Contribution of Remote Sensing for the Mapping of the Yaoundé Metadiorites

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ABSTRACT

Geologists face a number of problems, mainly related to the difficulty of covering the entire terrain, leading to various pieces of information collected and its extrapolation for drawing maps. To overcome these problems, we have proposed to use remote sensing which is a current tool for rock mapping. Remote sensing is a modern tool to highlight several information that conventional mapping methods do not allow. Thus, the objective of this work is to update the geological contours of the Yaoundé metadiorites by processing satellite images coupled with the classical approach. Sentinel 1-A radar images were used. A textural analysis of these images was carried out using the GLCM (Grey Level Co-occurrence Matrix) method, resulting in eight co-occurrence indices, among which three were chosen to perform colored compositions. The colored compositions obtained are VMH and HMV. And the contrasts obtained were compared with maps from previous work and also with field work. The metasedimentary rocks (kyanite - garnet migmatites and garnet micaschists) and metaigneous rocks (metadiorite) constitute the metamorphic complex distinctly mapped by exploiting remote sensing data, superposition maps from previous work and integrating the new sampling points. Remote sensing in geological mapping thus plays an important role mainly in the urbanized study area as it detects the metadiorites under the metasediments despite the existence of anthropogenic works and low vegetation cover.

Keywords: Mapping, Metadiorites, Metasediments, Remote Sensing, Textural Analysis.

I. INTRODUCTION

Geological mapping is the representation of the geological rocks and structures of a region on the outcrop or subsurface level. It is therefore essential to master all modern methodologies and techniques of geological mapping. Recently, computer-assisted mapping (remote sensing and satellite image processing) has emerged as an effective, accurate and reliable geological mapping tool for geologists, especially when mapping a large and contrasting urbanized and heavily vegetated areas, where outcrops are often inaccessible, complicating conventional mapping work. Several geological mapping projects were carried out in the southern part of the Pan-African Range in Cameroon, including pioneering work [1–2] and recent work [3–7]. These works have highlighted a metasedimentary package intruded by a meta-igneous package. Each monograph provided specific information that improved the understanding of the Pan-African belt. Most maps resulting from these works were produced by conventional mapping methods. Generally, geologists face a number of problems, mainly related to the difficulty of covering the entire terrain (limited time and access, natural hazards), leading to various pieces of information collected, but also in its extrapolation for the drawing of the map model. Thus, the present work is a monograph on Yaoundé and its surroundings for an update of a detailed geological map.
by combining remote sensing and field work. Usually there are differences between some formations described on the maps and the field observations, due to the use of empirical methods of surveying at a small scale and not very precise cartographic rendering methods. To enhance the international scientific challenges facing Cameroon, it is important to have efficient tools such as GIS (Geological Information Systems) for the design and dissemination of updated geological maps. It is to promote a clear knowledge of geology of the region. The objective of this work is to update the geological contours of the Yaoundé metadiorites using satellite images coupled with field observations.

II. GEOLOGICAL SETTING

The North Equatorial Pan-African belt in Cameroon is subdivided into three lithotectonic domains (Fig. 1): the Northern, Central and Southern domains [8]. The sector studied, belongs to the southern domain, and has been the subject of numerous works such as [2], [6], [7], [9]–[13]. The Southern Domain, also known as the Southern Group of the Pan-African belt in Cameroon, comprises the lower Dja and Yakadouma series [14]; the low-grade Ayos-Mbalmayo-Bengbis series [15], and the medium- to high-grade Yaoundé series [2]. The Yaoundé series, to which the study area belongs, consists of metasedimentary and metagneous rocks recrystallised under medium and high pressure conditions (600-800°C; 9-12 kb) during the Pan-African orogeny [2], [11], [16]–[18]. The metasedimentary rocks consist of garnet - kyanite migmates and garnet micaschists with intercalated levels of calcium silicate rocks and locally quartzites, serpentinites, and talcschist. The meta-igneous rocks consist of plutonic rocks (metadiorites, orthoamphibolite, metatenalite, metagabbro). All these rocks were involved in thrusting tectonics of the Neoproterozoic age [2], [4], [9], [19]–[20]. The deformation history shows that the Yaoundé series rocks are polyphase and monogenic in evolution [2] with four deformation phases [9]–[10]: phases D1 and D2 are the main ductile deformation events (635–615 Ma) that led to the development of the S2 regional foliation. Phase D1 predates calc-alkaline dioritic cluster emplacement and is responsible for nappe emplacement that led to high-pressure, soft-sediment granulite facies metamorphism. Strong repressing of the nappes during D2 symmetrical extension, probably associated with large-scale foliation boudinage and/or gneissic doming, gave rise to flat regional textures that were affected by folding phases D3 (600–580 Ma) and D4 (pre-545 Ma).

III. METHODOLOGY

Review Stage The methodology includes numerical analysis, analogue analysis, and fieldwork.

A. Digital Analysis

The Sentinel-1A radar images used in this work were downloaded from ASF.alaska.edu.com. The two scenes submitted for processing were acquired on 16 July 2021 and 26 September 2021. The software used was ENVI 4.7 and ERDAS IMAGINE 2014. The processing is as follows:

1) Mosaicking of radar images and extraction of the study area

This step juxtaposes two or more images into a single image. As the contrast between the scenes is identical, this operation allowed the homogenized mosaic image where the study area was extracted.

2) Data pre-processing

Here is the digitization, geo-referencing, speckle reduction, and image mosaicking of maps. The geo-referencing was done in the projected coordinate system UTM WGS84 zone 32N.

3) Textural analysis

The textural analysis consists of calculating a series of measurements in order to define a perceived texture on an image. This provides information on the spatial arrangement of colors or intensities of colors in all or part of the image. Among the textural analysis methods defined by [22], the statistical approach was used.

4) Statistical approach

The statistical method takes into account the first, second and third order attributes. The textural analyses in this work are based on the first two orders including the most common model, the Grey Level Co-occurrence Matrix (GLCM) proposed by [23]. This model counts the number of occurrences of (times of simultaneous appearance) two pixels in the image at a distance in the same direction. There are many studies on the application of the GLCM technique on synthetic aperture and/or optical radar images in geological applications [24]–[30]. The implementation of the GLCM performed in the ENVI software environment, using the 7 x 7 matrix allowed the calculation and creation of eight normalized
co-occurrence indices: mean, variance, contrast, dissimilarity, homogeneity, entropy, second moment, and correlation. These co-occurrence indices are used in lithological discrimination.

5) Rock Discrimination

- Color composition (CC)

The rock formations were delineated by visual interpretation of tonal variation, contrast, and texture. For the eight co-occurrence indices created, three indices highlight the morph structure of the study area and facilitate the delineation of geological structures. The combination of these three indices in color composition (variance, mean, homogeneity) on the RGB bands respectively will be followed by the equalization histogram.

- Equalization histogram

The histogram of an image measures the distribution of grey levels in the image. For a grey level X, the histogram enlightens us on the probability of finding a pixel with a value of X by drawing a pixel at random in the image. Thus, general information about the appearance of the image was obtained. This is why a visually pleasing image is usually characterized by a balanced histogram (close to a flat function).

B. Analog Analysis

The digitally analyzed processed maps were integrated into the ArcGis 10.3 software where the geological maps from the previous work were overlaid. After this stage, we went into the field to verify the information obtained by image processing.

C. Fieldwork

Ten field campaigns of three days each were carried out to verify the information obtained by image processing. At each outcrop point, GPS coordinates were taken in order to compare the contrast obtained by image processing with the type of rock. After confirming the type of rocks by macroscopic and microscopic petrographic studies, a sampling map was drawn up. A superposition of the sampling map with the map obtained after the analog analysis allowed the geological contours of the Yaoundé metadiorites to update. The simplified methodology of this work is presented in Fig. 2.

IV. RESULTS

A. Processing of Sentinel-1A Radar Images over Yaoundé and its Surroundings

1) Mosaic results and pre-processing in Argegis

The combination of the two image scenes resulted in a single image (Fig. 3a), including the study area. After extraction of this area from the mosaic image (Fig. 3b), pre-processing (radar speckle reduction, orthorectification, and georeferencing) was applied to obtain a usable image (Fig. 3c).

2) Textural analysis result in Envi 4.7

The GLCM implementation was run in ENVI, using a 7×7 window. A pixel 1 shift on the Sentinel-1A single band allowed the calculation and creation of eight normalized co-occurrence indices (Fig. 4a–4h). Based on the indices proposed by the [23], eight textural parameters are calculated (Table 1). For the eight co-occurrence indices created, three indices highlighting the morphing structure of the study area and facilitating lithology discrimination were selected. This was based on their standard deviation value [23], [31] and their different functions (Table 1): homogeneity, mean, and variance. This statistical method allows the identification and selection of the parameters that best define the elements from the measurement of grey tone distributions.

| Indications   | Standard value deviation | Characteristics of the indications                      |
|---------------|--------------------------|---------------------------------------------------------|
| Contrast      | 47.393663                | Contrast (47.393663): its low value express small local variations |
| Correlation   | 53.115005                | Indicate the linear degree of relationship between the various occurrences of the image |
| Dissimilarity | 54.103326                | It measures the homogeneity; its low value characterizes a homogeneous texture |
| Entropy       | 61.72592                 | Measure the disorder; its high value explains the strong disorder in global texture with pixels rather different on both sides; |
| Homogeneity   | 61.771344                | Give an idea of the local similarities; it reflects the existence of uniform beaches of texture. More its value is higher, more the texture is coarse as the case of the images obtained after treatment; |
| Average       | 55.461142                | Its value is all the more than the same occurrence of gray level appears in the texture; |
| Second moment | 53.637846                | It measures the homogeneity; its strong value characterizes an homogeneous texture; |
| Variance      | 48.897044                | Its strong value characterizes a fine texture (pepper and salt) contrary to that obtained in this study (coarse texture). |
3) Colored compositions

Variance, homogeneity and mean are the best indices used for lithological discrimination in radar images [31]. Through several combinations of these three textural parameters in colored composition (CC) for the RGB channels, two interesting images are obtained: Variance-Mean-Homogeneity (VMH) and Homogeneity-Mean-Variance (HMV). An enhancement (image contrast improvement) by dynamic histogram spreading on ERDAS followed, resulting in better visualization of the image (Fig. 5).

B. GIS mapping

1) Mapping on the basis of color variations

The result of the satellite image processing is an image whose characteristic colors are digitalized into three potential formations (Fig. 6).

2) Superposition of maps from previous works

The previously processed image is superimposed with the geological map of [1] (Fig. 7), [32] (Fig. 8), [9] (Fig. 9a), and [11] (Fig. 9b).

C. Field Descriptions and Petrography

The information obtained after processing satellite images is verified by the field works. A lithological inventory and petrographic study of the geological formations of Yaoundé and its surroundings were carried out to better appreciate the geological contours of metadiorites. This fieldwork, notably the description of the outcrops coupled with the microscopic study, helped to distinguish a single exclusively metamorphic lithological ensemble divided into two units, the meta-igneous and the metasediments. The samples are presented in Fig. 10.
1) Meta-igneous unit

The metaigneous rocks are metadiorites and pyroxenites, outcropping in form of domes, slabs, or blocks (Fig. 11a and 11b). They are dark to light grey. The minerals are coarse-, medium- and fine-grained. They show a weak foliation, often discontinuous and folded, of light quartzofeldspathic and dark ferromagnesian beds (Fig. 11c). Migmatization shows millimetric to centimetric levels of leucosome witnessing partial melting (Fig. 12c).

Migmatites are heterogeneous rocks made of paleosome showing a gneissic structure (alternation of light and dark beds) and neozone (constituted by leucosome and melanosome). Overall, there are pockets of garnet, amphibole, biotite and feldspar (Figs. 11d). The leucosomes underlie the foliation and they have a granodioritic composition [6]. They alternate with palaesosome and thus define the lithological foliation, observed in Fam-Assi, Mvolyé, and Nkolonbon quarries. Centimetric to decametric thickness leucosomes are boudinaged or folded (Fig. 11c).

The metadiorites present a granonematolepidoblastic texture (Fig. 11e), made up of quartz, plagioclase, garnet, amphibole, biotite, pyroxene and K-feldspar. Accessory minerals are titanite, magnetite, zircon, apatite and opaque minerals. Quartz (5-10%) is in polycrystalline ribbons (0.2-0.7 mm), or anhedral crystals. Quartz is also found as inclusion in garnet or interstitial between amphibole and plagioclase. Plagioclase (35-45%) is anhedral to subhedral with variable sizes ranging from 0.3 to 2 mm (Fig. 11e). Some crystals show quartz in the microfractures and others are in inclusion within garnet. Garnet (15%) is subhedral with sizes from 0.5 to 2.5 mm. Some porphyroblasts show biotite and amphibole inclusions and are rimmed by biotite (Fig. 11e–11f). Amphibole (15%) is anhedral to subhedral with sizes varying from 0.2-1.9 mm. Smaller crystals are often associated with biotite in the ferromagnesian layers while larger crystals are associated with quartz and plagioclase in the clear layers. Biotite (10%) appears as oriented lamellae with variable length (0.3 to 1.5 mm) and at times shows zircon inclusions. Pyroxenes (20%) are porphyroblasts up to 1.8 mm in length. K-feldspar (3%) is anhedral to subhedral in variable size (0.1 to 3 mm) and shows biotite and amphibole inclusions. Accessories (<5%) are apatite, zircon, tourmaline and opaque minerals.

Leucosomes show granolepidoblastic texture (Fig. 11g) made up of quartz, plagioclase, biotite, muscovite, tourmaline and opaque minerals. Quartz (20%) is anhedral to subhedral, mostly occupying the interstices of other minerals. Plagioclase (40%) appears as porphyroblasts up to 2 mm in size (Fig. 12h), and contains quartz and biotite inclusions. Biotite (10%) appears as elongated lamellae or as inclusions in other minerals. Tourmaline is rare, and disseminated (Fig. 11g).

2) Metasedimentary unit

This unit is represented by kyanite-garnet migmatites outcropping in the rest of the study area. They outcrop as domes, showing grey color, and a foliation characterized by leucosomes alternating with paleosomes (Figs. 12a, 12b). Leucosomes are locally boudinaged, folded and sheared (Fig. 12d). Besides there are clusters of biotite and muscovite (Fig. 12c) as well as augen feldspar and oriented kyanite (Fig. 12e). At the microscopic scale, the metasediments show granolepidoblastic texture (Fig. 12f) made up of quartz, plagioclase, K-feldspar, garnet, kyanite, sillimanite, biotite and muscovite. Accessories are titanite, zircon and opaque minerals. Garnet (10-15%) is euhedral to subhedral, with quartz and biotite inclusions. Biotite and muscovite rim most porphyroblasts. Biotite (10%) occurs as elongated subhedral flakes forming discontinuous mica-rich layers (Fig. 12f). K-feldspar (15%) occurs as subhedral crystals ranging in size from 1.5-2 mm. Quartz (15-20%) is anhedral to subhedral, locally recrystallized into sub-grains round garnet, kyanite and K-feldspar. Plagioclase (15%) occurs in small subhedral patches with sizes varying between 0.5 and 2 mm (Fig. 12g). Kyanite (5-10%) occurs as euhedral crystals (0.3 to 3 mm) scattered in the rock. Sillimanite occurs as subhedral porphyroblasts often in association with biotite (Fig. 12e).
Fig. 7: Comparative map from [1] and the processed satellite image.

Fig. 8: Comparison of the formations obtained with [32].
Fig. 9. a) Superposition with [9] map, b) Superposition with [11] map.

Fig. 10. Sampling Map.
Fig. 11. Photographs and microphotographs of the meta-igneous rocks: a, b) Outcrops of metasediment blocks on metadiorites, c) Folded and boudinaged foliation, d) Biotite clusters in leucosome, e) Granonematolepidoblastic texture in metadiorites, f) Quartz, plagioclase, biotite inclusions in garnet porphyroblasts, g) Granolepidoblastic texture in the leucosome, h) Fissured plagioclase porphyroblast in the leucosome. Note a biotite layer.
Fig. 12. Photographs and microphotographs of garnet and kyanite migmatites: (a, b) Lithological band-like foliation; (c) Biotite clusters; (d) Boudinaged and sheared partial melt track; (e) Kyanite crystals in leucosome; (f) Discontinuous biotite layers; (g) Plagioclase porphyroblasts with biotite inclusions; (h) Sillimanite crystals in fine biotite crystals.

Fig. 13. Superposition of the geological contours of previous work with the results obtained in this work.

Fig. 14. Synthesis lithological map of Yaounde.
V. DISCUSSION

A. Satellite images

Radar image captors have shown particular interest in geological and mining exploration [33]–[37]. Similarly, the contribution of Radar imagery proved particularly useful. In tropical or heavily vegetated areas, as well as in urban areas, the radar wave penetrates the ground to a depth of 1 to 2 m and reveals buried geological structures and fossil water systems [38]–[41]. Among the possible color compositions, the two selected images VMH and HMV allowed the differentiation of the formations. [42] applied this methodology. The colored compositions of the selected indices (Fig. 5c, d) show contrasting areas in terms of texture and tone, high variability, and areas of local homogeneity. Geological structures and contours are more visible, showing that these images provide an interesting basis for geological contour discrimination. The color "cyan" at the center of the HMV image (Fig. 5c) corresponds to hillsides and/or metadiorites mapped by [9].

The color “red to orange” on the same image corresponds to metasediments. The yellow-orange color covers the south-east of the area where micaschists were mapped by [32]. The dark red areas refer to high altitude massifs (Nkobisson, Ebang, Nkooza, Fam-Assi, Nyom, etc.) in the north-west of the image as well as anthropic constructions (Nsimalen airport, air base, etc.) and lakes (municipal and Razel lakes). The VMH image (Fig. 5d) shows the same features as in the HVM image but with different colors. The yellow color represents metadiorites. The blue-green color represents metasediments (garnet and kyanite migmatites). The color “cyan” represents micaschists while the dark blue color represents anthropic constructions.

These different results obtained helped to update the contours of the Yaoundé metadiorites (Fig. 14). However, the zones of shallow metasediments thickness are confused with the metadiorites below.

B. Petrography

The rocks studied belong to the Yaoundé series of Neoproterozoic age [10]. The main paragenesis of mapped rocks are defined by: Pl+P lite+Grt+Qtz+Kfs+Bs+px (metadiorites) and Qtz+Kfs+Kny+Pl+Gr+Bs+Ms+Sill (kyanite-garnet migmatites), characteristic of a medium to high-grade metamorphism. [28] observed similar paragenesis.

C. Mapping in GIS

Among the treatments applied to the Sentinel-1A radar images covering the study area, the most effective are the VMH-RGB and HMV-RGB color compositions. The final 1,200,000 lithological map (Fig. 14) results from the combination of previous works [9], [11], [32] and textural, morphological and petrographic data of this study. Previous work and field observations then become tools of reference, examination and confirmation. Field observations show metadiorites at lower altitudes between 679 and 779 m below metasediments (Fig. 11a, b), hence the heterogeneous texture of the processed satellite image, rendering the identification of the geological contours of petrographic types complex. The VMH and HMV digitalized images superimposed on the geological map of [1] allowed to verify the concordance degree of maps (Fig. 13). The concordance map, superimposed on maps from previous works [9], [11] led to the new accurate lithological map (Fig. 14).

VI. CONCLUSION

The main objectives were to process satellite images (Sentinel-1A radar images) combined with field data to update the mapping of the Yaoundé metadiorites. After processing, the color contrasts were compared with the previous geological maps and field data. The result shows that:

1. The color contrasts correspond more or less to the lithological limits in the previous work.
2. The metadiorites do not outcrop continuously as indicated in the previous work, but intrude locally the metasediments.
3. The metadiorites are below the metasediments. Some color contrasts, corresponding to metadiorites on the processed image are instead metasediments on the field.

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