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Litho-Structural Analysis of the Sara-Fier Ring Complex, Northcentral Nigeria

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Abstract

The Sara-Fier igneous Complex is an excellent example of high level, anorogenic granite suites of North-central Nigeria. It is part of the larger Younger granite province, which has been traced to the central HoggarProvince. The Sara-Fier Complex is characterised by different variety of intrusive and extrusive granitic rocks. Although the area is interesting in terms of geologic-tectonic setting and potentials, detailed litho-structural assessment and interpretation of features in this area is lacking, probably due accessibility problem occasioned by the hilly and rugged nature of these terrains. For these reasons application was made of principal component analysis (PCA) and band ratio (BR) techniques on Landsat 8 data for lithological discrimination while for structural interpretation, filtering techniques of edge enhancement and edge detection was applied on digital elevation model (DEM) acquired by shuttle radartopographic mission (SRTM) sensor. The Principal Component Analysis (PCA), Band Ratioing (BR), Minimum Noise Filter (MNF), False Colour Composite (FCC) image as well as directional filters help in the discrimination between different granitic rock units in the area. This was found to conform to field verification of lithology and structures subsequently conducted. For structural interpretation, DEM was used to generate shaded relief model and edge maps which enable detailed structural interpretation. The structural features extracted from remote sensing data were integrated with the updated geological map to generate a litho-structural map of the study area. Integration of spectral information and structural information from images with geological data provide a better understanding of the spatial relationships between the litho-tectonic units. The general trend of the lineaments in study area can be grouped into three major trends of as WNW-ESE, NNE-SSW and ENE-WSW. It is observed that the orientation of the extracted lineaments varies across the volcanic centres. For instance lineament in centre one has a dominant orientation of NNE-SSW; in centre two, the dominant orientation is WNW-ESE. Centre three and four are similar in orientation to centre one, while centre five is essentially ENE-WSW in orientation. Around the northern part of the study area, the biotite granite group III, hornblende biotite granite, riebeckite granite as well as hornblende pyroxene-fayalite granite were affected by the Kwappa fault line which causes displacement in these units. It is also observed that the density of lineament is relatively higher in this northern part of the study area. Furthermore, lineaments associated with the fault line are roughly E-W in orientation, with a geologic implication of gemstone mineralization along the fault plane of Kwappa valley. Density of lineaments is relatively low to the south, in volcanic centres four and five. These results contribute towards a better understanding of regional tectonics of the study area. It also underscores the relevance of remotely acquired data as aid to geological mapping and mineral exploration.

Keywords

Sara-Fier, Ring complex, Structure, Granite, Landsat

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Introduction

Sara and Fier, which are the type locations for the complex, are two localities within Bauchi and Plateau states respectively, located in Pankshin sheet 190 and Maijuju sheet 169 and lies between latitudes 9°14'N and 9°38'N, and longitudes 9°17'E and 9°30'E. Sara-Fier complex forms part of the eastern margin of the plateau Younger Granite province, standing apart from the main group of plateau Younger Granites, which lies to the west and northwest, (Figure 1). It is composed almost entirely of intrusive rocks with reportedly preserved remnants of volcanic in some places [1].

The utility of remotely sensed data in geological applications such as lithological discrimination, mineral detection, mineral potential and hydrothermal alteration mapping at various scales have shown agreat success [2-5]. Spaceborne 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 [3].

Lineaments have been defined as extended mappable linear or curvilinear features of a surface whose parts align in straight or nearly straight lines

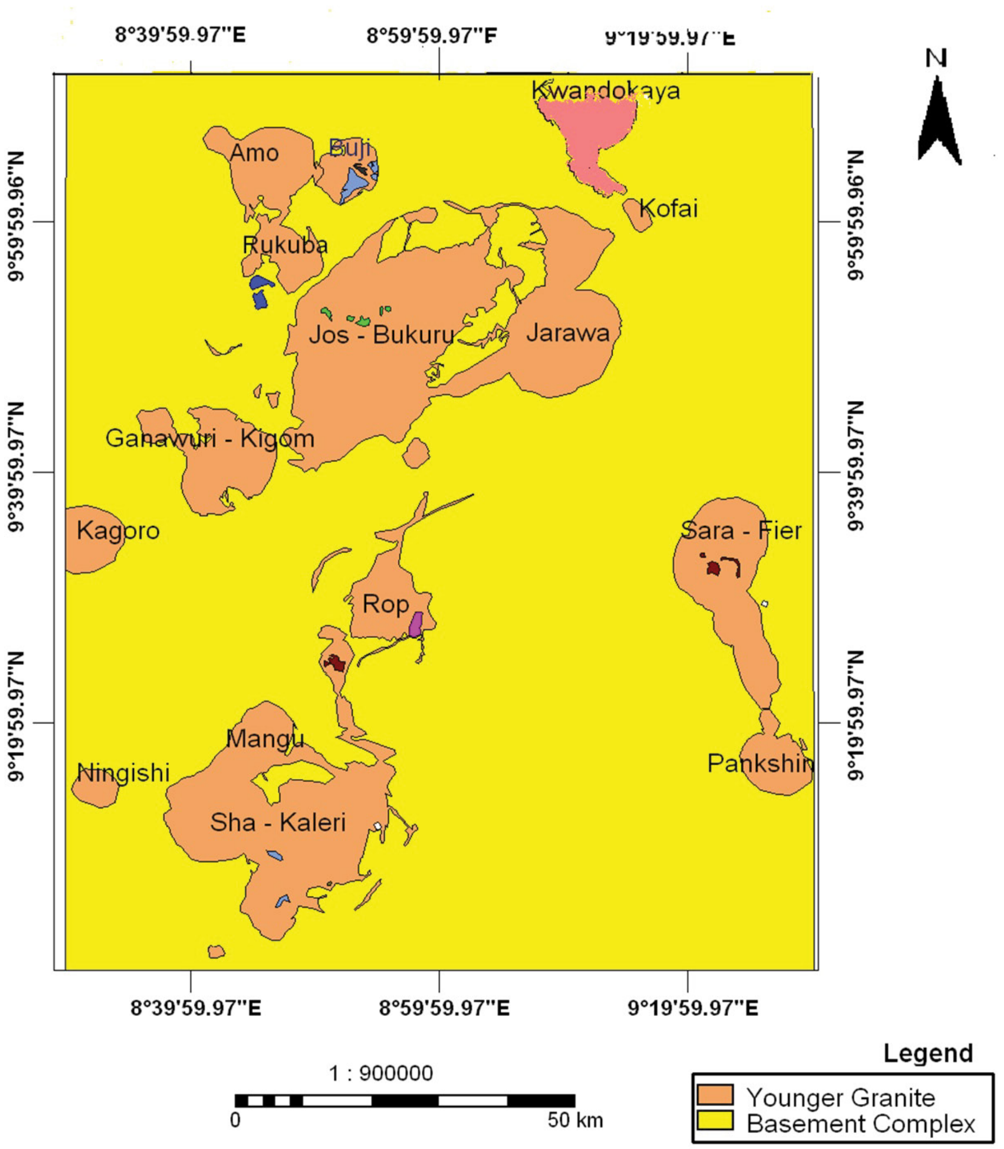

Figure 1: Sara-Fier Complex within the Younger Granite province of Jos Plateau (Modified after Buchanan, et al. [24]).

that may be the expression of folds, fractures, or faults in the subsurface [6]. Fractures are structural features emplaced by tectonic deformation on rocks. Structural mapping is considered very important in several aspects of geosciences such as mineral exploration [7], hot spring detection, hydrogeological studies [8], earthquake and landslide risk assessment and site selection for engineering construction of dam and bridges [9]. 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 [7]. 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.

Two categories of computerized image processing procedures are commonly used for lineament extraction. The first involves mainly the enhancement of linear features using standard image processing methods such as edge detection and directional filters for subsequent visual interpretation while the second category involves automatic computer processing of the original digital data for the production of a lineament map [10]. Additionally, various types of remotely sensed data have been used for lineament extraction.

Most of the previous studies in the area have focused more on geochemical investigations, [11-13]. There has not been detailed regional geological assessment and structural interpretation of structural features in the area due to inaccessibility as a result of thick vegetation. This study, therefore, integrates Landsat 8 and Shuttle Radar Thematic Mapper (SRTM) for lithological and structural interpretation in the Sara-Fier ring complex.

Regional Geological Setting

The Younger Granite ring complexes of Nigeria (Figure 1) form part of a wider province of alkaline anorogenic magmatism which in turn is located within a larger Pan African Mobile Belt. The Pan African mobile belt is sandwiched between the geologically more stable and older West African Craton and Congo Craton. The Younger Granite province is characterized by numerous high-level, non-orogenic granitic ring complexes that are confined to a narrow intrusive zone, extending for about 1300 km from the northern Air region of Niger Republic to the margin of the Benue valley in Nigeria and some part of Cameroon. These complexes range in age from late Paleozoic to Tertiary. Rb/Sr whole rock dating indicates that the oldest complex of Adrar Bous in the north of Niger is Ordovician in age, with progressively younger ages southwards. The most southerly ring complex of Afu is Late Jurassic in age [11]. The Nigerian occurrence of the Younger Granite Complex is geographically restricted to the central part of the Country, (Figure 2). These alkaline ring complexes were emplaced in various parts of the African continent, following the Pan-African Orogeny and during one or more successive periods of Phanerozoic anorogenic magmatism, [11,14-16]. Aeromagnetic anomalies suggest that a series of buried NE-SW lineaments of incipient rifts controlled the disposition of the individual complexes [17].

Materials and Methods

Published literature of the Sara-Fier Complex was used as a geological guide to interpret and assess the image results while software packages such as ENVI® 4.8 and ArcGIS® 9.3 were used to process the imagery. 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° directional

Figure 2: Generalized Geological Map of Nigeria (Modified after Ajibade, et al. [25]).

filters, 45° directional filter and 90° 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 [18]. 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 [19]. 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 [20,21]. PCA involves transformation of multivariate data into new coordinate system. Principal component analysis (PCA) was done using the MNF result as input.

Results and Discussions

Pre-existing geological maps were updated by analysis of Landsat8 multispectral data using PCA and MNF, and SRTM DEM data using edge enhancement, edge detection and shaded relief model. The colour, morphology, roughness and texture relating to each lithology in the processed remote sensing data were evaluated in order to update the geometry of the lithological units. The different processed imagery show comparative effectiveness in highlighting the different lithological units. The update was therefore restricted to lithologies that can be identified unquestionably in the processed data. Structural features were extracted using both automated and visual approach. The structural features extracted include fold orientations, fractures and faults. Lineaments extracted from DEM are mostly those induced by lithological boundaries which were recognised as boundaries between the volcanic centres within the granite suite. Fractures were found to cut across lineaments almost perpendicularly. The structural features extracted from remote sensing data were integrated with the updated geological map to generate a litho-structural map of the study area (Figure 3). Integration of spectral information and structural information from images with geological data provide a better understanding of the spatial relationships between the litho-tectonic units. Although Shuttle Radar Thematic Mapper (SRTM) image did not give optimal discrimination between the different granitic rocks, which are more discriminated by other imagery, it nevertheless highlights major structures such as faults and boundaries between volcanic centres.

Turner [1] identified five volcanic centres within the Sara-Fier Complex. Centre one is the largest but much of the original structure has been destroyed by the development of later centres. Centre two forms the compact upland massif of the northern Sara hills. Centre three is smaller than centres one and two, while centre four occupies the area of the Fier hills and is elliptical in shape with a N-S orientation. Centre five is the Pankshin complex constituting the southernmost part of the Sara-Fier Complex. Examination of results reveals that the Younger Granite suites form resistant elongate bodies, occurring as stocks, and are well exposed enough to be identified from optical remote sensing imagery. The adjoining, undifferentiated Basement Complex rocks generally occur as low-lying outcrops, which are in most places covered by vegetation thereby obscuring their spectral response. Furthermore, it was observed that

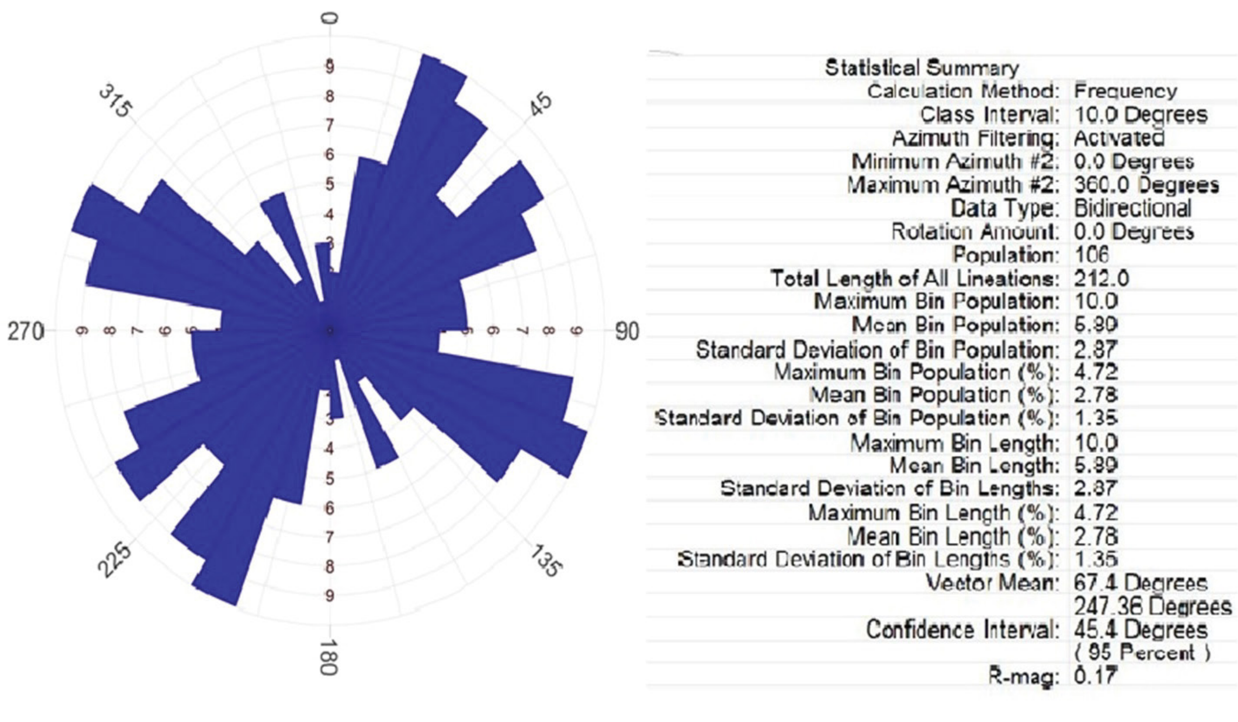

Figure 3: Rose diagram showing length and frequency of lineament from Remote sensing data.

Table 1: Eigenvector matrix and loadings of principal component analysis on Landsat 8 OLI.

COVARIANCE MATRIX			
Layer	1	2	3
1	0.00569	-0.01683	0.00587
2	-0.01683	0.09738	-0.03310
3	0.00587	-0.03310	0.02012
CORRELATION MATRIX			
1	1.00000	-0.71498	0.54915
2	-0.71498	1.00000	-0.74772
3	0.54915	-0.74772	1.00000
Eigen values			
	0.11259	0.00790	0.00270
Input Layer			
1	-0.16444	-0.06107	0.98450
2	0.92533	0.33614	0.17541
3	-0.34164	0.93983	0.00124
PERCENT AND ACCUMULATIVE EIGENVALUES			
	Eigen Value	% Eigen Values	Cumulative
1	0.11259	91.3966	91.3966
2	0.00790	6.4135	97.8101
3	0.00270	2.1899	100.0000

majority of the processed images were able to differentiate the different lithologies that makes up the granite suites due to the contrast in their spectral responses.

The result of PCA with eigenvector loading of each band and their correlation with the input bands is presented in Table 1. The value with positive or negative eigen vector loadings indicate a particular spectral responses of the target materials (reflectance or absorption), which reflect the statistical variance that would be mapped into each single PCA image as bright or dark pixels [22]. PC1 with the highest eigenvalue explains 91.40% of the total variance of the input data and has highest positive and negative correlation with band 1 and band 3 respectively.

Different layers of the processed image showed comparative clarity of display of the different granitic rock types. This necessitated the use of the different components in order to capture the different rock types in the complex. On the false colour composite map (Figure 4b), riebeckite granite stands out with pinkish grey colour while syenite is seen to have dark grey with a bold outline. Biotite granite type I and II also stand out with high relief in the image. On the minimum noise filter (MNF) image (Figure 4d), biotite granite type I and II, rhyolite and hornblende-pyroxene-fayalite granite are clearly distinguishable from the image. Biotite granite type III is only partly distinguished. Biotite granite type I is most prominently outlined in the principal component analysis (PCA; Figure 4c), followed by the hornblende-pyroxene-fayalite granite and syenite. Biotite granites type I and III are only partly distinguishable from the image. On the composite (RBG; Figure 4a) image, biotite granite type I and II are the most prominent, while rhyolites, hornblende-pyroxene-fayalite granite and syenite are next in line. Biotite granite type III is only partly outlined.

Structural trends of the study area are captured well by the remotely sensed data, particularly when compared with the geological map of the area, (Figure 5). Directional filters (Figure 6), helps to accentuate fractures and joints (lineaments) while false colour composite and the Normalized Difference Vegetation Index (NDVI) of the Landsat imagery highlighted the regional structures as well as outlines of some of the lithological units. Flow direction and hill shade images of the Shuttle Radar Thematic Mapper (SRTM) highlighted both lineament and regional structural trends. Outlines of the major rock units as well as the drainage pattern were fairly accurately delineated. Furthermore, extracted lineament map superimposed on that of drainage showed a structurally controlled pattern of drainage with channels taking their sources from the peak of the hills.

A total of 106 lineaments were extracted through automated method (Figure 7). The general trend of the lineaments in study area can be grouped into three major trends of as WNW-ESE, NNE-SSW and ENE-WSW (Figure 3). The extracted lineaments represent valleys, ridges and slope-breaks. N280° - N310° directions have the highest frequency of lineament which is followed by N20° - N40° and then N50° - N70°. Based on this frequency the trend of the lineaments in the area can be described as WNW-ESE, NNE-SSW and ENE-WSW. Most of the lineaments trending in the WNW-ESE main direction are associated with Kwappa fault, which occurs as elongate valley oriented in the NW-SE

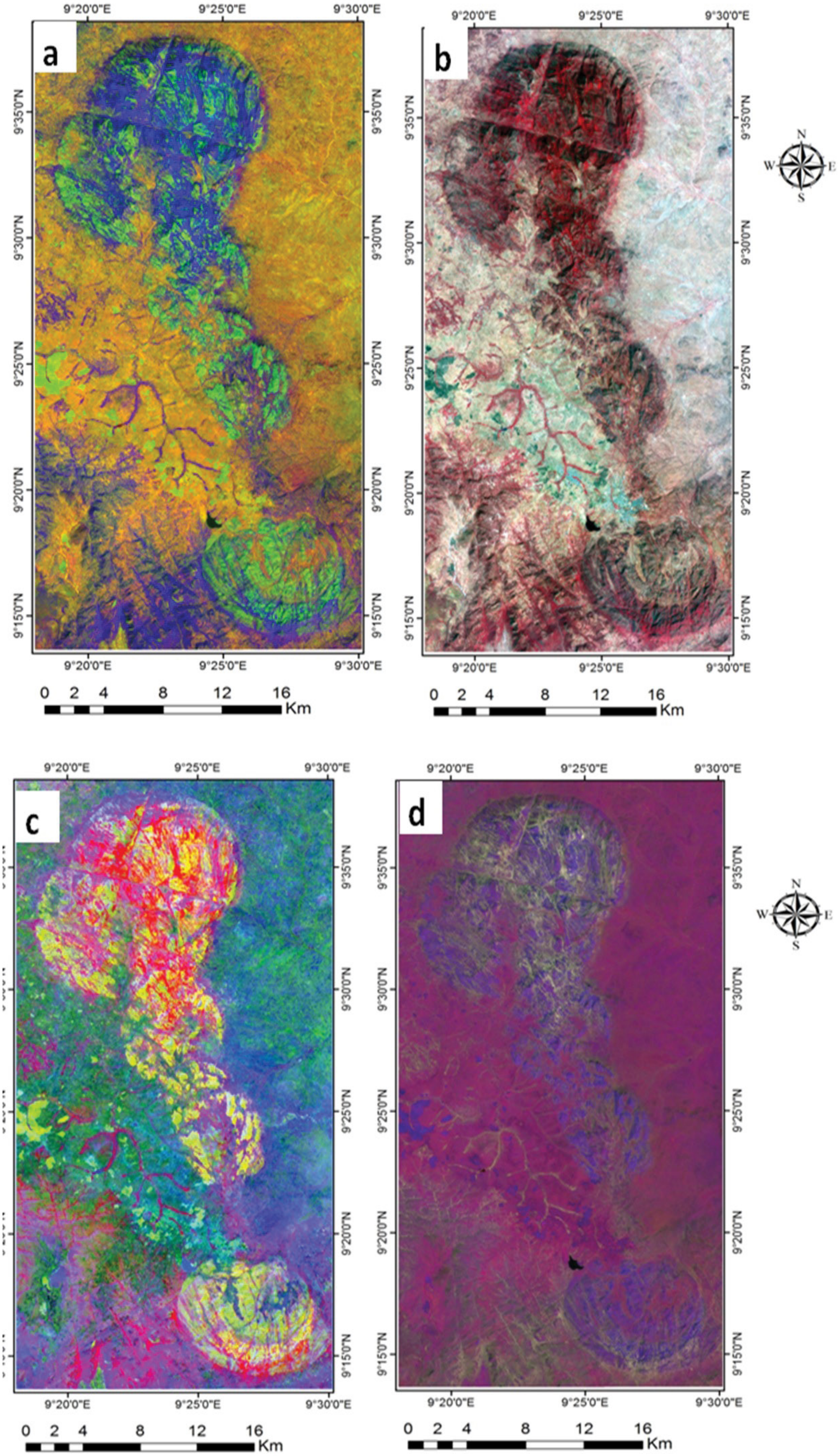

Figure 4: Landsat image of the study area displayed as: a) Colour composite of Red, Blue and Green; b) False colour composite; c) Principal component analysis (PCA); d) Minimum noise fraction (MNF).

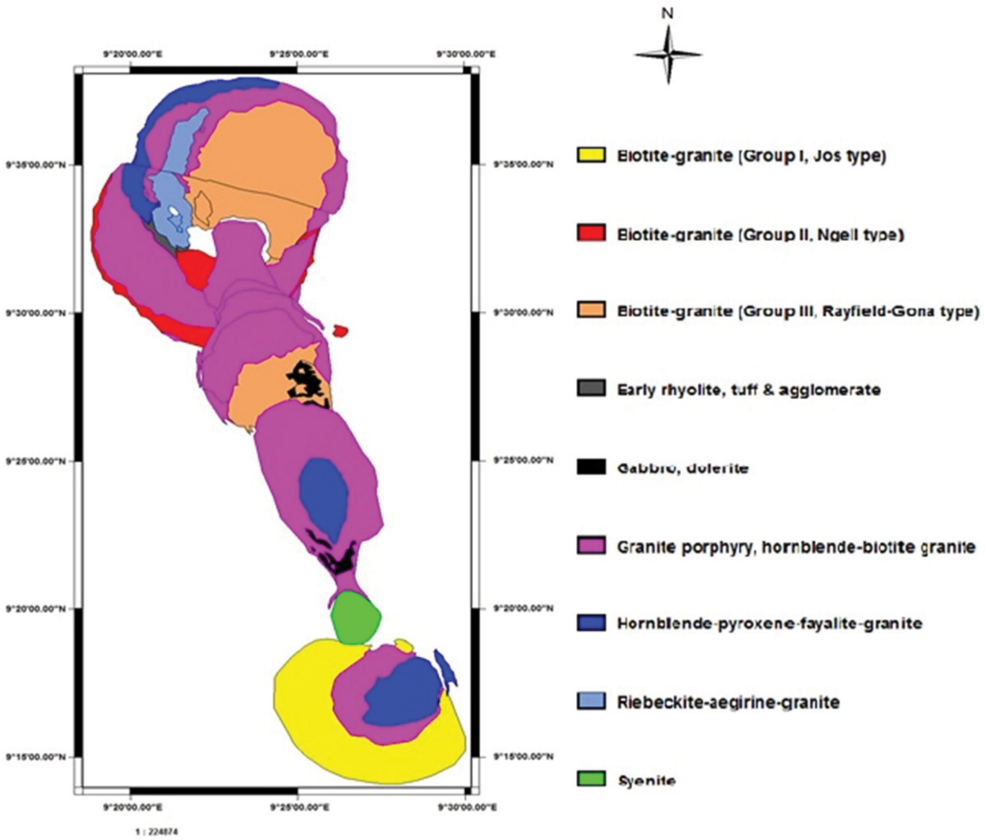

Figure 5: Geological Map of the Study Area (modified after Buchanan, et al. [22]).

direction, while small proportions of the lineament occurring in the extreme north of the complex have N-S trend. It is observed that the orientation of the extracted lineaments varies across the volcanic centres. For instance lineament in centre one has a dominant orientation of NNE-SSW; in centre two, the dominant orientation is WNW-ESE. Centre three and four are similar in orientation to centre one, while centre five is essentially ENE-WSW in orientation.

Apart from the fact that the Younger Granite were known to be highly mineralized in minerals like cassiterite, wolframite, molybdenite, some of them are also known to harbor gemstones such as topaz, emerald and sapphire, [11,23]. Kwappa valley in particular is replete with mine holes dug and abandoned by local (artisanal) miners in search of gemstones. Concentration of gemstone along Kwappa valley may not be unconnected with the Kwappa fault line from which the valley originated.

Around the northern part of the study area, biotite granite group III, hornblende biotite granite, riebeckite granite as well as hornblende pyroxene-fayalite granite were affected by the Kwappa fault line which causes displacement in these units. It is also observed that the density of lineament is relatively higher in this northern part of the study area. Furthermore, lineaments associated with the fault line are roughly E-W in orientation. Density of lineaments is relatively low to the south, in volcanic centres four and five.

Summary and Conclusion

It is possible to generate a predictive surficial geology map, based on Landsat data, which broadly defines the main surficial geology units in the study area. When the predictive map was compared visually to published surficial geology maps, there were obvious visual similarities in the distribution of the rock units. While the Landsat-derived map is no substitute for goodfield mapping, it has the most value in areas where the surficial geology is either very poorly, or very well known. Where poorly known, it provides a preliminary reconnaissance tool. The remote sensing approaches in lithological discrimination are influenced by difference in reflectivity of different rock types in the visible to shortwave portions. Based on the different methods adopted, different layers were found to

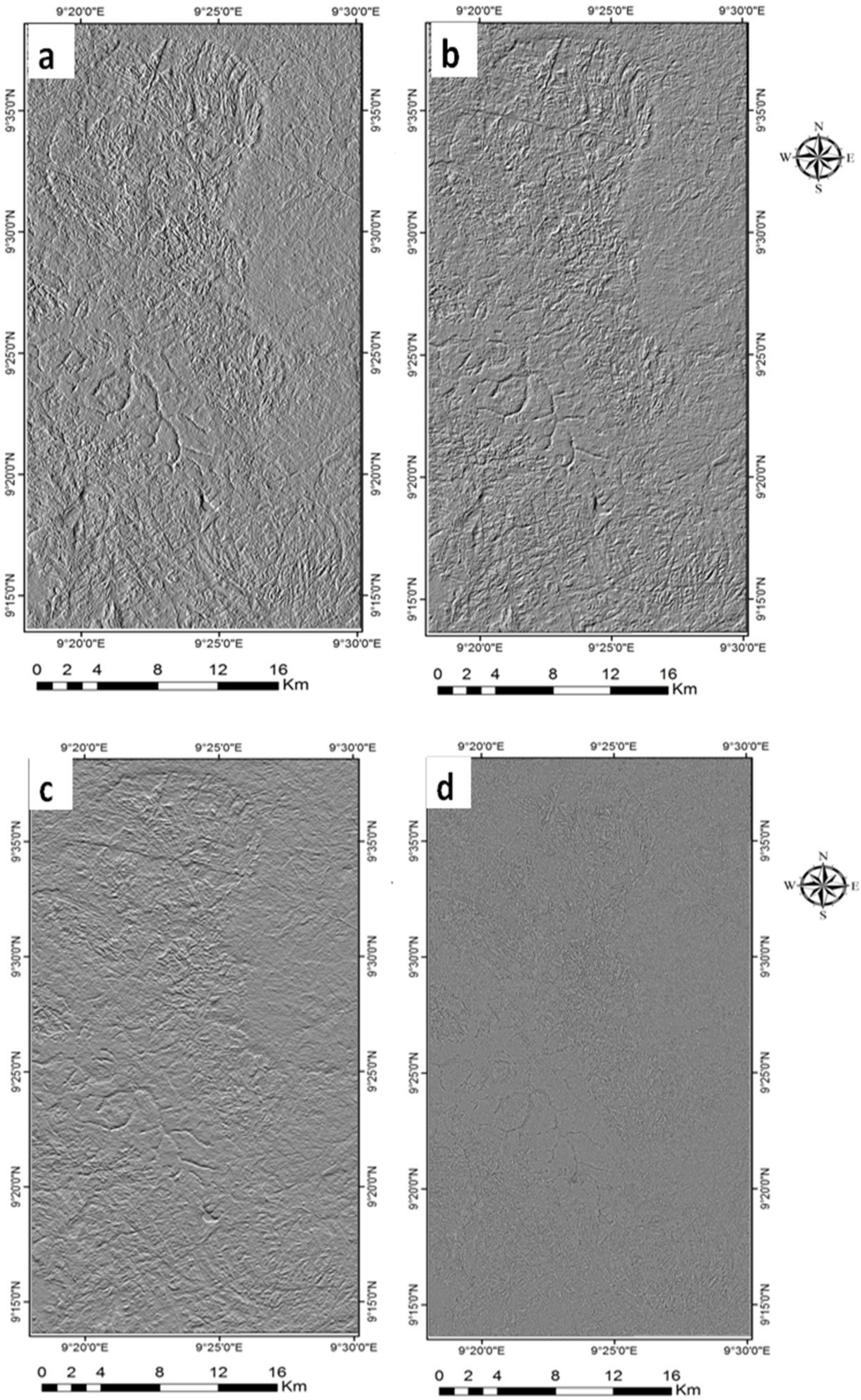

Figure 6: Directional filters to highlight fractures in different directions: a) 0° filter; b) 45° filter; c) 90° filter; d) Laplacian filter.

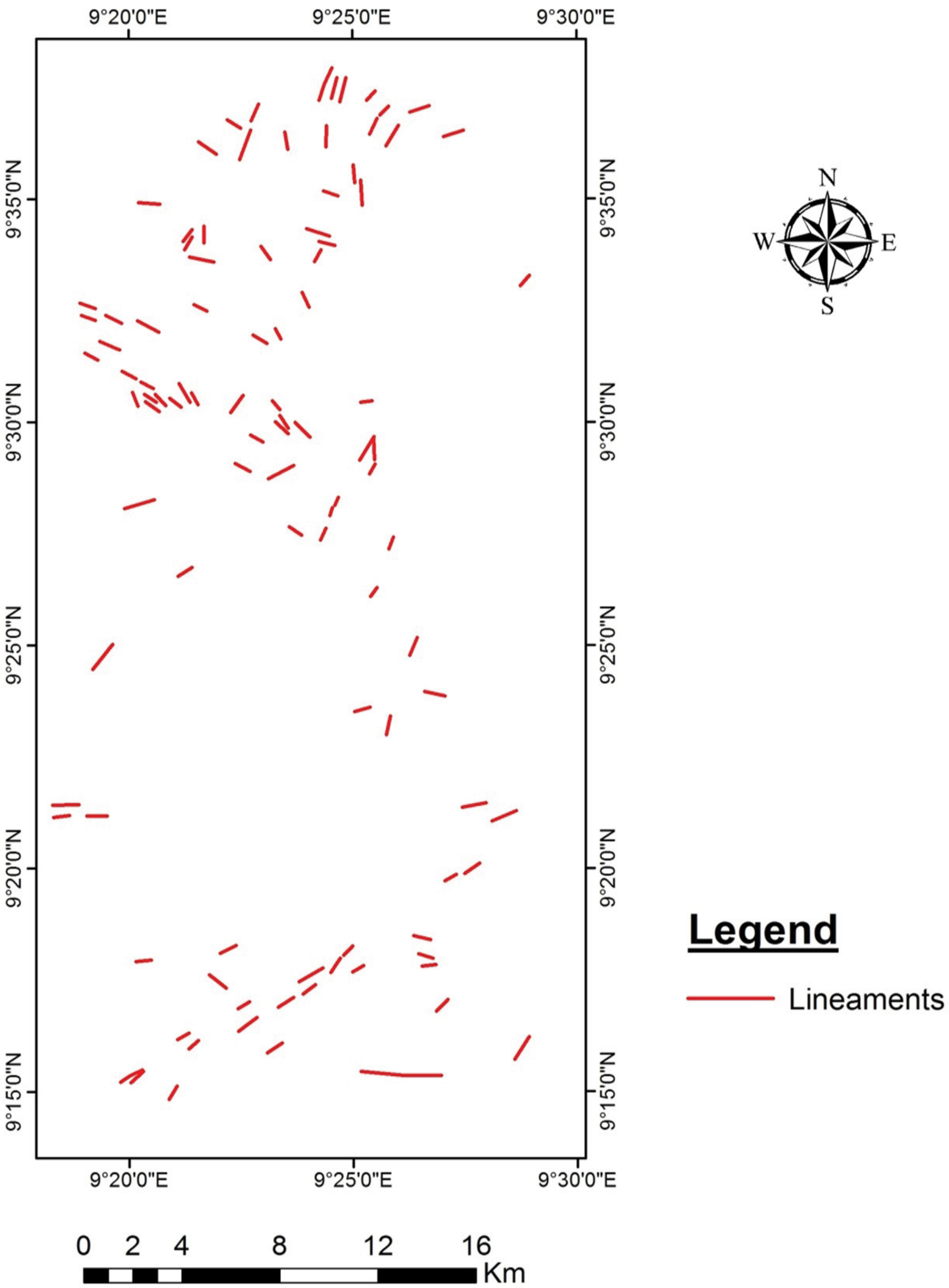

Figure 7: Lineament map derived from remote sensing data of the study area.

vary in their ability discriminate different lithology. Hence integration of airborne/satellite derived geophysical data such as gamma ray spectrometry and gravity data with optical satellite remotely sensing data will greatly improve lithological mapping in highly rugged environment such as the study area. Although vegetation cover hinders optimum retrieval of lithologic information from optical data, however radar data from SRTM enabled derivation of synoptic structural pattern of the study area. The study illustrated the effectiveness of SRTM, and Landsat data to discriminate the lithological units in the area.

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