

Lineament and Lithological Mapping of Meta-Sediments and Granitoids of Goz-Beïda (Eastern Chad) Based on Semi-Automatic Processing of Landsat 8 Oli/Tirs Images

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Abstract Using Landsat-8 OLI/TIR image combined with field and pre-existing data permit us to create lineament and lithological map of Goz-Beïda area. The PCA images were subjected to Sobel directional filters using the semi-automatic extraction method to discriminate lineaments. By combining the 7/5/1 bands in RGB mode, the PCA images (PCA1, PCA2, PCA3) in RGB mode and the ratio bands 7/5, 4/5, 1/7 are used to discriminate the lithological types. The results show that the main lineaments are characterized by NE-SW and NNE-SSW directions. The N-S, ENE-WSW and NW-SE directions correspond to mean directions. Several lithological types are discriminated: two-mica quartzite, metapelite, pyroxene monzonite, biotite granite and two-mica leucogranite. The rocks types are partially covered by alluvial deposits.

Keywords: Goz-Beïda, Landsat8 OLI/TIR, Lineament map, Lithological map and Eastern Chad

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1. Introduction

In recent decades, Landsat imaging has proved to provide interesting information related to geological mapping. They help to identify the lithological types, the geological boundaries and specially identify the lineaments. Chad is one of the countries in Central Africa (Figure 1A), made up of Precambrian crystalline rocks, formed during the Pan-African orogeny (700 - 500 Ma) [1]. These crystalline rocks are divided into five massifs: the Tibesti massif in the north, the Ouaddaï massif in the east, the Guera massif in the centre, the Mayo Kebbi massif in the south-west and the Baïbokoum massif in the south (Figure. 1B) [2,3,4]. The Goz-Beïda (study area), belongs to the southern half of the Ouaddaï massif [5]. The geological map available for this region shows poorly defined metamorphic and magmatic rocks. The available lineament map is not in detail. In this article, we use Landsat 8 OLI/TIR images to produce a new lineament map and a lithological map of Goz-Beïda.

2. Geological Setting

Goz-Beïda is located in the southern part of the Ouaddaï massif (figure B, C) and is part of the Orogenic Belt of Central Africa. Several petrographic, structural, geochemical and geochronological studies have been carried out in this area [4,5,6,7]. There are meta-sedimentary rocks (paragneiss, metapelite, quartzite and marble) are interleaved with amphibolite. These meta-sedimentary rocks, recrystallized under green-schist and amphibolite conditions, are intruded by batholiths of peraluminous leucogranite and small plutons of pyroxene monzonite, hornblende granodiorite and biotite granite forming high-K to shoshonitic calc-alkaline series [7,5]. The age of the peraluminous granites was constrained by U-Pb dating on zircon, giving 635 ± 3 Ma for biotite leucogranite and 613 ± 8 Ma for muscovite and garnet leucogranite [5]. The age of the metaluminous, high-K to shoshonitic calc-alkaline was determined at 540 ± 5 Ma for biotite granite [5]. These data allow us to conclude that the geology of the Goz-Beïda formed continental back-arc basin characterized by high geothermal gradient leading to partial melting of the middle to lower crust around 635-612 Ma. This evolution culminated in the emplacement of high-K to shoshonitic calc-alkaline plutons typical of post-collisional series following tectonic inversion of the basin [5].

Structurally, the metamorphic rocks is affected by a first phase of deformation (D_1), corresponding to composite S_0/S_1 foliation with main azimuth direction NE-SW and weak to medium dips ($9-39^\circ$) towards NW or SE [4]. This foliation is associated with mineral lineation L_1 plunging weakly (10°) to the NW. This foliation is locally affected by isoclinal P_1 folds. A second phase of deformation (D_2) corresponding to the development of axial S_2 schistosity, oriented NE-SW or NNE-SSW with shallow to steep dips ($10-79^\circ$) to the NW or ESE [4]. This schistosity is associated with L_2 lineation plunging weakly (30°) to the NW. A third phase of deformation (D_3) corresponding to P_3 folds affecting S_0/S_{1-2} foliation, and locally associated with weakly expressed S_3 axial plane schistosity, are oriented ENE or NE with moderate to steep dips ($60-75^\circ$) to the NW or NNW [4]. The dykes, lineament and lithological contact offsets, interpreted as fractures, are associated with this third phase of deformation and show a main NE-SW direction [4,5].

3. Materials and Methods

3.1. Data Used

To carry out this work, we used the following data: (a) Landsat 8 OLI/TIRS images provided by the USGS (United States Geological Survey) and freely downloaded in Geotiff format, (b) Geological map of Equatorial Africa (on the scale of 1:500,000). Sheet of Adré N°: ND-34 SE.0-74 provided by [6] and (c) Litho-structural data obtained directly from the field. Landsat 8 image data are extracted from scene 180/51, belonging to zone 34 North of the Universal Transverse Mercator (UTM) map projection and using the WGS 84 geodetic reference system. These imagery data contain 9 spectral bands from the OLI (Operational Land Imager) instrument and two spectral bands from the TIRS (Thermal Infrared Sensor) instrument, as shown in Table 1.

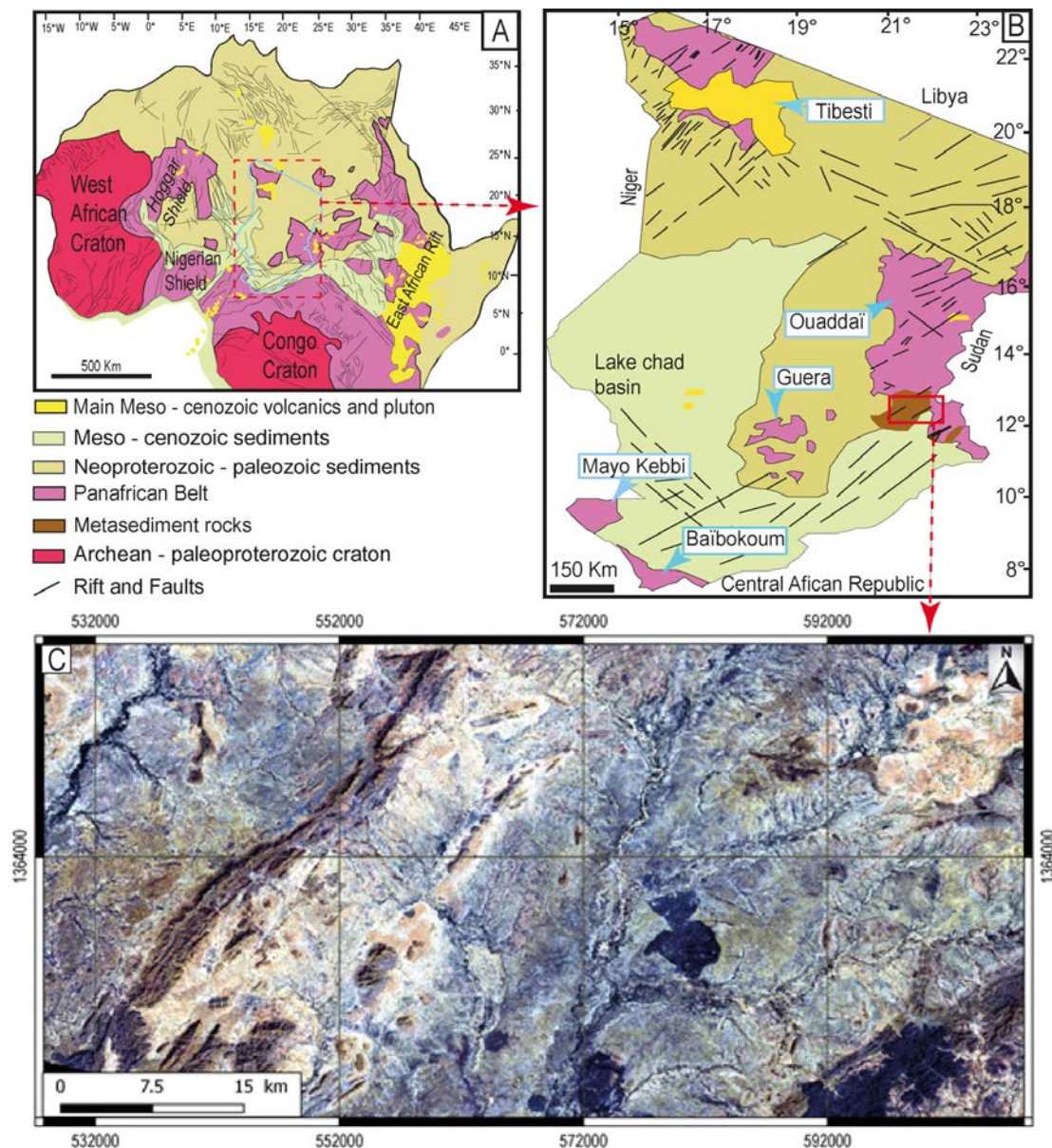


Figure 1. A) Tectonic Map of Africa, location map of Chad. The main geologic features of Africa are indicated [8,9]. B) Geological map of Chad showing the Precambrian formations. C) Satellite image of the study area pre-processed using radiometric calibration and atmospheric correction

Table 1. Characteristics of the Landsat-8 OLI/TIR bands or channels

OLI instrument		
spectral band	wavelength (μm)	Resolution (m)
Band 1 - Aerosols	0,433 - 0,453	30
Band 2 - Bleue	0,450 - 0,515	30
Band 3 - Green	0,525 - 0,600	30
Band 4 - Red	0,630 - 0,680	30
Band 5 - near infrared	0,845 - 0,885	30
Band 6 - mid-infrared 1	1,560 - 1,660	30
Band 7 - mid-infrared 2	2,100 - 2,300	30
Band 8 - Panchromatic	0,500 - 0,680	30
Band 9 - Cirrus	1,360 - 1,390	30
TIR instrument		
Bande 10 - mid-infrared	10,30 - 11,30	100
Bande 11 - mid-infrared	11,50 - 12,50	100

3.2. Processing

To make the OLI bands readable, we applied pre-processing based on radiometric calibration and atmospheric correction using the FLASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) module. Images with a lot of noise were then subjected to an inverse MNF (Maximum Noise Fraction) transformation. This operation produces surface reflectance bands with minimal noise. Specific processing is based on colored composition (CC) and consists of generating true or false color images using the Optimum Index Factor (OIF). This method results in the three bands of the 180/50 scene producing the maximum amount of information. Principal component analysis (PCA) makes the information less redundant, reducing or condensing the topographical and spectral characteristics [10,11]. For this work, PCA is applied to the 7 bands of the OLI tools, resulting in 6 components: PCA1, PCA2, PCA3, PCA4, PCA5 and PCA7 (band 6 is not taken into account). The result shows that the ACP1, ACP2 and ACP3 bands provide the most information in RGB mode. Like PCA, the band ratio method increases the topography and enhances the contrast between mineral surfaces [12]. The combinations of the colored composition of the ratio bands that can be adapted to our study area are: [7/5, 4/5, 1/7]. The ACP1 band, which contains the most information, is subjected to the Sobel filter (gradient of

dimension 7×7). The application matrices for these directional filters are presented in Table 2 and are still very effective for evaluating lineaments in four main directions: N-S, E-W, NE-SW and NW-SE [13]. These processing techniques are summarized in Figure 2.

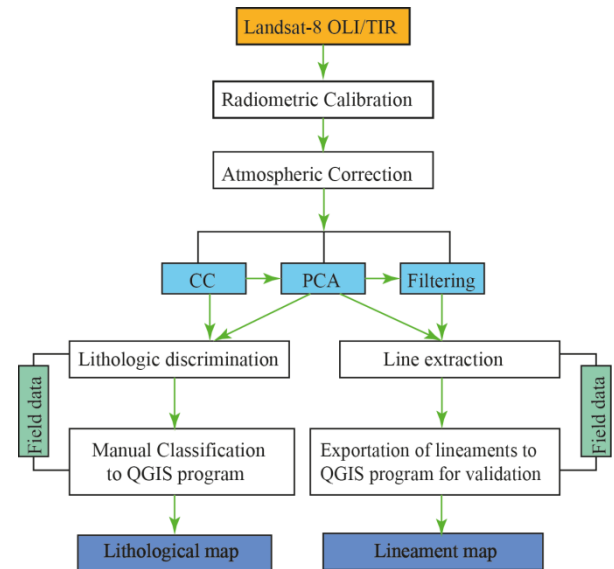


Figure 2. The various Landsat-8 OLI/TIR image processing techniques used in this study. CC (Colored Composition); PCA (Principal Component Analysis)

4. Results and Analysis

4.1. Lineament Maps of Goz-Beïda

The four directional images obtained from the Sobel filters using the Envi software are shown in Figure 3. To map all the linear structures, we are applying the semi-automatic extraction method using the Line module of PCI Géomatica (Figure 4). The extracted linear structures are overlay on the geological and topographical map (1:500,000) using Qgis software. This process is used to remove all lineaments related to human activities such as roads and houses. Lineament map obtained by manual elimination is shown in Figure 5. The directional rose diagram of these lineaments is generated by Qgis in directional classes of 20° intervals (Figure 6).

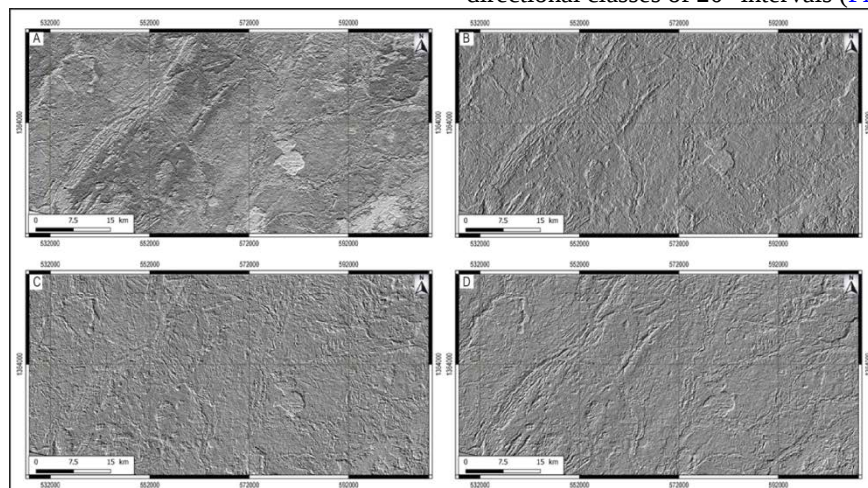


Figure 3. Images from Sobel directional filters. A) N-S direction; B) E-W direction; C) NE-SW direction and D) NW-SE direction

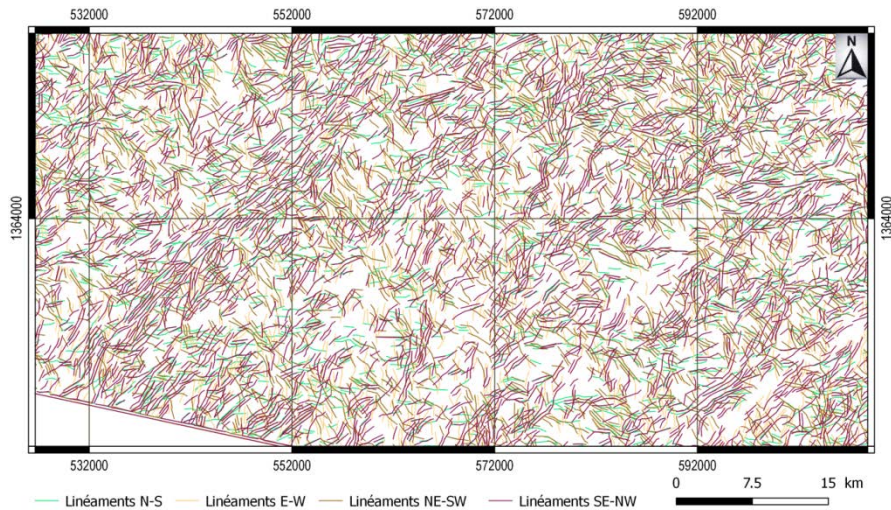


Figure 4. Lineament map obtained by automatic extraction method

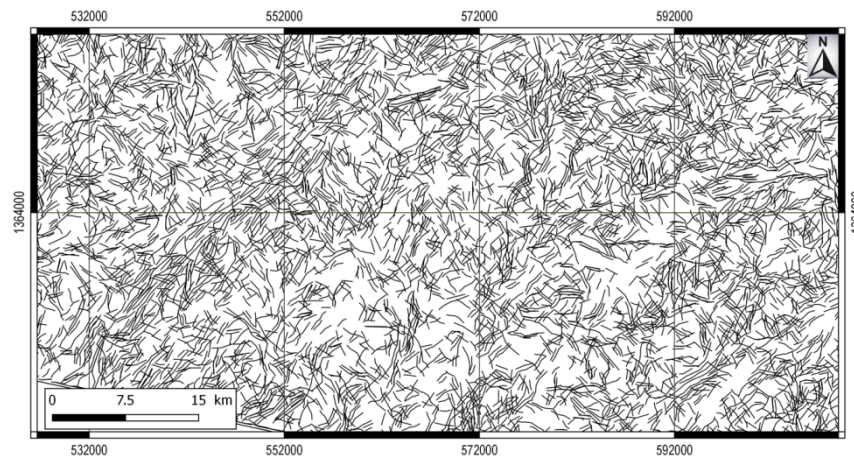


Figure 5. Lineaments map of Goz-Beïda after validation

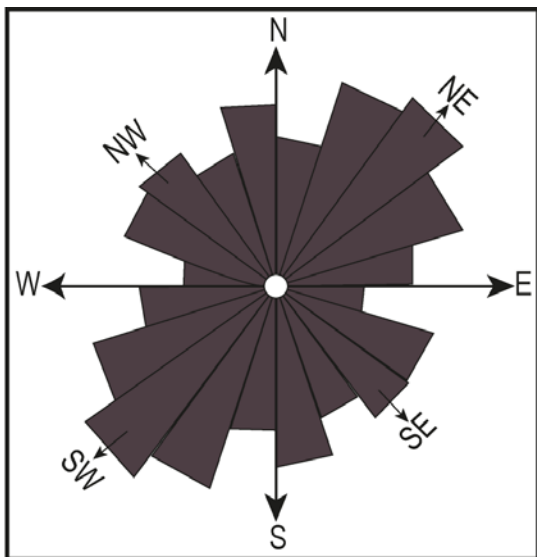


Figure 6. Rose diagram of lineament directions extracted from satellite images

4.1.1. Structural Significance of the Lineaments

The dominant lineaments are identified to strike NE-SW and NNE-SSW. The N-S, ENE-WSW and NW-SE directions correspond respectively to secondary directions. By comparing these data with those obtained in the field, the tectonic context of the study area can be

discussed. The NE-SW and NNE-SSW directions are identical with those of the S_0/S_1 foliation and the S_2 and S_3 schistosity obtained by [4]. The NW-SE direction is perpendicular to the directions of these three deformation phases (D_1 , D_2 and D_3) and corresponds to the plunge of L_1 and L_2 lineation. These directions are consistent with those of the quartz veins containing gold mineralization described by [14].

4.2. Lithological Mapping of Goz-Beïda

Images produced by this process are compared with the existing map and field data. This makes it possible to identify three zones of interest corresponding to meta-sediments, granitoids and alluvial deposits.

4.2.1. Discrimination of Meta-sediments

The meta-sediments are made up of two-mica quartzite and métapelite, characterized by a dark color, very little recognizable due to medium to intense weathering (Djerosse et al in progress) and vegetation covered (Figure 7). Principal component analysis (PCA) offers a very interesting result for discriminating metasedimentary rocks. Images resulting from this analysis (Figure 8) show that meta-sedimentary rocks are completely devoid of vegetation cover. These rocks are characterized by high surface reflectance and a dark pink color. As in the RGB

color composition analysis, it is difficult to make differentiate two-mica quartzites and metapelite in the images obtained from the principal component analysis. The similarity in color of these two lithological types is also related to the similarity in their mineralogical composition, dominated by quartz.

4.2.2. Granitoids Discrimination

Granitoids are very well discriminated and are colored red (Figure 7) or light pink (Figure 8). Compared with the field data, the granitoids with rounded or sub-rounded boundaries correspond to biotite granites and pyroxene monzonites. Those that are concordant to the foliation of the meta-sediments correspond to two-mica leucogranites.

4.2.3. Discrimination of Alluvial Deposits

The image produced by principal component analysis ACP1, ACP2 and ACP3 is very well suited to discriminating alluvial formations (Figure 8) in our study area. These are

characterized by dark blue or light blue colors.

4.2.4. Examples of Meta-sedimentary Rocks

Two lithological types of metasedimentary rocks have been identified:

- Two micas quartzites form an elongated ridge running NE-SW. They are cut by quartz veins parallel to the main foliation (Figure 9a, b and c). Thin sections show that these rocks are characterized by a grano-lepidoblastic texture. They are mainly composed of quartz, micas, garnet and sillimanite. Secondary minerals include tourmaline, zircon and opaque minerals.

- Metapelites outcrop in small hills (Figure 9d, e and f). They are also cut by quartzo-feldspathic veins, quartz veins and microfractures indicating a succession of brittle and ductile deformation. Thin sections show a grano-lepidoblastic texture, composed mainly of quartz, micas, plagioclase and garnet. Secondary minerals include tourmaline, monazite, epidote and opaque minerals.

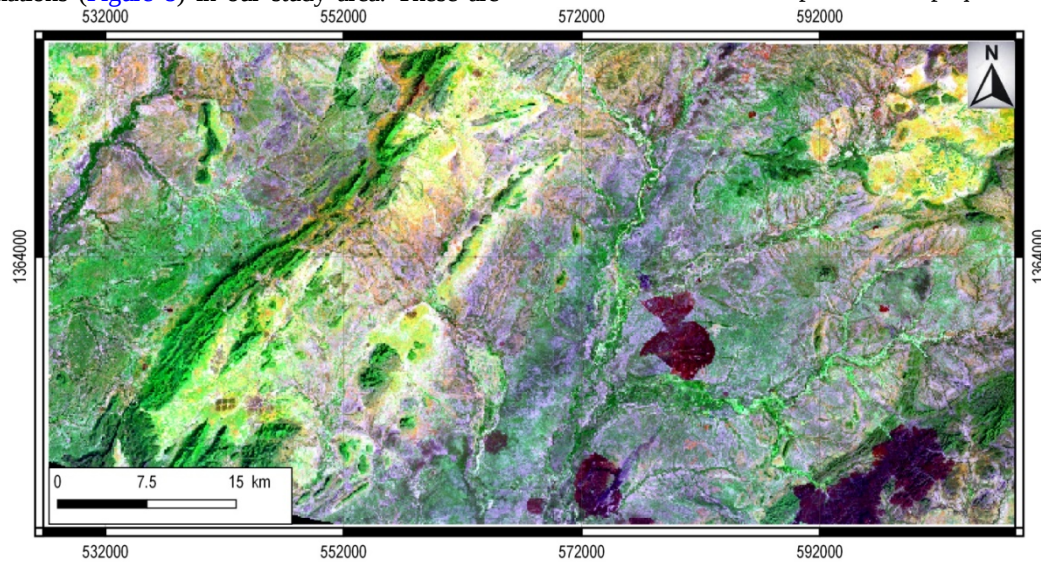


Figure 7. Image resulting from Color Composition (RGB) processing using the 7/5/1band combination

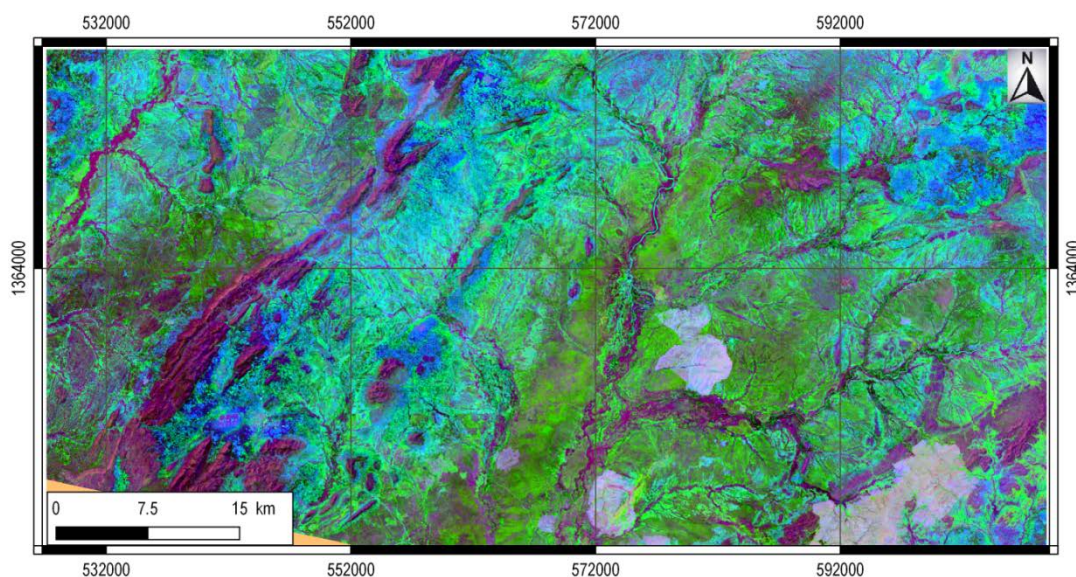


Figure 8. Image processed by Principal Component Analysis (PCA1, PCA2 and PCA3) in RGB mode

4.2.5. Examples of Granitoids

These are composed of three lithology:

- Pyroxene monzonite occurs as a slab and shows no deformation structure in the solid state (Figure 9g, h and i). The rock has a gritty porphyroid texture and is composed of feldspar, clinopyroxene, plagioclase, orthopyroxene, biotite, amphibole and oxide.
- Biotite granite occurs as medium- to fine-grained slabs and blocks. It is marked by basic enclaves and enclaves of amphibole and biotite granite (Figure 9j, k and

l). Thin sections show a heterogranular grainy texture and are composed of potassic feldspar, plagioclase, quartz, biotite, epidote and opaques.

- The muscovite leucogranite occurs in small elongated clusters or slabs oriented parallel to the foliation of the meta-sediments. It is locally cut by veins of folded pegmatite and enclaves of diorite (Figure 9m, n and o). The thin sections have a grainy texture and the rock is composed of potassic feldspar, quartz, plagioclase, muscovite, garnet and oxide.

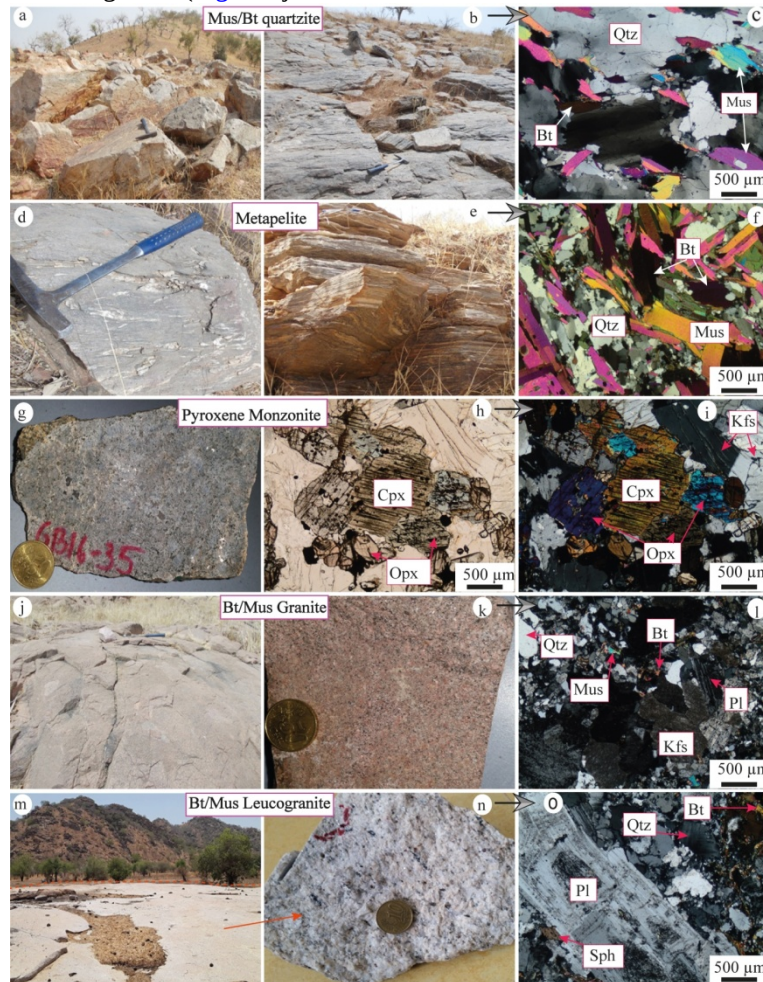


Figure 9. Macroscopic and microscopic photographs: (a, b and c) muscovite/biotite quartzite; (d, e and f) metapelite; (g, h and i) pyroxene monzonite; (j, k and l) biotite/muscovite granite and (m, n and o) biotite/muscovite leucogranite

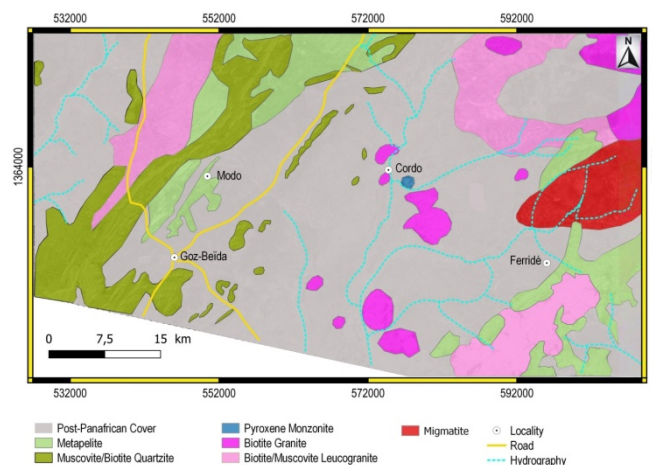


Figure 10. lithological map of Goz-Beida

5. Conclusion

The use of Landsat-8 OLI coupled with pre-existing data and field data has enabled the lineament map to be produced and the different lithological types in Goz-Beïda and the surrounding area to be distinguished. The semi-automatic extraction method followed by manual validation was used to extract the lineaments. The main lineaments are characterized by NE-SW and NNE-SSW directions. The N-S, ENE-WSW and NW-SE directions correspond to mean directions. All these lineaments are associated with the various deformation structures (foliation, schistosity and lineation) that have affected the study area. Two groups of formations are distinguished: meta-sedimentary formations (two-mica quartzites and metapelites) and granitoids represented by pyroxene monzonite and biotite granites, which are discordant with the meta-sediments, and two-mica leucogranites, which are concordant with the foliation of the metasediments.

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