THE LANDSAT 7 ETM+ REMOTE SENSING IMAGERY FOR LITHOLOGICAL AND STRUCTURAL MAPPING IN THE CENTRAL CÔTE D'IVOIRE (WEST AFRICA): CASE OF DABAKALA AREA

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Abstract

The control of different faults networks is a capital tool, due to the fact that any fault zone is dependent on the possibility of concentration of useful minerals such as gold. Also, it is clear that most of the identified faults date for most long time and it is imperative to update structural maps.
From remote sensing from Landsat 7 ETM+ of Dabakala area (Central Côte d'Ivoire), we extracted lineaments from an analogical analysis supplemented by numerical analyzes using directional filters and textures. Subsequently, we determined the limits of the lithological units from their textures and colors. All news faults obtained were incorporated into the existing ones. The assimilation of some lineaments fractures and faults was made on the basis of pre-existing map data and field observations. A sketch lithostructural map was also obtained.
Regarding lithological distinctions, eleven optically distinct zones, categorized into three main provinces, have been identified. Several major faults directions were mapped. These are the mostly N-S to NNE-SSW with sinistral, dextral N90° to N100° direction and dextral or sinistral NW-SE to NNW-SSE direction.

A significant structure appears on the Landsat ETM+ colored composition of ACPs Band Ratios 5-7/3-5/3-2. This is the Sarala fault (FSr), with N075° to N080° direction, which is identified for the first time. Other structures appear on the processed images should be checked in the field.

Keywords: Landsat ETM$^+$, Analogical and Digital Analysis, Lithostructural Map, Dabakala, Côte d'Ivoire

Introduction

The technical analysis of remote sensing imagery has improved geological investigations (lithological mapping, soil mapping, structural mapping and search for underground water from the lineaments network). In the past, geological maps were prepared from field observations through conventional methods. By delaying this type of information collected along the cross lines on the topographic base and extrapolating the details on the final map, some errors are induced thus leading to inappropriate maps.

Since the development of the of remote sensing imagery technology, mapping procedures have constantly evolved.

Lithological mapping in areas of savannah where there is a high lateritic cover was always a challenge. There are always discussions about the accuracy of lithological boundaries and structural details on the maps. The big advantage of remote sensing imagery is the synoptic view. It provides a regional overview and interrelations between different areas. The increasing of the resolution in multi-spectral bands, as well as advanced capabilities of processing techniques expands the potential of remote sensing by delineating the lithological contacts and geological structures with greater accuracy (Drury, 1987).

The Dabakala area (Fig. 1) includes three gold districts: the Fettêkro in southwest of Dabakala, high N'Zi in the northwest of Dabakala and Gorowi hill in the northern of Dabakala. These districts are the subject of numerous campaigns by several exploration companies. The strong combined lateritic cover and the scarcity of outcrops makes is a problematic to establish lithologic geological maps and especially precise structural. To overcome these deficiencies and inaccuracies in the mapping of this region, we have exploited the advantages of remote sensing imagery.

The objective of this work is to use Landsat 7 ETM$^+$ to the lithological and structural mapping of Dabakala area (NE of Côte d'Ivoire). This will allow the updating of existing maps; specifically, this is:

1) manual interpretation of the images to highlight the main facies-images, and the lineaments;

2) digital interpretation of the images by combining new channels, relatively favorable to the delineation of lithological units and extraction of faults networks;

3) combining the set of data obtained for the production of a preliminary map;

4) check it with pre-existing documents and data collected in the field (lithology and lineaments corresponding to actual faults zones) in order to finalize the lithological and structural geological map.

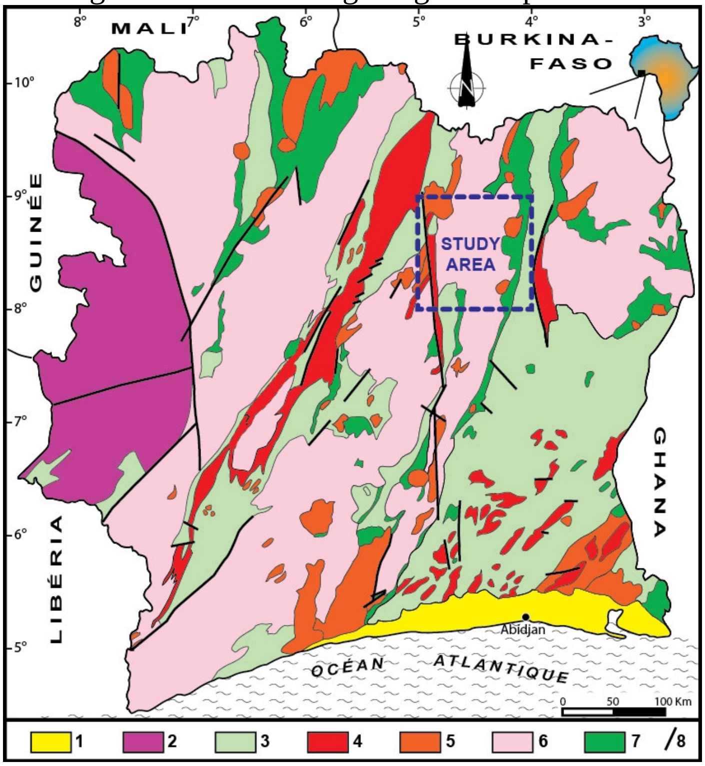

Figure 1: Simplified geological map of the Côte d'Ivoire and location of the study area. 1 = post-Birimian formations; Paleoproterozoic domain: 2 = two micas granitoids basin-type; 3 = undifferentiated granitoids; 4 = metasediments; 5 = granitoids of greenstone belts; 6 = volcanics; 7 = Archean field; 8 = major faults.

Geological setting

We distinguish from east to west, four geomorphologic units:

- the Gorowi mountains overlooking the Comoé belt with peaks over 500 m;

- the granitic-gneissic peneplain of Dabakala punctuated by many isolated inselbergs or forming small mountains which rarely exceed 200m;

- the Fettêkro greenstone belt very rugged (Mont Niangbion, 600 m) in the southwest zone;

- the plain of Nzi oscillating between 150 m and 250 m.

The formations of the Dabakala region that belong to the domain Baoulé-Mossi (Arnould *et al*., 1958; Lemoine, 1998; Leake, 1992, Vidal *et al.,* 2009), can be divided into four major categories:

1) to the west, the Bandama volcano-sedimentary basin (also called High N'Zi) ending the north-east Katiola a granitic gneiss occupying the entire western part;

2) to the Southwest, the volcano-sedimentary of Fettêkro chain;

3) in the East, the volcano-sedimentary M'Bahiakro and Gorowi Mountains greenstone belts. It is also called High Comoé basin in the north and Average Comoé Average in the South.

4) intrusions or batholiths of granitoids between these different volcano-sedimentary units or belts.

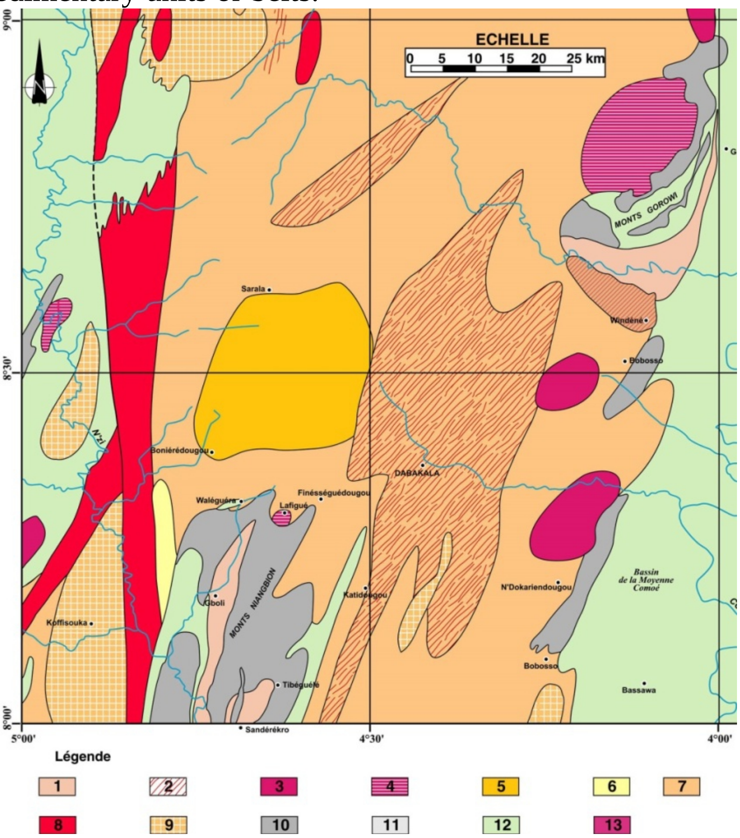

Figure 2: Simplified geological map of Eastern Central Côte d'Ivoire, modified from Arnould *et al*., 1958. 1=Tuffs; 2=Migmatites; 3=Akeritic biotite granites; 4=Diorite; 5=Sarala type granites; 6=Porphyritic biotite granites; 7=Biotite granites; 8=Two-mica granites; 9=Koffissiokaha type granodiorites; 10=Undifferentiated green rocks; 11=Basic tuffs; 12=Undifferentiated shales; 13=Akeritic saussuritised granites.

Migmatites are highly developed in the area Dabakala (Lemoine, 1988). They presents differents facies, from the least migmatitic granits to anatexics granites migmatitisés. This latter type is underdeveloped and represent low mappable areas. The migmatitisation affects various facies that we find sometimes almost unscathed as paleosom, sometimes discreetly migmatitised or partially "diluted" in the leucosom. The three most frequent facies are distinguished: migmatitic gneiss, migmatitic granites and banded migmatites (Fig. 2). Works of Adou (2000) redefines the migmatitic rocks lyke to Dabakala granites and argues that they do not meet the definition of "migmatites" nor "migmatitic gneiss".

Material and Methods

Material

The Landsat 7 ETM^+ remote sensing imageries in the study region, whose characteristics are presented in Table 1 were obtained from the website of the University of Maryland in the United States at http: //www.glcf.umiacs.umd.edu. They are of good quality and free of interference signals as hedged cloudy. However, the images having been acquired during the dry season, you can meet some places smoke from bush fires or season fires.

We used a total of 9 images (bands 10, 20, 30, 40, 50, 61, 62, 70 and 80; see Table 1). The band 80 is the panchromatic band resolution 14.25 meters to the ground. The location of the image is shown in Figure 3.

Table 1: Characteristic of Landsat 7 ETM^+ images data of Dabakala-Nassian area.

Type	Orthorectified GEO-TIFF images of Landsat 7 ETM^+
Acquisition date	January 29, 2002
Path/Row	196/054 and 197/054 for the northwestern area
Image Centre	9°39’13,72 N ; 5°09’05,78 W
Number of channels (bands)	9 bands (B1, B2, B3, B4, B5, B6.1, B6.2, B7 and B8)
Resolution or pixel size (m)	28.5m for B1, B2, B3, B4, B5 et B7 57m for B6.1 et B6.2 14.25m for B8
Projection system	UTM, Zone 30N
Ellipsoid	WGS-84
Spectral characteristics	B1: blue; B2: green; B3: red, B4: near infrared; B5: mid infrared; B6: thermal infrared; B7: far infrared; B8: panchromatic

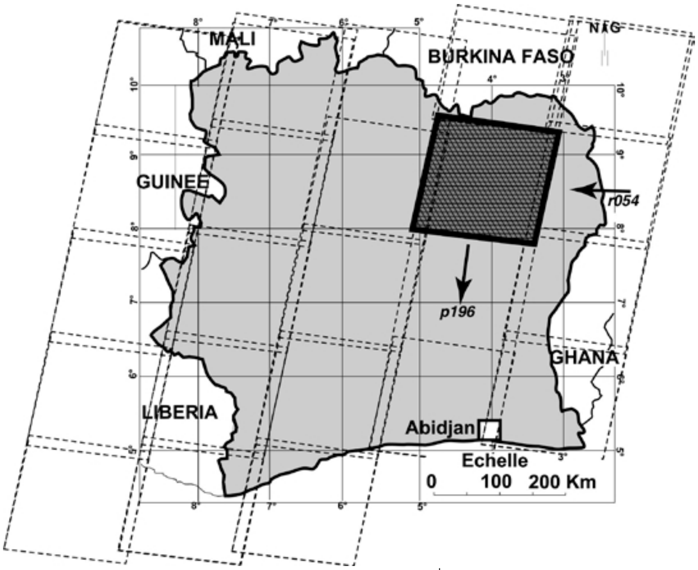

Figure 3: Location map of the Landsat 7 ETM^{+} image (Path 196, Row 054).

The map database used in this study includes:

- geological map established at 1/500 000(Arnould *et al.*, 1958);

- geological maps established at 1/200 000 for the localities of Dabakala, Kong and Nassian (Delor *et al.*, 1995);

- geological maps produced at 1/100 000 (Leake *et al.*, 1997);

- aeromagnetic maps at 1/200 000 (sheets of Dabakala, Kong and Nassian, and Tehini-Bouna). Maps realized in 1976 by the company "Data Plotting Services Ltd" under the supervision of the Geological Survey of Canada;

- and some topographic maps of the study area.

Investigation of lithologies and lineaments

Two types of analyzes were performed on images. This is the analogical analysis and the numerical analysis.

- **Analogical analysis**

It is based on the analysis of textures, shapes, organization of lineaments and colors. We outlining by paper superimposed on an image in color composite [channel 7 (far infrared), 5 (mid infrared) and 2 (green)] respectively associated with red, green and blue). This image (Fig. 4) provides a better contrast of the color image.

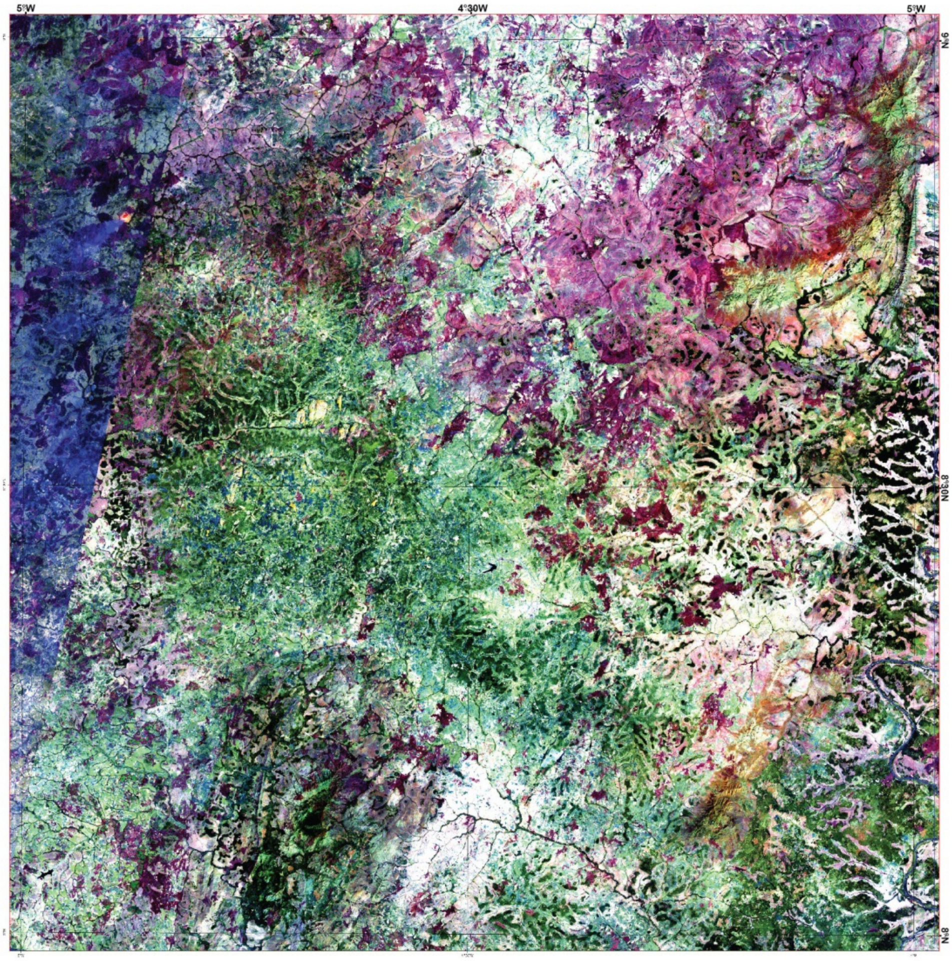

Figure 4: Landsat 7 ETM+ Image, in color composite of 752 of Dabakala area.

The completion of a geological map from remote image sensing data must respect the different steps (Fig. 5):

1) analogical analysis that involves the extraction of lineaments in the determination of geological domains and extracting drainage network and infrastructure on paper;

2) a numerical analysis by processing the data obtained from software such as Envi 4.5, Adobe Illustrator and Adobe Photoshop;

3) a phase of validation of data from analogical and digital analysis (from pre-existing geological maps and field observations);

4) the definitive compilation of the geological map.

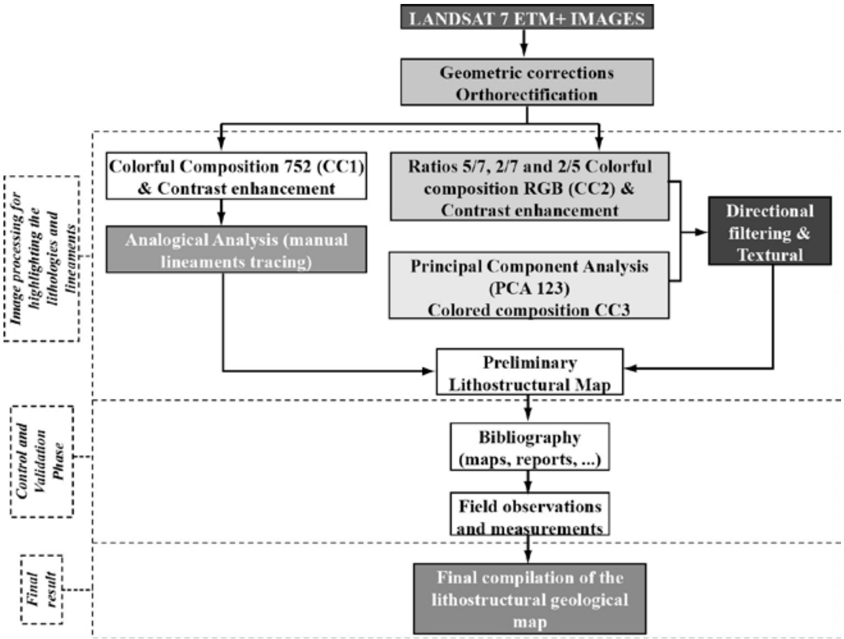

Figure 5: Processing chain of a remote sensing Landsat 7 ETM+ image.

So we were able to highlight the different towns of our area; then we have materialized the river system, the various lithological boundaries having a particular spectral signature and finally all lineaments structures. This succession of operations has helped to achieve the preliminary map. The determination of geological domains was done through the shades, textures and analyzing shapes on the image.

Texture on Landsat 7 ETM^+ image highly depends on the vegetation and lateritic cover. It is represented by a smooth or rough appearance. The shape, in turn, refers to the circular structures observed on the images that can match the concentric faults or fractures networks; the magmatic foliation which emphasizes the character of diapiric granite and or stages of different arenization (Scanvic *et al.*, 1984 ; Guillet *et al.*, 1985 ; Rolet *et al.*, 1993 ; Ouattara, 1998 ; Ouattara *et al.*, 2010). The circular structures characterize the majority of granitoids.

- **Numerical analysis**

Digital Landsat ETM^+ images, for the investigation of lithology and lineaments in our study area, were analyzed using several techniques in order to understand the best suited for the discrimination of lithologies. The Envi 4.5 software has been used as a platform for all analysis and processing.

Different images treatment procedures were applied such as ratios, principal component analysis (PCA) and directional filters or masks. Filtering consists in changing the value of a pixel based on that of its neighbors (Touzi *et al.*, 1988 ; Nezry *et al.*, 1991 ; Lopez *et al.*, 1993 ; Yesou *et al.*, 1993). The filter type used depends on the desired results. We have, for example, low-pass filters corresponding to a smoothing of the image by removing the high frequencies. We have also high-pass filters which function is to eliminate the low frequencies and allow edge detection.

For our study, we used directional filters, particularly the Yesou, the Prewitt and the Sobel filters. These directional filters whose application matrices are shown in Tables 2 and 3 were designed to bring out or hide specific characteristics of an image based on their frequency related to the texture (Himyari *et al.*, 2002 ; Jourda *et al.*, 2006 ; Ta *et al.*, 2008 ; Djemai *et al.*, 2009 ; Guergour and Amri, 2009 ; Kouamé *et al.*, 2009). The images obtained were then processed with Adobe Illustrator software to define and redraw lithological boundaries and faults networks. The procedure for processing and image interpretation is shown in Figure 5.

Table 2: Sobel filters matrix

1	**1**	**1**	**2**	**1**	**1**	**1**	**-1**	**-1**	**-1**	**0**	**1**	**1**	**1**
1	**1**	**2**	**3**	**2**	**1**	**1**	**-1**	**-1**	**-2**	**0**	**2**	**1**	**1**
1	**2**	**3**	**4**	**3**	**2**	**1**	**-1**	**-2**	**-3**	**0**	**3**	**2**	**1**
0	**0**	**0**	**0**	**0**	**0**	**0**	**-2**	**-3**	**-4**	**0**	**4**	**3**	**2**
-1	**-2**	**-3**	**-4**	**-3**	**-2**	**-1**	**-1**	**-2**	**-3**	**0**	**3**	**2**	**1**
-1	**-1**	**-2**	**-3**	**-2**	**-1**	**-1**	**-1**	**-1**	**-2**	**0**	**2**	**1**	**1**
-1	**-1**	**-1**	**-2**	**-1**	**-1**	**-1**	**-1**	**-1**	**-1**	**0**	**1**	**1**	**1**
Filtre SOBEL de direction N-S							**Filtre SOBEL de direction E-O**						
0	**1**	**1**	**1**	**1**	**1**	**2**	**2**	**1**	**1**	**1**	**1**	**1**	**0**
-1	**0**	**2**	**2**	**2**	**3**	**1**	**1**	**3**	**2**	**2**	**2**	**0**	**-1**
-1	**-2**	**0**	**3**	**4**	**2**	**1**	**1**	**2**	**4**	**3**	**0**	**-2**	**-1**
-1	**-2**	**-3**	**0**	**3**	**2**	**1**	**1**	**2**	**3**	**0**	**-3**	**-2**	**-1**
-1	**-2**	**-4**	**-3**	**0**	**2**	**1**	**1**	**2**	**0**	**-3**	**-4**	**-2**	**-1**
-1	**-3**	**-2**	**-2**	**-2**	**0**	**1**	**1**	**0**	**-2**	**-2**	**-2**	**-3**	**-1**
-2	**-1**	**-1**	**-1**	**-1**	**-1**	**0**	**0**	**-1**	**-1**	**-1**	**-1**	**-1**	**-2**
Filtre SOBEL de direction NE-SO							**Filtre SOBEL de direction NO-SE**						

Table 3: Yesou and Prewitt filters matrix

1	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
1	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
1	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
-1	**-2**	**-3**	**-7**	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**-1**
-1	**-2**	**-3**	**-3**	**1**	**1**	**1**	**-1**	**-1**	**-1**	**-1**	**-1**	**-1**	**-1**
-1	**-2**	**-2**	**-2**	**1**	**1**	**1**	**-1**	**-1**	**-1**	**-1**	**-1**	**-1**	**-1**
-1	**-1**	**-1**	**-1**	**1**	**1**	**1**	**-1**	**-1**	**-1**	**-1**	**-1**	**-1**	**-1**
Filtre PREWITT							**Filtre YESOU**						

- **Data Validation of the preliminary map obtained**

Control and validation phase of geological accidents extracted manually and digital ETM^+ treatments was essential to appreciate the relevance of the method used and the results obtained. The data from the geological maps are compared to linear structures extracted from remote sensing images to give them a structural significance (Kouamé, 1999 ; Kouamé *et al.*, 1999 ; Lasm, 2000). When the anthropogenic linear structure was proven (roads, trails, forests limits or cultivated areas, power lines,…), it is deleted. Thus, those remaining are likely match fracturing (Faillat, 1986; Lasm, 2000 ; Lasm and Razack, 2001 ; Lasm *et al.*, 2004; Kouamé *et al.*, 2006).

After this, we will also compare these data with the available documents, including the pre-existing geological maps. The map obtained will be complemented by field observations and compared to the existing map data in order to know the geological nature of the objects observed, geological structures in outcrop and their relative chronology.

Results

Lithological mapping

Three (3) large areas, divided into eleven (11) sub-zones of different lithological types can be observed. These are (Fig. 6):

- **ZONE A**

It is located in the western part of the area and contains eight (8) sub-areas.

Zone A1: corresponds to the granitic area of eastern Katiola and the N'Zi shear zone. It corresponds to Timbe, Koffissiokaha, Kowara granites and the N'Zi gneiss. On the colored composition image 752, it is characterized by a dendritic river system and discontinuous lineaments. On the ground, near the N'Zi bridge, the N'Zi shear zone is marked by a granitic gneiss intruded by diorite dykes and pegmatites (Fig. 7A).

Zone A2a: corresponds to a band of volcano-sedimentary formations.

Zone A2b: is the North termination of Fettêkro greenstone belt. On the image, we have broken lines and discontinuous structures with NS and NE-SW directions. One can observe some circular structures probably corresponding to granitics intrusions bodies. We can also meet mafic rocks (metabasalts, metatufs, metabreccias, (Fig. 7B)), metasediments and diorites.

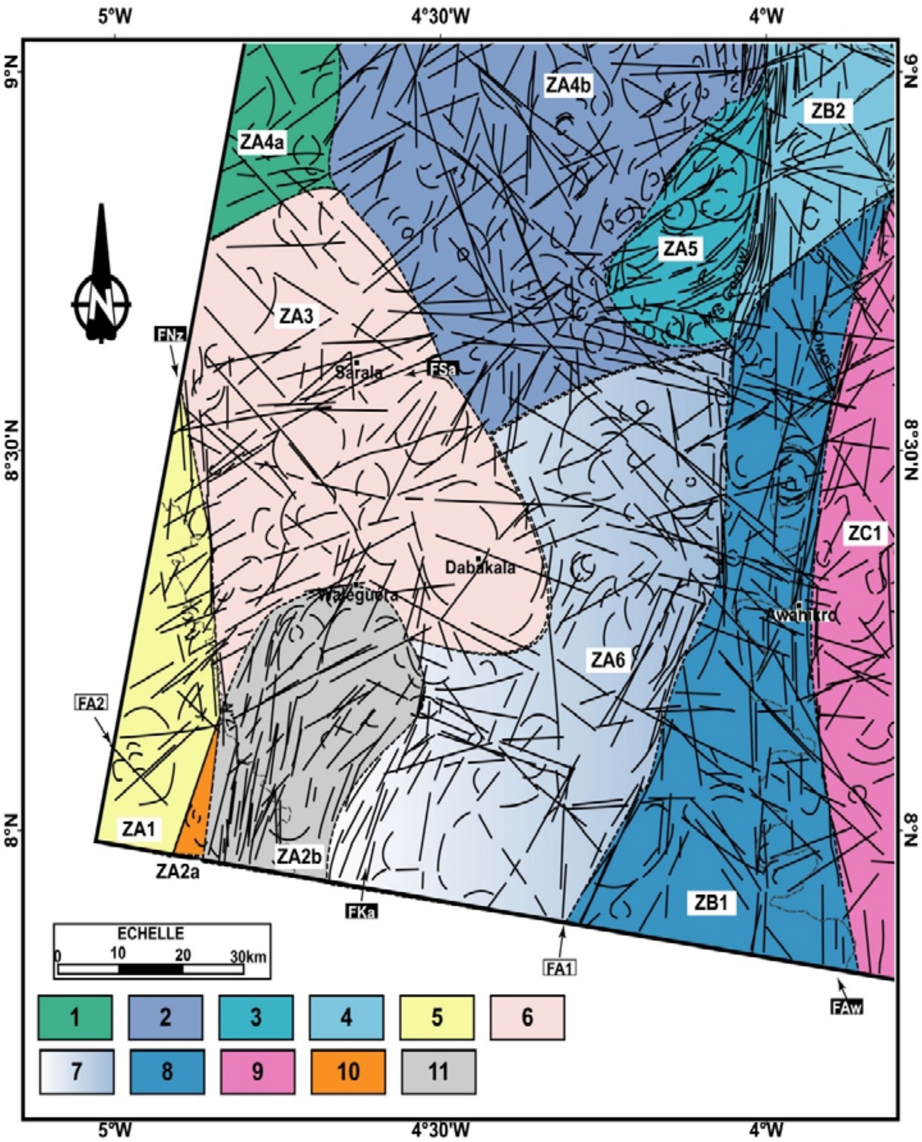

Figure 6: Final geological map showing major lithological units, faults and fractures, and circular structures.

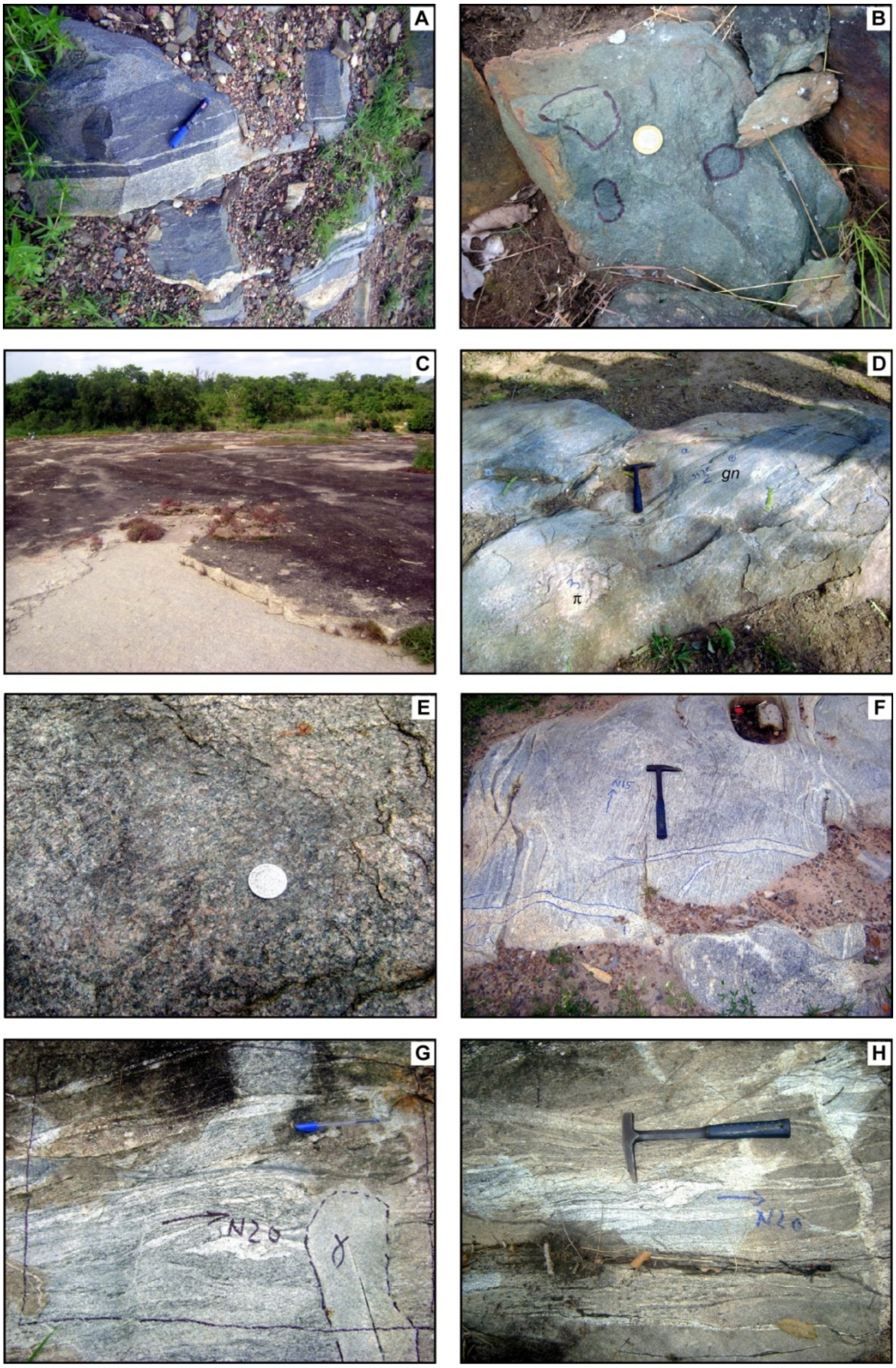

Figure 7: Outcrops photographic plate of the area A. □=granite; □=pegmatite; gn=gneiss.

Zone A3: is the area of Sarala-Boniérédougou granites. This area shows many circular structures reflecting several granitic plutons. On the ground, near Sougbana, we have a leucocratic with little biotite granite (Fig. 7C). Its texture is coarse grained and porphyritic. This rock contains numerous N100° pegmatite dykes. In place, we have biotite granites that contain granitic gneiss and pegmatite enclaves (Fig. 7D).

Zone A4a: corresponds to formations of the western region and have been qualified as Koffissiokaha granodiorites type (Arnould *et al.*, 1958); circular structures are encountered there.

Zone A4b: corresponds to granitoids of eastern Kong. They are qualified as biotite granites. The hydrographic network is dendritic with numerous circular structures.

Zone A5: corresponds to Windéné formations. We have granites, schists, granodiorites and greenstones. This area is characterized by hills and sub-circular intrusions. The Windéné intrusion is a pink-greenish rock. It is an alkaline granite with porphyritic coarse grainy texture (Fig. 7E).

Zone A6: corresponds to the formations of Dabakala and Katidougou, with elliptical structures. Qualified as anatexites (Arnould *et al.*, 1958), of migmatitic (Lemoine, 1988) or granitic gneiss (Leake, 1992; Adou, 2000), these formations are schistosed (Fig. 7F). The schistosity is folded and injected by a fine grain biotite granite. This rocks is a migmatitic gneiss. Between Gbamélédougou and Katidougou, we have augen gneiss N20° (Fig. 7G). These rocks are also injected by a late biotite granite. The Katidougou granite, in the south, is strongly schistose rock (Fig. 7H).

- **ZONE B**

It is located in the central part of the area and includes two (2) sub-areas.

Zone B1: is in the south-central area. We have a zebra texture structured by the branches of the Comoé river. Map data indicate undifferentiated and greenstone schists (Arnould *et al.*, 1958).

Zone B2: is in the south-central area. The texture is similar that of the Zone A4B, but as essentially mapped as metasedimentary formations above N'Zi.

- **ZONE C**

It is located in the eastern part and to the Zone C1 on Figure 6, and corresponds to the Awahikro two-mica leucogranitic batholith (Arnould *et al.*, 1958; Vidal *et al.*, 2009).

Structural mapping

The structural data were obtained from the interpretation (visual or analogical and digital) of images and field measurements.

Several lineaments directions can be recorded on our interpreted image: NS to NNE-SSW; N90° to N100°; NW-SE to NNW-SSE (Fig. 6).

- **N-S TO NNE-SSW LINEAMENTS**

Lineaments correspond to NS to NNE-SSW fractures, mainly located in Zones A and B are the mylonitic district of Brobo-N'Zi (FNz), of Katidougou (FKa), of Ouandérama and Awahikro fault (FAw). These faults are mostly marked by augen gneiss clearly indicating sinistral ductile shear zones.

Concerning the FNz, its major direction is N160° to N170° with a dip of 70°E. It is intersected by sinistral N120°-75° NE faults (Fig. 8 A and B). The set is crosscutted by N040° and N070° faults. The accident of Katidougou (FKa) corresponds to a gneiss with a schistosity (N020° direction and a dip of 80°SE). This schistosity is intruded by N080° pegmatite veins and dykes. All this is intersected by a small dextral N030° shear zone. Other shear zones are observed (dextral N080°-30°N and N010° (Fig. 8C, D, E and F)).

The Awahikro (FAw) shear zone is NNW-SSE in its southern part and become NNE-SSW in its northern part. The Ouandérama shear zone distorts the Gorowi Mountains formations on the eastern border to the east Dabakala before Comoé River. The Gansé shear zone (north of Zone B) limits the volcano-sedimentary basin of the high Comoé and basement gneiss (see also Lüdtke *et al.*, 1999).

- **N90° TO N100° LINEAMENTS**

This is the Waléguéra shear zone which is a reverse fault that overlapping Niangbion mountains and the G'Boly syncline in the greensbelt of Fettêkro (Lemoine, 1988; Yao, 1998). It is the contact zone of mafic rocks, constituting the Niangbion hills, and further north, with andesitic pyroclastics of Lafigué.

The major Windéné shear zone (N100° to N110°) is a ductile dextral strike-slip already described by (Lüdtke *et al.*, 1995). In the intrusive diorite, we note the presence of several tension gashes. The largest have a N020° direction with sulphides, among which we have small N135° gashes (Fig. 9A).

On Figure 9B, there several quartz veins interconnected. Chronologically, the N140° veins are the oldest, then the N020° sinistral, the dextral N070° and N095° are the younger. All those are crosscutted by dextral N135° faults. In the alkaline porphyritic granite of Windéné, we have many regular N060° and N090° faults which are ductile shear zones which seem to be conjugated (Fig. 9C). Dextral N095° tension gashes can be observed. In the Katidougou type, N080° faults crosscut the schistosity in dextral (Fig. 9D).

Figure 8: Outcrops photographic plate showing some structures in Zone A.

- **NW-SE TO NNW-SSE LINEAMENTS**

These are East Kong and Kong faults. They have not been verified in the field. A significant structure appears on the Landsat ETM$^+$ in colored composition of PCAs bands ratios 5-7/3-5/3-2. This is the fault of Sarala (FSr), (N075° to N080°direction) which is identified for the first time.

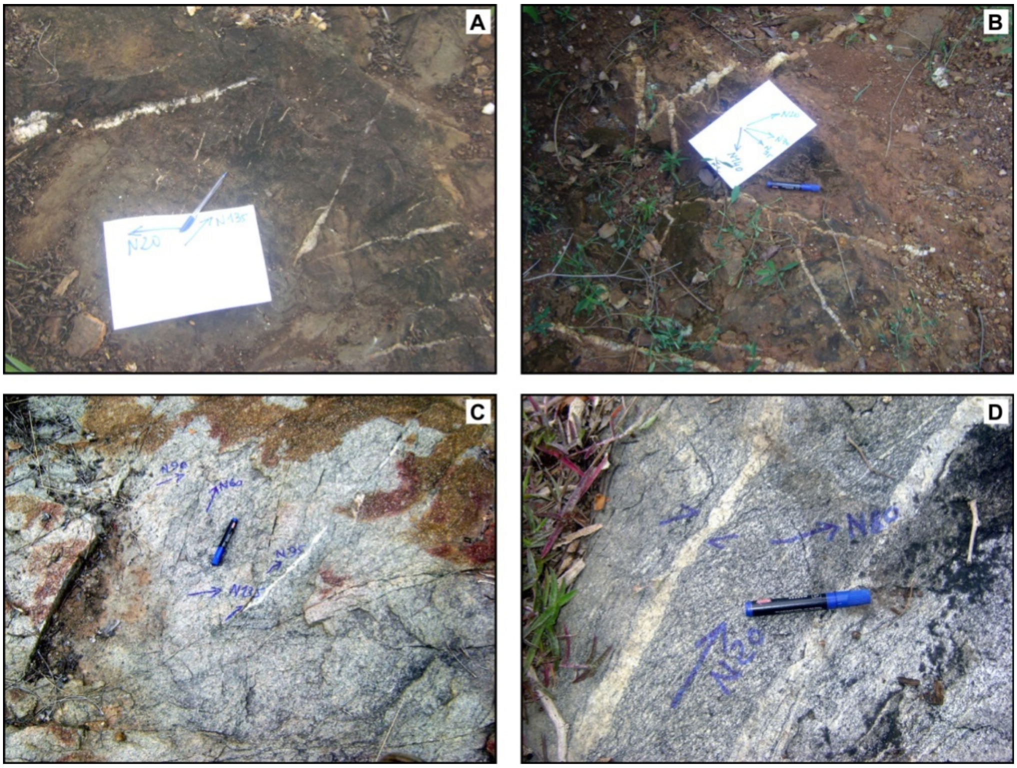

Figure 9: Outcrops photographic plate showing some tension gashes in the Windéné massive and East-West direction structures.

Discussion

This part is to make a review of the entire procedure used in this study.

Methodology used

The realization of the lithological and structural geological map from Landsat ETM^+ in the Dabakala region was possible through the application of available techniques in remote sensing imagery for the detection of major faults networks present in this part of the country. The manual and digital extraction methods of lineaments are methods generally used for mapping.

The manual extraction method consisted of a systematic identification of lineaments by the materialization of the river system and quantitatively localities. The digital extraction method use several filters: Sobel, Prewitt and Directional, textures filters (measures of occurrences and co-occurrences) and Principal Components Analyses (ACPs) using Envi 4.5 software.

Comparative analysis of extracting lineaments manually and numerically

The manual extraction of lineaments is a method subject to the assessment and the sensitivity of the human eye. This intrinsic characteristic of the method does not allow an accurate geological mapping. The clarity of images is also an additional problem that compromises the reliability of this method. Therefore, applying this method even on a remote sensing image of high resolution cannot allow an exhaustive interpretation of lineaments.

In contrast, the digital extraction method of lineaments and fractures network or computer assisted not only offers a better readability, but also permits the observations in many ways through the use of filters (enhancement of structures). These strengths enable different mapping as close as possible to reality characterized by greater accuracy. Applying the technics resulting from this method (superposition of interpretations) may result in preliminary geological map with giving greater certainty, position and direction of faults.

Comparison of results obtained from the filters

The results obtained of the interpretation of filtered images generally show eleven lithological zones divided into three major main provinces. These different areas characterized by particular lithologic facies are mostly identifiable from the composite color 752. This also highlights circular structures. The enhancement of the linear or circular structures and lineaments structures were performed by applying the Prewitt filter, Sobel, directional filters on the spectral bands (either alone or on all three bands) and texture filters.

Thus, interpretation of images from the application of Prewitt filters on the panchromatic band (band 8), Prewitt E-O and Sobel NW-SE show a concentration of circular structures especially in areas A and C. The Prewitt filter on panchromatic band shows above general management and E-W WNW-ESE lineaments, while the Prewitt E-W filter on the band 7 does more out mainly oriented WSW-ENE lineaments. The NW-SE Sobel filter also highlights the lineaments oriented almost E-W. N-S lineaments are highlighted by all the filters used for this study. It is important to note that the highest densities of lineaments are observable on Prewitt filters on panchromatic band and Prewitt E-W. Unfortunately, the application of Yesou filters gives very little structures.

Relations between lineaments and faults directions

Lineaments are on the remote sensing image (filtered or colored composition), linear structures, lengths, directions, and observable curves, reflecting the presence of structural elements. Lineaments may correspond to directions of fracturing if they have previously been validated or confirmed by a visit on the field or using pre-existing documents (geological maps, previous studies). In this case, the direction and length of a lineament may represent the characteristics of a fracture (especially faults).

After extracting the roads, power lines and other linear structures, some lineaments were validated as fractures and faults from existing geological maps and others by field observations. Note that the study area is highly fractured, which can be explained by the nature of deformed rocks or basement.

New directions identified in relation to pre-existing geological maps

The structural data from the pre-existing geological maps and particularly fracturing map of Côte d'Ivoire show us of the fact that major fracturing directions are between N00° (N-S) and NE-SW to NNE-SSW, E-W to N110° and NW-SE.

We have found, on our preliminary geological map, other major directions of additives fractures to the directions previously found. These are dextral N80° to N95° fractures, sinistral N120° to N130°fractures and the sinistral N150° to N160° fractures. The Sarala (FSr) fault, with N075° to N080° direction, is identified for the first time. This fault affects the western edge of the Gorowi Mountains and crosscut granitoids in the north of Sarala.
Other structures appear on the processed image and are to be checked on the ground. There are the FA1, FA2 (in Zone A) and FA3 (Zone C) structures (Figure 6). Thrusting areas previously mapped (Lemoine, 1988; Leake, 1992; Lüdtke *et al.*, 1995; Yao, 1998) are not recognizable on our image.

Contribution of geological sketch improving existing geological maps

The evolution of concepts, knowledge, tools and methods of apprehension is such that after ten years, a map is, in part, obsolete, we must rework the complete and clear it.

Through our geological sketch produced through remote sensing images from Landsat ETM^+, we have shown that there is a perpetual progress of analytical methods or using new tools that continually provide new informations that must be integrated with data already existing. Thus our sketch could reveal lithological and structural separate areas.

Contribution geological sketch to mining exploration in the study area

Mineral exploration in the Dabakala region is an activity that is booming and is a real economic asset for the country. This is, in particular, the area in the northern of Fettêkro greenstone belt (Sodemi for Gold), Gorowi hills and Bobosso (Newcrest Mining for Gold).

The lithostructural mapping proposed by this study and the relative chronology of the various faults allow these companies better targets structures to prospect.

Conclusion

For this study, we applied all the principles that govern the implementation of a geological map with remote sensing. So we extracted lineaments from an analog analysis supplemented by numerical analyzes using filters (directional and textures). Subsequently, we determined the limits of the lithological units by their texture and color and integrated all the new information to existing ones. Eleven optically distinct areas, divided into three provinces, have been identified.

The assimilation of some lineaments fractures and faults was made on the basis of pre-existing map data and field observations. We have, through these means, could get a structural map showing all major fractures and faults in the Dabakala region.

After this study, it appears that the major directions of fractures are: NS to NNE-SSW sinistral for most; N90° to N100° dextral; NW-SE to NNW-SSE dextral or sinistral.

We must also add that the sub meridian fractures are the oldest and those of East-West management seem to be the latest.

A significant structure appears on the Landsat ETM$^+$ in color composition of ACPs Band Ratios 5-7/3-5/3-2. This is the Sarala fault (FSr), with N075° to N080° direction, which is identified for the first time.

Furthermore, the presence of tension gashes in the study area, containing sulphides is a good indicator of gold mineralization. We hope that the lithostructural map Dabakala region obtained as a result of the interpretation of Landsat ETM$^+$, will help to revitalize the mining sector guarantees better performance.

References:

Adou M. *Cartographie de la feuille de Dabakala (Centre-Nord de la Côte d'Ivoire) à 1/200000, Nature, âge et origine des granitoïdes*. Thèse de Lnpl Nancy, France, 170 p., 2000.

Arnould M., Bonnault D. et Soule De la Font D. *Carte géologique de reconnaissance à 1/500000 de la feuille de Katiola*. BRGM, Dir. Mines Géol. Côte-d'Ivoire, Abidjan, 1958.

Delor C., Siméon Y., Vidal M., Zeade Z., Koné Y., Adou M., Dibouahi J., Bi Irié D., Yao B.D., N'Da D., Pouclet A., Konan G., Diaby I., Chiron J. C., Dommanget A., Kouamelan A. N., Peucat J.J., Cocherie A. & Cautru, J.P. *Notice explicative de la carte géologique de la Côte d'Ivoire à 1/200000,* *feuille de Nassian*. Ministère des Mines et de l'Energie, DMG, Abidjan, Côte d'Ivoire, 1995.

Djemai S., Bendaoud A., Haddum H., Ouzegane K. and Kienast J.R. *Apport des images Landsat 7 ETM$^+$ pour la cartographie géologique des terrains archéens en zone aride : Exemple du terrane de l'In Ouzzal (Hoggar occidentale, Algerie)*. III^{èmes} Journées d'Animation Scientifique du réseau de Télédétection de l'AUF JAS'09, Sous le thème : «Imagerie Satellitaire Multisources : Approches Méthodologiques et Applications», Alger, 8-11 novembre 2009, 2009.

Drury S.A. *Image Interpretation in Geology*. Allen & Unwin Publisher, 1987.

Faillat J.P. *Aquifères fissurés en zone tropicale humide : structure, hydrodynamique et hydrochimie (Afrique de l'Ouest)*. Thèse de doctorat ès Sciences Naturelles, Université du Languedoc-Montpellier II, France, 534 p., 1986.

Guergour L. and Amri K. *Contribution des images Landsat 7 ETM$^+$ à la cartographie géologique et structurale du Bassin de Tin Séririne. (Tassilis Oua N Ahaggar. Hoggar), Algérie*. III^{èmes} Journées d'Animation Scientifique du réseau de Télédétection de l'AUF JAS'09, Sous le thème : «Imagerie Satellitaire Multisources : Approches Méthodologiques et Applications», Alger, 8-11 novembre 2009, 2009.

Guillet Ph., Bouchez J.L. & Vigneresse J.L. *Le complexe granitique de Plouaret (bretagne): mise en évidence structurale et gravimétrique de diapirs emboîtés*. Bull. Soc. Géol. Fr., 8, I, 4 : 503-513, 1985.

Himyari S. M., Hoepffner C., Benzakour M. and Hadani D.E. *Etude structurale du haut atlas oriental Maroc) à l'aide de l'analyse linéamentaire des images HRV XS) de Spot*. Revue Télédétection, vol. 02, n°. 4, pp. 243-253, 2002.

Jourda J.P., Djagoua. E.V., Kouamé K.F., Saley M.B., Gronayes C., Achy J.J., Biémi J. and Razack M. *Identification et cartographie des unités lithologiques et des accidents structuraux majeurs du département de Korhogo (Nord de la Côte d'Ivoire) : Apport de l'imagerie ETM$^+$ de Landsat*. Revue Télédétection, vol. 6, n°. 2, pp. 123-142, 2006.

Kouamé K.F., Penven M. J. and Kouadio B. H. *Contribution des images d'Aster de Terra et d'un modèle numérique d'altitude à la cartographie morphostructurale du massif des Toura (Ouest de la Côte d'Ivoire)*. Revue Télédétection, vol. 6, n°. 2, pp. 103-121, 2006.

Kouamé K.F. *Hydrogéologie des aquifères discontinus de la région semi-montagneuse de Man-Danané Ouest de la Côte d'Ivoire). Apport des données des images satellitales et des méthodes statistique et fractale à l'élaboration d'un système d'information hydrogéologique à référence* *spatiale*. Thèse de 3ème cycle, Université de Cocody-Abidjan, Côte d'Ivoire, 194 p., 1999.

Kouamé K.F., Lasm T., Saley M. B., Tonyé E., Bernier M. and Wade S. *Extraction linéamentaire par morphologie mathématique sur une image RSO de RadarSat-1 : application au socle Archéen de la Côte d'Ivoire.* IIIèmes Journées d'Animation Scientifique du réseau de Télédétection de l'AUF JAS'09, Sous le thème : «Imagerie Satellitaire Multisources : Approches Méthodologiques et Applications», Alger, 8-11 novembre 2009, 2009.

Kouamé K.F., Gioan P., Biémi J., Affian K. *Méthode de cartographie des discontinuités-images satellitales : Exemple de la région semi-montagneuse à l'ouest de la Côte d'Ivoire.* Revue Télédétection, vol. 2, 139-156, 1999.

Lasm T. and Razack M. *Lois d'échelle dans la fracturation des roches dures cristallines et dans le réseau hydrographique associé.* Compte Rendu Académie des Sciences Paris, Science de la Terre et des planètes, vol. 333, pp. 225-232, 2001.

Lasm T. *Hydrogéologie des réservoirs fracturés de socle : analyses statistique et géostatistique de la fracturation et des propriétés hydrauliques. Application à la région des montagnes de Côte d'Ivoire (Domaine Archéen).* Thèse Université de Poitiers (France), 274 p., 2000.

Lasm T., Kouamé K.F., Soro N., Jourda J.P. and Biémi J. *Analyse géostatistique de la fracturation extraite de l'imagerie spatiale aéroportée et satellitaire. Application à la région de Man-Danané (Ouest de la Côte d'Ivoire).* Revue Ivoirienne des Sciences et Technologie, vol. 5, pp. 135-154, 2004.

Leake B.E., Wooley A.R., Arps C.E.S., Birch W.D., Gilbert M.C., Grice J.D., Hawthorne F.C., Kato A., Kisch H.J., Krivovichev V.G., Linthout K., Laird J., Mandarino J., Maresch W.V., Nickel E.H., Rock N.M.S., Schumacher J.C., Smith J.C., Stephenson N.C.N., Ungaretti L., Whittaher E.J.W. & Youzhi G. *Nomenclature of amphiboles - Report of the subcommittee on amphiboles of the International Mineralogical Association Commission on New Minerals and Mineral Names*. Eur. J. Mineral., 9 : 623-651, 1997.

Leake M.H. *The petrogenesis and structural evolution of the early Proterozoic Fettekro greenstone belt, Dabakala region, NE Côte d'Ivoire*. Unpub. Thesis, Portsmouth, U.K., 315 p., 1992.

Lemoine S. *Evolution géologique de la région de Dabakala (NE de la Côte-d'Ivoire) au Protérozoïque. Possibilités d'extension au reste de la Côte-d'Ivoire et au Burkina Faso: similitudes et différences; les linéaments de Greenville-Ferkessédougou et Grand Cess-Niakaramandougou.* Thèse ès Sciences, Univ. Cl.-Ferrand, 388 p., 1988.

Lopez A., Nezry E., Touzi R. and Laur H. *Structure detection and statistical adaptive speckle filtering in SAR image*. International Journal of Remote Sensing, vol. 14, n°. 9, pp. 1735-1758, 1993.

Lüdtke G., Hirdes W., Konan G., Kone Y, Yao D., Diarra S. & Zamble Z. *Géologie de la Région Haute Comoé Nord*. BGR/Ministère des Ressources Minières et Pétrolières, Direction de la Géologie, Abidjan, Côte d'Ivoire, 1995.

Lüdtke, G., Hirdes W., Konan G., Koné Y., N'Da D., Traoré Y. and Zamblé Z.B. *Géologie de la Région Haute Comoé Sud, carte géologique à 1/100000, feuilles Dabakala 2b,d et 4b,d - 1ère édition*. Projet de coopération géologique ivoiro-allemenande (1995-1996), Ministère des Ressources Minières et Pétrolières, Direction de la Géologie, Bulletin n°2, 1999.

Nezry E., Lopez A. and Touzi R. *Detection of structural and textural features for SAR images filtering*. in proceeding of IGARSS 91, pp. 2169-2172, 1991.

Ouattara G. *Structure du batholite de Ferkessédougou (secteur de Zuénoula, Côte-d'Ivoire) : Implications sur l'interprétation du paléoprotérozoïque d'Afrique de l'ouest à 2.1 Ga*. Thèse doctorat, Université d'Orléans, France, 291 p., 1998.

Ouattara G., Koffi G.B. et Yao K.A. *Cartographie géologique à l'aide de l'imagerie Satellitale Radar ERS-1: Mise en Évidence de Structures Circulaires Emboîtées (Pipes Kimberlitiques Diamantifères?) dans la Région de Tortiya au nord de la Côte d'Ivoire (Craton Ouest Africain)*. European Journal of Scientific Research, ISSN 1450-216X Vol.45 No.2, pp.212-220, 2010.

Rolet J., Yesou H., Besnus Y. *Structures circulaires et réseaux de fractures en pays granitique. Analyse de données SPOT, Landsat TM et Seasat sur le Massif armoricain*. Bulletin de la Société Géologique de France, 164, 2, 199-214, 1993.

Scanvic J.Y., Dutartre Ph. & King Ch. *Correlations between spatial remote sensing, geochemical and geophysical data in the western France: an integrative and orientation technique for geological mapping and ore exploration*. In: Teleki P. And Weber C Eds., Remote sensing for geological mapping, IUGS, 18 : 57-78, 1984.

Ta M.Y., Lasm T., Jourda J.P., Kouamé K.F. and Razack M. *Cartographie des accidents géologiques par imagerie satellitaire Landsat-7 ETM^{+} et analyse des réseaux de fractures du socle précambrien de la région de Bondoukou (Nord-Est de la Côte d'Ivoire)*. Revue Télédétection, vol. 8, n°. 2, pp. 119-135, 2008.

Touzi R., Lopez A. and Bousquest P. *A statistical and geometrical edge detector for SAR images*. IEEE Transactions on Geoscience, Remote Sensing, vol. 26, n°. 6, pp. 764-773, 1988.

Vidal M., Gumiaux C. Cagnard F Pouclet A., Ouattara G. et Pichon M. *Evolution of a Paleoproterozoic "weak type " orogeny in the West African Craton (Ivory Coast)*. Tectonophysics 477, pp. 145 - 159, 2009.

Yao B.D. *Lithostratigraphie et pétrologie des formations birimiennes de Toumodi-Fettekro (Côte-d'Ivoire): Implication pour l'évolution pour l'évolution crustale du Paléoprotéroïque du craton Ouest-Africain*. Thèse doctorat, Université d'Orléans, France, 191 p., 1998.

Yésou H., Pion J. C., Besnus Y. and Saint-Jean R. *Amélioration des données SPOT pour la cartographie structurale en milieu tropical. Exemple de la région des chapeaux de fer de Pagala Togo)*. III^{èmes} Journées Scientifiques du Réseau Télédétection UREF, Toulouse, 13-16 novembre 1990, pp. 143-164, 1993.