproterozoic base metal sulfide and gold mineralization in North Hamisana shear zone, South Eastern Desert, Egypt: the integrated field, structural, Landsat 7 ETM+ and ASTER data approach. Ore Geol. Rev. 79, 62–77.

Kumar, C., Shetty, A., Raval, S., Sharma, R. & Ray, P.K.C. (2015). Lithological Discrimination and Mapping using ASTER SWIR Data in the Udaipur area of Rajasthan, India. Procedia, *Earth and Planetary Science*, 11, 180–188. https://doi.org/10.1016/j.proeps.2015.06.022.

Oke, S.A., Abimbola, A.F & Rammlmair, D. (2014). Mineralogical and geochemical characterization of gold bearing quartz veins and soils in parts of Maru schist belt area, northwestern Nigeria. *Journal of Geological Research* (Hindawi Publishing Corporation) 314214, 1 – 17. https://doi.org/10.1155/2014/314214.

Patra, I., Chaturvedi, A. K., Srivastava, P. K. & Ramayya, M. S. (2013). Integrated Interpretation of Satellite Imagery, Aeromagnetic, Aeroradiometric and Ground Exploration Data-sets to Delineate Favorable Target Zones for Unconformity Related Uranium Mineralization, Khariar Basin, Central India. *Journal Geological Society of India*. 81, 299-308. https://doi.org/10.1007/s12594-013-0041-7.

Perry, J. & Vincent, R. K. (2009). ASTER brightness and ratio codes for minerals: application to lithologic mapping in the West-Central Power River Basin, Wyoming. *Rev. Econ. Geol.* 16, 143–168.

Rahaman, M.A (1988). Recent advances in the study of the Basement Complex of Nig. In: Oluyide, P.O. et al (Eds), *Precambrian Geology of Nig*eria. (pp. 11-43), Geology Survey Nig. Publishing

Richards, J.A., (2013). *Remote Sensing Digital Image Analysis* (Fifth). Springer Berlin Heidelberg.

Rogge, D.M., Rivard, B., Zhang, J., Sanchez, A., Harris, J. & Feng, J., (2007). Integration of spatial–spectral information for the improved extraction of end members. *Remote Sens. Environ.* 110 (3) 287–303. http://doi.org/10.1016/j.rse.2007.02.019.

Rowan, L.C.& Lathram, E.H. (1980). Mineral exploration in: B.S. Siegal, A.R. Gillespie, (Eds.), *Remote Sensing in Geology* (pp. 553–605) John Wiley and sons, New York.

Sabins, F.F. (1999). Remote sensing for mineral exploration. *Ore Geology Reviews*, 14(3), 157-183. https://doi.org/10.1016/S0169-1368(99)00007-4.

Sabins, F.F. (1996). *Remote Sensing: Principles and Interpretation*, (third edition) W. H. Freeman and Company, New York.

Salau, S. L., Danbatta, U. A., & Agunleti, Y. S. (2016). The interpretation of aeromagnetic and satellite imagery for structures coincident with gold mineralization in Anka Schist Belt, northwestern Nigeria. *IOSR Journal of Applied Geology and Geophysics, 4*(5), 29–34. https://doi.org/10.9790/0990-0405022934

Saleh, J. (2011). Lead poisoning in Zamfara state, Nigeria: a review. *A publication of environment and health.*

Sani, A. A., Aku, M. O., & Saleh, M. (2025). A fuzzy logic approach for gold mineralization zones mapping in western parts of Zamfara State, north-western Nigeria based on harmonized Landsat and Sentinel-2 L30 data. *Dutse Journal of Pure and Applied Sciences, 11*(4d), 244–263.

Sijmons, K. (1987). Computer-assisted detection of linear features from digital remote sensing data. *ITC Journal 1*, 23–31. https://documentation.ensg.eu/index.php?lvl=notice_display&id=24369.

Stefouli, M., Angellopoulos, A., Perantonis, S., Vassilas, N., Ambazis, N. & Charou, E. (1996). *Integrated Analysis and Use of Remotely Sensed Data for the Seismic Risk Assessment of the Southwest Peloponnessus Greece. First* Congress of the Balkan Geophysical Society, Athens Greece.

Turner, D.C. (1983). Upper Proterozoic schist belts in Nigerian sector of the Pan African Province of West Africa. *Precambrian Research*, 21, 55-59. https://doi.org/10.1016/0301-9268(83)90005-0.

Umaru, A. O. & Ibrahim, A. K. (2020). Utilizing Landsat-8 sensor operational land image data for hydrothermal alteration mapping within Anka Schist Belt, Northwestern Nigeria. *Zbornik Radova Departmana za Geografiju, Turizam i Hotelijerstvo*, 49(2), 127–149. https://doi.org/10.5937/zbdght2002127a

Van der Meer, F. D., Van der Werff, H. M., Van Ruitenbeek, F. J., Hecker, C. A., Bakker, W. H., Noomen, M. F. & Woldai, T. (2012). Multi-and hyperspectral geologic remote sensing: A review. *International Journal of Applied Earth Observation and Geoinformation* 14(1), 112-128. http://doi.org/10.1016/j.jag.2011.08.002.

Woakes, M. & Bafor, B.E. (1984). Primary gold mineralization in Nigeria. in: R.P. Foster (ed.) GOLD '82. *The Geology, Geochemistry and Genesis of Gold Deposits*, (pp. 661-671) A.A. Balkema, Rotterdam.

Zoheir, B. & Emam, A., (2014). Field and ASTER imagery data for the setting of gold mineralization in Western Allaqi–Heiani belt, Egypt: A case study from the Haimur deposit. *Journal of African Earth Sciences* 99, 150-164. https://doi.org/10.1016/j.jafrearsci.2014.06.007

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