University of the Witwatersrand

School of Geosciences

Honours Project

GIS interpretation of NE Burkina Faso using Landsat imagery combined with radiometric and magnetic data

Makobo Mohale

0709012W

Supervisor: Prof. K.A.A. Ncube-Hein

Co-Supervisor: Julia Mambo

Table of Contents

1. CHAPTER 1

2. CHAPTER 2: GEOLOGY

CHAPTER 3: METHODOLOGY

CHAPTER 4: RESULTS

LIST OF FIGURES

Figure 5.1: Interpretative geology map of the Markoye Shear Zone based on combined regional magnetic data (RTP and RTP 1st vertical derivative), Landsat imagery, with Landsat image p194r050_741 as underlay (Tshibubudze et al., 2009).

Figure 5.2: Strato-tectonic-magmatic map of Burkina Faso with distribution of structures and lithology.

LIST OF TABLES

ACRONYMS AND ABBREVIATIONS

The following abbreviations are used:

GIS- Geographic Information System

RGB-Red, Green, Blue

TTG- Tonalite Tronjomite Granodiorite

OGGB- Oudalan-Gorouol Greenstone Belt

BGGB- Boroum-Goren Greenstone Belt

GGB- Goren Greenstone Belt

MSZ- Markoye Shear Zone

SSZ- Sabce Shear Zone

BSZ- Belahouro Shear Zone

FCC- False Colour Composite

ACKNOWLEDGEMENTS

This project was made possible by my supervisor Prof. Kim Ncube-Hein and AMIRA WAXI who provided all the LANDSAT and ASTER imagery and the radiometric and magnetic data. Thanks to the following people who have motivated, guided and helped me when I was completing this work: My supervisors Prof. Kim Ncube-Hein who guided and gave me a chance to undertake a project for Burkina Faso, for her patience and her constructive comments and for letting me do something new that I knew nothing about. Through doing the GIS and Remote Sensing work I acquired a lot of knowledge. Thanks to Julia Mambo for guiding and helping me understand Remote Sensing. To my family, friends, thanks for your support and words of encouragement. Mr. Asinne Tshibubudze thanks for taking time off and helping me when I lost hope, to Miss Todani Funyufunyu for teaching me how to use CorelDraw software. Finally to God be the glory and honour, for His love, mercy, protection, wisdom and knowledge that guides my footsteps.

DECLARATION

I declare that this dissertation/thesis is my own work. I have correctly acknowledged all the sources, to ideas used in this dissertation/thesis. This dissertation/thesis is submitted for a Bachelor of Science degree with Honours in Geology at the University of the Witwatersrand, Johannesburg. It has not been submitted before in any other university for any examination or degree.

Signature: ______________________ Date: 22 October 2010

ABSTRACT

Satellite images are among continuous sources of digital data for mapping geological structures, lithologies and for human geography studies. In this study, a strato-tectonic-magmatic map of NE Burkina Faso was created using Landsat 7 imagery combined with radiometric and magnetic data. Four different false color composite images of Landsat data (FCC 731,742,753 and 432) RGB images were generated and evaluated for lithological mapping and human geography studies. A false color composite image of Landsat data 731 (RGB) was generated and used for production of the strato-tectonic-magmatic map for the study area. Analysis of geological structures such as lineaments, shear zone, dykes, plutons and lithological discrimination as well as geographic features was carried out using IDRISI Kilimanjaro software and CorelDraw X3 ® software packages.

Throughout this study Landsat data 731(RGB) was used for extraction process. From this study it was found that the study area is dominated by NE-NNW trending shear zones, NW trending dykes and the extracted lineament trends are east to ENE, north to NNW and NEasterly. There are four greenstone belts in the study area and these are underlain by laterite. Sand dunes cover most of the northern Burkina Faso. The features extracted from the Landsat 7 were also evident in, magnetic and radiometric data. Landsat 7 imagery can be used successfully for geological mapping.

CHAPTER 1: INTRODUCTION

1.1 Preamble

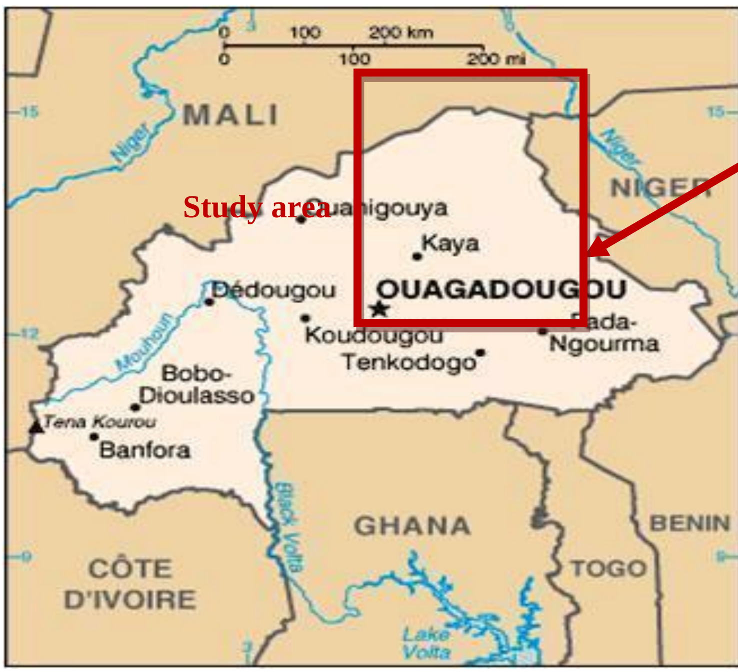
Most geological maps of Burkina Faso are outdated and due to high cost of aerial photography the maps have not been updated. There is massive investment in exploration in NE Burkina Faso and there are few geological maps that assist in targeting, with the latest being completed by Castaing in 2003. Therefore a GIS interpretation was undertaken to create a strato-tectonic-magmatic map for the area. GIS interpretation has become the most important modern tool for geological interpretation and a fundamental approach in grassroots exploration for the delineation of resource potential. It involves the breaking up of complex data planes into simpler and more interpretable forms related to geological features. Remote sensing analysis from GIS is used to extract drainage and topographic patterns, curvilinear features and stands of lithologically related vegetation (Drury, 1987). As such, remote sensing techniques have great utility in lithologic discrimination, outcrop delineation and production of geological maps at different scales (Qari et al 2008).

This study focused on the identification of various lithological units using Landsat images with the aim of using them as part of a dataset for mineral (gold and other mineral commodities) potential targeting in Burkina Faso, mapping of geological structures and also land use/cover data sets. This was completed using six Landsat images, radiometric and magnetic data. The images will be georeferenced using geographic coordination systems or projections. Based on the spectral capabilities of Landsat 7 image data, the RGB (Red, Green, and Blue) band combination was prepared for discrimination of geological features (lithology, structure and contacts). Although the spectral capabilities of Landsat data do not provide new information on lithology, they are useful for extracting geological features that might have not been defined by field studies and aerial photography or maps in the area.

1.2 Location and physiography

The study area for the project is north east Burkina Faso. Burkina Faso is a landlocked country located in western Africa, north of Ghana (Fig 1.1). It shares borders with six countries namely Benin in the southeast, Ivory Coast in the south west, Togo and Ghana in the south, Mali in the north and Niger in the east. It has an area of 274.200 km^2 and an annual population growth of 2.7%.The capital city is Ouagadougou. The official language is French and regional languages include Dioula and Mooré.

Land use can be divided into three sections: arable land (17.66%), which is mainly land cultivated for crops that are replanted after each harvest (e.g. rice, maize, wheat), permanent land (0.22%), which is cultivated land that cannot be replanted after harvest(e.g. coffee, rubber) and other land (82.12%) which includes pastures, woodland, forest, built-on areas, barren lands and roads. The land surface is mainly defined by alluvial plains, low hills, and sand dunes of the Sahara Desert. Landforms in Burkina Faso include lakes, rivers, mountains and wetlands. In the north and east of the country vegetation consists of acacia woodland and scrub, expanding into semi-desert in the dry season in the north. The rest of the country's vegetation is sparse savanna grasslands as well as dry forest areas with occasional shrub vegetation or acacia. The country has a subtropical sahelian climate with two distinct seasons, i.e. rainy season and dry season.



1.3 Problem statement

Most geological maps of Burkina Faso are outdated and due to high cost of aerial photography the maps have not been updated, this research will test whether GIS interpretation techniques can be used for geological mapping using Landsat, magnetic and radiometric and to update the geological map of Burkina Faso.

1.4 Aims and Objectives

The aim of the project is to create a strato-tectonic-magmatic map of NE Burkina Faso for exploration targeting. The map will be created using six Landsat images, magnetic & radiometric data. Using the imagery it will be possible to extract geological boundaries (lithological contacts), structures, dykes, lineaments, land use and land cover datasets. Through doing this work knowledge about GIS and Remote sensing will be gained.

1.5 Research questions

Are GIS and/or Remote sensing good for geological mapping and effective?

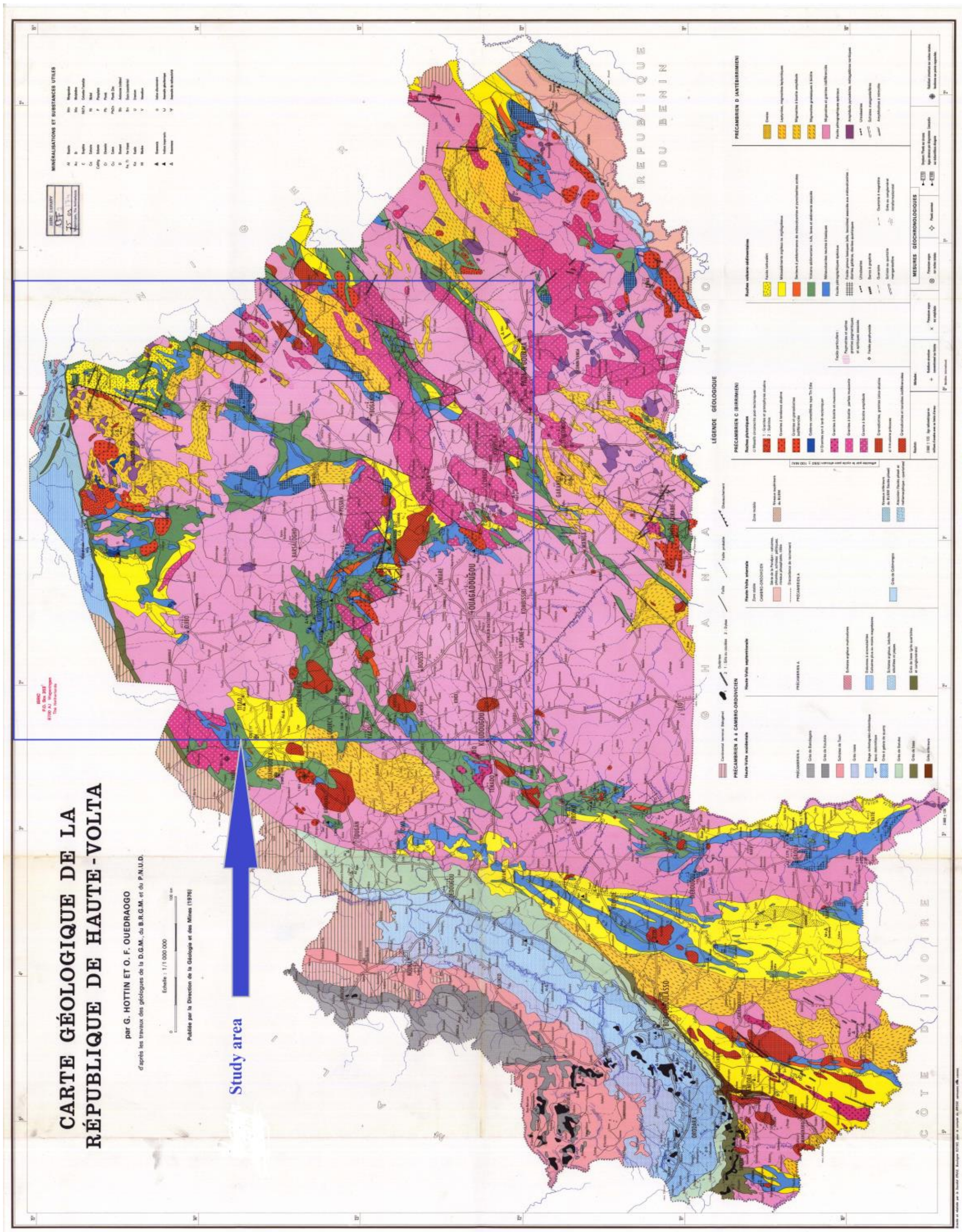


Figure 1.2: Geological map of Burkina Faso showing study area (Hottin & Ouedraogo, 1992)

CHAPTER 2: REGIONAL GEOLOGY

2.1 Stratigraphy

The lithostratigraphy in north-eastern Burkina Faso is defined by NE-trending Birimian meta-volcaniclastic greywacke and intercalated meta-conglomerate, siltstone and shale (Figure 1. 2). The Birimian stratigraphy was divided into two parts by Junner (1935; 1940) in (Leube et al., 1990), the lower Birimian series and the upper Birimian series. The lower Birimian series is predominantly sedimentary in origin and includes dacitic/rhyodacitic meta-volcaniclastic sediments, meta-greywacke with intercalated black meta-siltstone and manganiferous chert, argillite, shale and chemical meta-sedimentary (Feybesse et al., 1990; Leube et al., 1990; Hirdes et al., 1990; Milési et al., 1991). The upper Birimian series consists of metamorphosed basic and intermediate lavas and pyroclastic rocks (Feybesse et al., 1990; Leube et al., 1990; Hirdes et al., 1996; Milési et al., 1991, 1992; Naba, 2004; Tshibubudze et al., 2009). The Birimian sequences were metamorphosed during the Eburnean Orogeny and were intruded by numerous calc-alkaline plutons including tonalite (TTG), granodiorite, diorite and meta-diorite bodies that are collectively termed the Eburnean granitoids (Pons et al., 1995; Naba et al., 2004; Pawlig et al., 2006). Lateritic profiles cover much of the West African craton.

The Birimian sequences were metamorphosed during the Eburnean Orogeny where the meta-volcanic and metasedimentary rocks were subjected to crustal shortening associated with greenschist facies regional metamorphism (Oberthur et al., 1998) and by further metamorphism related to the intrusion of granitoids (Milesi et al., 1989, 1991; Bossiére et al., 1996; Hirdes et al. 1996; Hein et al., 2004). Metamorphic grade includes greenschist facies with formation of dominant chloride–muscovite mineral assemblage and abundant hornblende and andalusite mineral assemblages which are low to medium grade amphibolites facies (Bossiére et al., 1996; Béziat et al., 2000; Naba et al., 2004; Pawlig et al., 2006).

The Tarkwa Group unconformably overlies the Birimian sequence (Leube et al., 1990; Milési et al., 1992; Castaing et al., 2003). It has been divided into three units: the Banket Series, Phyllite Unit and Meta-Sandstone unit. There is further division into the Banket quartz lithic meta-sandstone unit and the Banket meta-conglomerate unit of the Banket series (Tunks et al., 2004).

2.2 Structures

In NE Burkina Faso there are four greenstone belts, of which three have been studied, namely, the Goren and Oudalan-Gorouol greenstone belts (Fig. 2.1) which have been studied by Hein et al. (2004) Hein et al. (2010) and Tshibubudze et al. (2009) and the Yalogo greenstone belt which has not been studied to date.

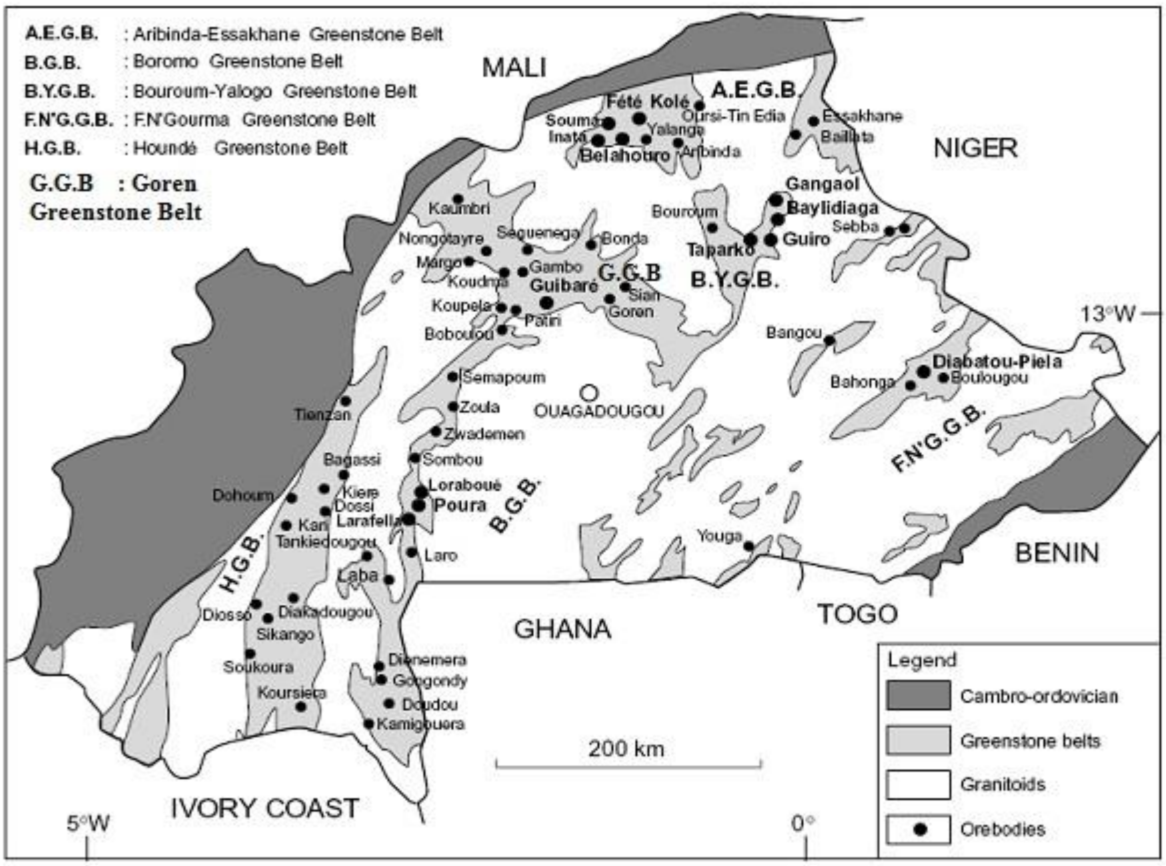


Figure 2.1: Greenstone belts of Burkina Faso after Béziat et al. (2008)

The Oudalan–Gorouol greenstone belt (OGGB) hosts gold deposits at Essakane, Gossey, Korizena and Falagountou (Tshibubudze et al., 2010). In the OGGB, the Birimian supracrustal sequences are dominated by meta-volcaniclastic greywacke that is intercalated with meta-conglomerate, siltone and shale, carbonate (dolomite) and volcanic units (pillow lavas). The OGGB is surrounded by plutonic rocks including granite, TTG suite granitoids and granite gneiss (Tshibubudze et al., 2010). It is crosscut by the NNE trending Markoye Shear Zone, NE trending Tin Takanet-Bellekcire Shear Zone, westerly trending

Dori Shear Zone, north trending Kargouna Shear Zone, Takabougou Shear Zone and Bom Kodjelé Shear Zone (Tshibubudze et al., 2010).

The Goren Greenstone Belt (GGB) forms part of the largest Boromo-Goren Greenstone Belt (BGGB) .The GGB segment of the BGGB trends SE across the Yatenga, Bam, and Sanmatenga districts (Hein et al., 2004). In the GGB there are two Birimian formations: the Lower and Upper Birimian which are described based on studies done by Attoh (1982) and Feybesse et al. (1990) and craton-scale studies by Milési et al. (1989), Abouchami et al. (1990), Hottin and Ouedraogo (1992) and Boher et al (1992). The studies indicate that the

1) Lower Birimian which includes a volcano-sedimentary package with intercalated fluvial deltaic meta-sediments is unconformably overlain by the:

2) Upper Birimian which is a volcanic-volcanoclastic package.

Further investigations on lithologies and structures completed by Hein et al. 2004 at Sanmatenga district indicate that the deposition of the volcanic, metasedimentary and turbidic rocks in the Gorem segment of the BGGB is in three conformable successions: a lower volcano- sedimentary succession, mafic-intermediate volcanic succession, and an upper volcano-sedimentary succession. The successions indicate interplay of marine-deltaic sedimentary processes and volcanic activity. The deposition was interpreted to have occurred within a marginal marine setting adjacent to an emergent volcanic centre or island arc setting (Hein et al., 2004). The conformable nature (angular unconformity) of the successions: the 1) Lower Birimian and 2) Upper Birimian does not provide any case of separation into two formations in the Sanmatenga district described from previous studies by Attoh (1982) and Feybesse et al., (1990).

The Birimian Bouroum-Yalogo greenstone belt is a Y-shaped terrane located between large Eburnean granitoid batholiths 200 km northeast of Ouagadougou (Ducellier 1963). It consists of: (1) metagranites, metagabbro-diorites and metaquartzite of the Bamga series (Hottin and Ouedraogo 1976; Sawadogo 1983; Zonou, 1987) interpreted as early Birimian and dated at 2. 18 Ga (Boher et al. 1992); (2) overlying mafic lava flows and pillow lavas (Zonou et al.,1985) with associated pyroclastites, volcaniclastic rocks and immature sediments mainly at lower levels and calc-alkaline andesite, dacite and lamprophyre at upper levels, all affected by a greenschist-facies metamorphism; and (3) basic to intermediate plutons later emplaced.

Markoye Shear zone

In the NE Burkina Faso the Palaeoproterozoic Birimian Domain of the West African Craton is crosscut by the NE-trending Markoye Shear Zone (MSZ) which is a first crustal scale structure. The MSZ marks the western boundary of the Oudalan-Gorouol Greenstone Belt which extends into the Niger

(Tshibubudze et al., 2009). The MSZ has undergone at least two phases of reactivation which happened at the same time as two phases of regional deformation. The first deformation, D1 resulted in the formation of NNW-NW trending folds and thrusts during dextral-reverse displacement of the MSZ. The second deformation, D2 involved a period of SE-NW crustal shortening and sinistral-reverse displacement on the MSZ and is correlated to the Eburnean Orogeny approximately 2.1 Ga (Tshibubudze et al., 2009).

Sabce Shear Zone

The Sabce Shear Zone (SSZ) is a NE trending sinistral-reverse shear zone. It is represented by a branch of the main zone at Tangapella. The branch consists of an array of interconnected sub-shears trending NE. The sub-shears crosscut and offset all the lithologies, F1 folds and D1 boudins at Tangapella area (Hein, 2010).

Belahouro Shear Zone

The Belahouro Shear Zone (BSZ) is a mineralised NNW trending shear zone. It is modelled as a back structure to the major NNE trending Markoye Shear Zone (Middleton et al., 1997)). The Belahouro Shear Zone is mineralised and is considered a prospective exploration target. Basalt and volcanoclastic within the NE portion of the region have a sheared contact and provide a lithological contrast (Middleton et al., 1997).

Laterites (Ferricrete)

An extensive residual laterite cap exists in the study area (Hein. 2008). Laterite is an iron-rich profile that is developed under tropical to sub-tropical condition due to long term exposure of rocks to the atmosphere and hydrosphere in tectonically stable areas (Dequincey et al., 2006).The ferricrete is matrix to clast supported and typically contains clasts and rock fragments of the underlying stratigraphy (Middleton et al., 1997) and is currently forming in lowland areas. The general outcrop distribution of ferricrete indicate that, the ferricrete has been eroded, deposited and cemented several times such that the current ferricrete profile is representative of several phases of ferricrete formation (Middleton et al., 1997). Studies done by Hein, 2008 in the Yatenga District show that ferricrete has a negative correlation with master joints. Using ^{10}Be and ^{26}Al isotopic depletion ratios of laterite, Brown et al. (1994) concluded that in-situ laterite in Burkina Faso formed during the upper Cretaceous to Eocene.

2.3. Case studies

The following case studies helped in choosing the methodology for this project.

2.3.1 Assessment of land degradation in the save catchment of Zimbabwe by Julia Mambo and Emma Archer, 2007.

<u>Methodology</u>

The methodology involves Buhera Straddles three landsat satellite scenes namely 169/74,169/73 and 168/74.Two sets of the three Landsat TM and ETM scenes for the years 1992 and 2002 were georeferenced using image to image rectification with SPOT images projected in UTM, (Zone 365) and referenced onto the WGS 84 ellipsoid. An average of 12 ground control points per image were used; with a residual error of approximately 2.1 metres. The three scenes were mosaiced and an image enclosing Buhera district was extracted, upon which subsequent image processing was undertaken. Two bands 3 and 4 were used for change detection analysis.

<u>Summary of methodology is displayed in the following diagram</u>

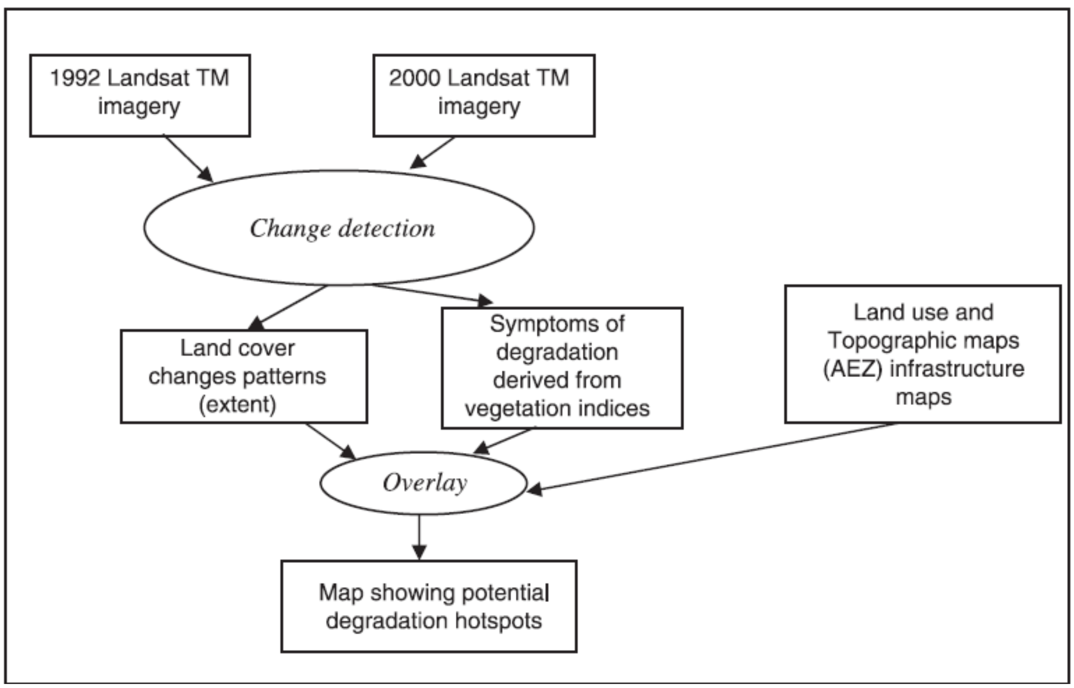


Figure 2.3.1: Flow diagram showing assessment of severity of degradation in the Save catchment.

2.3.2 Map updating using high resolution satellite imagery: A case of the kingdom of Swaziland, 2002.

A case study of the Kingdom of Swaziland on map updating using high resolution satellite imagery was completed because the map for the area is old, outdated and largely exist in analogue form. This work was undertaken by W. Ottichilo and E. Khamala. The country is covered by fourteen spot satellite imagery scene, four landsat TM satellite image scene and thirty-five 1:50000 topographic maps.

Methodology used high resolution remote sensing and GIS. This was implemented in five stages. These include:

1. Preliminary image interpretation: This involved classifying and interpretation. Preliminary maps were produced from colour, tone, pattern, texture, association, shape, size, shadows and size enabled photomorphic delineation of line and polygon.
2. Field observation: sample points were selected from preliminary interpretation.
3. Final image interpretations were**:** field work findings were incorporated to refine both the preliminary classification systems and preliminary image interpretation. This stage involved re-labelling and redrawing of certain feature boundaries to give the actual representation as revealed from fieldwork exercises.
4. Quality control: This stage involved cross-checking the feature boundaries to ensure accurate and consistent interpretation. Confirmation of feature codes/labels, polygon closures, line feature continuity among topological issues .After approval final interpretation would proceed for digitization.
5. Digitization of final interpretation: this was done on a scene by scene and theme to theme basis using ArcInfo, ArcView GIS Software. Land use and land cover polygons, hydrological features and the road network were digitized as independent thematic layers. Each thematic layer was then edited to eliminate digitization errors and thereafter coded and Georeferenced. Adjacent digital themes were edge matched and joined together to produce single nationwide thematic mosaics of the entire kingdom of Swaziland. Using ArcView, all the different national map layers were overlaid to produce a single multi-thematic map of Swaziland with scale of 1:250000.

From the methodology the following results were obtained:

National map of kingdom of Swaziland was produced using SPOT satellite imagery at scale of 1:250 000. The map carried eight land use/ land cover classes, hydrological features, transportation infrastructure, towns and administrative boundaries. A rich GIS database containing both spatial and aspatial information was developed. Satellite image interpretation accuracy was 80% indicating that the methodology is robust and reliable if well executed.

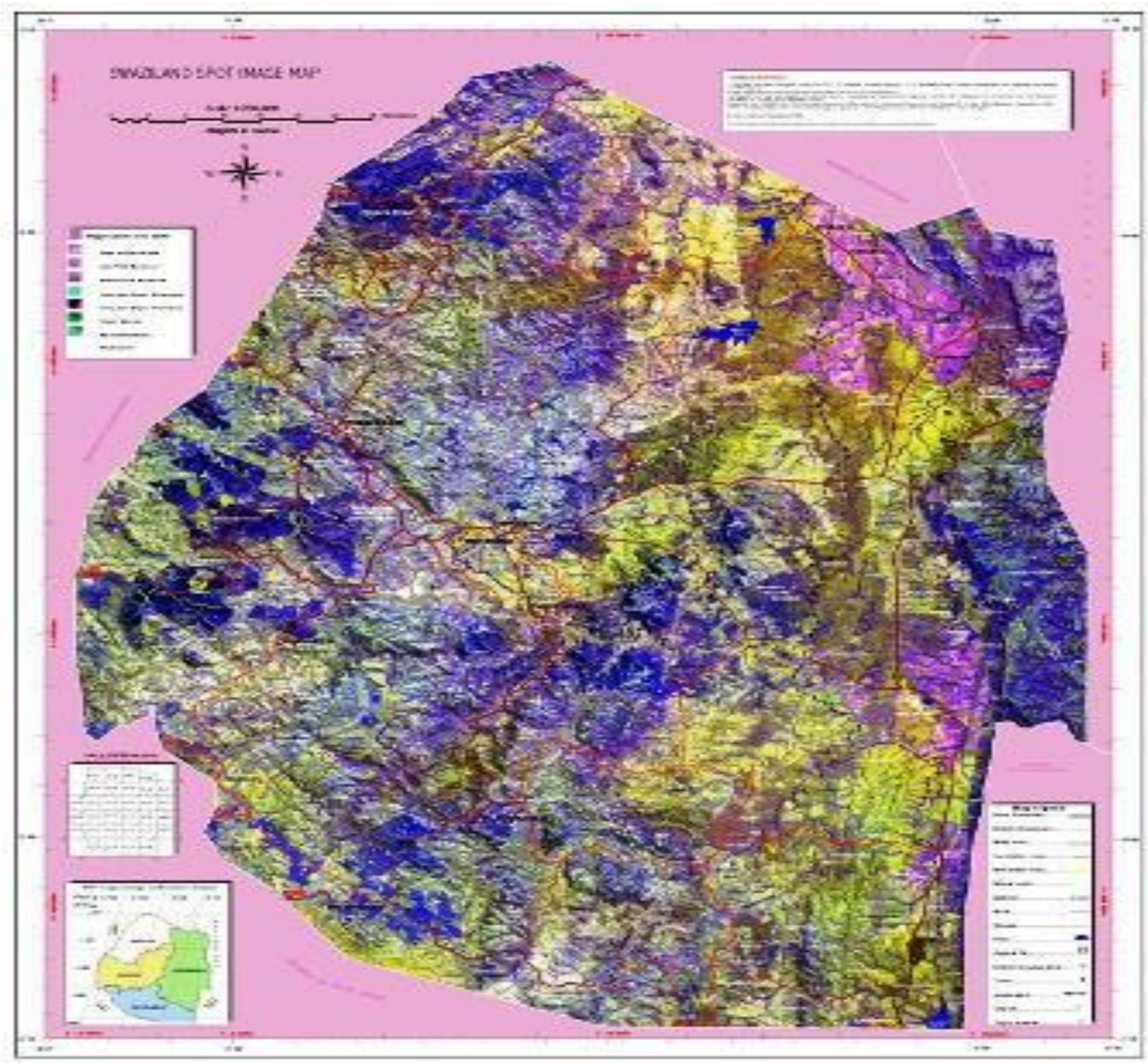


Figure 2.3.2: Updated national road network map overlaid on mosaiced SPOT satellite images of the Kingdom of Swaziland.

2.3.3 Photo geology presented by Drury, 1987.

<u>Methodology</u>

The methodology deals with extraction of geological structures to produce geological maps from aerial photos and satellite images. The following criteria are used to extract data: Colour and colour tones, topography and geometry, stream drainage patterns, vegetation anomalies. IDRISI software package, remote sensing and GIS are used considering the following four criteria:

1. Structural interpretation- determination of geomorphology, lineaments and line features, faults and folds, vegetation anomalies and drainage patterns.
2. Petrographic/lithologic interpretation- determination of rock types and boundaries of geological formations.
3. Using IDRISI colour & colour tones show shapes and sizes of features.
   -Shape is the geometric outline of an object and it gives information about the nature and geometry of the object.
   -size is the magnitude of an object or a single dimension of an object.

The geological interpretation of imagery

Colour and tones give brightness levels in digital images and reflection of colour tones of different materials on the earth helps to distinguish different materials and their boundaries e.g. water can be distinguished from soil since water has a different tone than soil (Lillesand & Kiefer, 1994; Konecny 2002; Prost, 2001).

2.3.4 Mapping land use/ cover distributions on a mountainous tropical island using remote sensing and GIS by Serwan M. J. Baban and Kamaruzaman Wan Yusuf, 2001

Study area: Langkawi Islands

Data collection and methodology

The study area has a Landsat TM satellite image for Langkawi Island, acquired on March 1995 was analysed using IDRISI, a raster-based GIS software program. Image was atmospherically corrected using the darkest pixel approach and geocorrected with a mean square (RMS) error of less than half a pixel. Using IDRISI, with composite images of the bands TM3, TM4 and TM5 an unsupervised classification of land use/cover was performed on the basis of spectral signatures for nine clustering areas. Secondary data was used to support this work. This consisted of a 1990 topographic map of scale 1:500 000, 1990 land use map of scale 1:150 000 and 1986 map at scale 1:100 000 and ground truth data from 255 sampled points. This was followed by a supervised classification for land use/cover where training sites were selected on the basis of the unsupervised classified image.

Using IDRISI, the polygons around each training area were digitized and assigned a unique identifier each cover type; a spectral signature for each class was created. Thematic content of the classified image was quantitavely assessed for accuracy by evaluating the correspondence between the class label assigned to a pixel in the image and true class as measured on ground. A direct comparison of classes was carried out based on geographical location with the available primary and secondary data. Most of the classes were easily separated and mapped due to their distinctive reflectance signatures within the TM bands used; their confinement of different parts of the area was based mainly on topography. Overall accuracy of the method was 90%.

CHAPTER 3: METHODOLOGY

3.1 Data used

The data consists of six Landsat 7 images each carrying eight bands, magnetic and radiometric data. Aeromagnetic data-125m pixel total magnetic intensity reduced to the pole 1st vertical derivative with NW shading UTM Zone 30N data was used from Mr. Mark Jessell, personal data. Radiometric data-total K-Th-U RGB radiometric data for NE Burkina Faso was used from AMIRA West African Exploration P734 project.

3.1.1 Landsat 7 imagery

Table 3.1: Satellite imagery type and georeference system used

Imagery type (Landsat 7)	Imagery date	UTM Zone
P194r050	2000/08/05	31N
P194r051	2001/10/11	30N
P194r052	1999/11/07	30N
P195r050	2000/08/12	30N
P195r051	2001/07/14	30N
P195r052	2001/11/03	30N

Landsat 7 band characteristics

Landsat 7 was launched on 15 April 1999 and is equipped with a multispectral sensor known as the Enhanced Thematic Mapper Plus or ETM+ sensor. Table 3.2(a) gives a summary of Landsat 7 characteristics and table 3.2(b) gives the summary of band characteristics as prescribed on the NASA website in the Landsat 7 science data and uses. Only bands 1, 2, 3, 4, 5, 7 were used for image processing and classification since they have the same resolution, rows and columns and Bands 6 and 8 were not used because Band 6 is a thermal infrared and Band 8 is a panchromatic band (table 3.2(b)).

Table 3.2 (a): Landsat 7 characteristics

Altitude:	705 kilometers (nominal)
Inclination:	98.2 degrees
:	Sun-synchronous near polar
Period of revolution:	98.9 minutes
Repeat coverage interval:	16 days (233 orbits)
Quantization:	Best 8 of 9 bits
Swath width:	185 kilometers

Table 3.2 (b): Band characteristics after Williams, 2009).

Band Number and spectral response	Spectral Range(microns)	Ground Resolution(m)	Uses
1(Blue)	0.45 – 0.515	30	Coastal water mapping, soil/vegetation discrimination, forest classification, man-made feature identification
2(Green)	0.525 – 0.605	30	Spanning the region between the blue and red chlorophyll absorption bands, this band shows the green reflectance of healthy vegetation. It is useful for differentiating between types of plants, determining the health of plants, and identifying manmade objects.
3(Red)	0.63 – 0.69	30	The visible red band is one of the most important bands for discriminating among different kinds of vegetation. It is also useful for mapping soil type boundaries and geological formation boundaries.
4(Near infrared)	0.75 – 0.90	30	This band is especially responsive to the amount of vegetation biomass present in a scene. It is useful for crop identification, for distinguishing between crops and soil, and for seeing the boundaries of bodies of water.(Biomass)
5(Mid-Infrared)	1.55 – 1.75	30	This band is sensitive to turgidity -- the amount of water in plants. Turgidity is useful in drought studies and plant vigor studies. In addition, this band can be used to discriminate between clouds, snow, and ice.
6(Thermal infrared).	10.4 – 12.5	60	Measures the amount of infrared radiant flux (heat) emitted from surfaces, and helps to locate geothermal activity, classify vegetation, analyze vegetation stress, and measure soil moisture.
7(Mid-infrared)	2.09 – 2.35	30	Helpful for discriminating among types of rock formations (Lithology) and hydrothermal mapping
PAN(8)	0.52 – 0.90	15	

Six Landsat 7 images in RGB 731 colour composite images were mosaic using CorelDraw X3 ® Software to be used for extraction of geological features (figure 1).

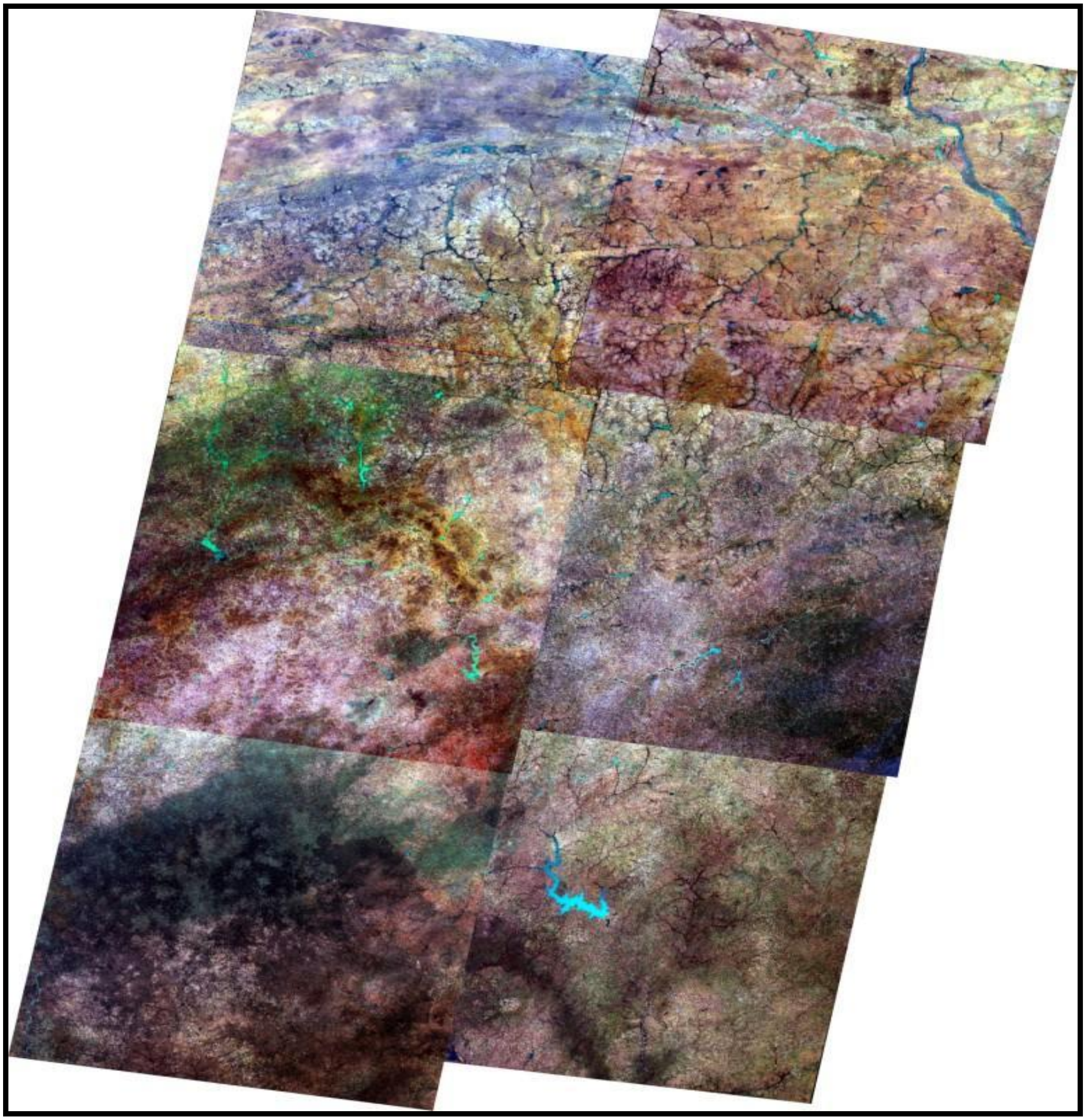


Figure 3.1: Mosaic of the six Landsat (RGB) 731 colour composite.

3.1.3 Aeromagnetic data

The aeromagnetic data has total magnetic intensity reduced to the pole 1st vertical derivative with NW shading UTM Zone 30N. Three images making the magnetic data will be used (figure 3). These images will be overlain using CorelDraw X3 ® software.

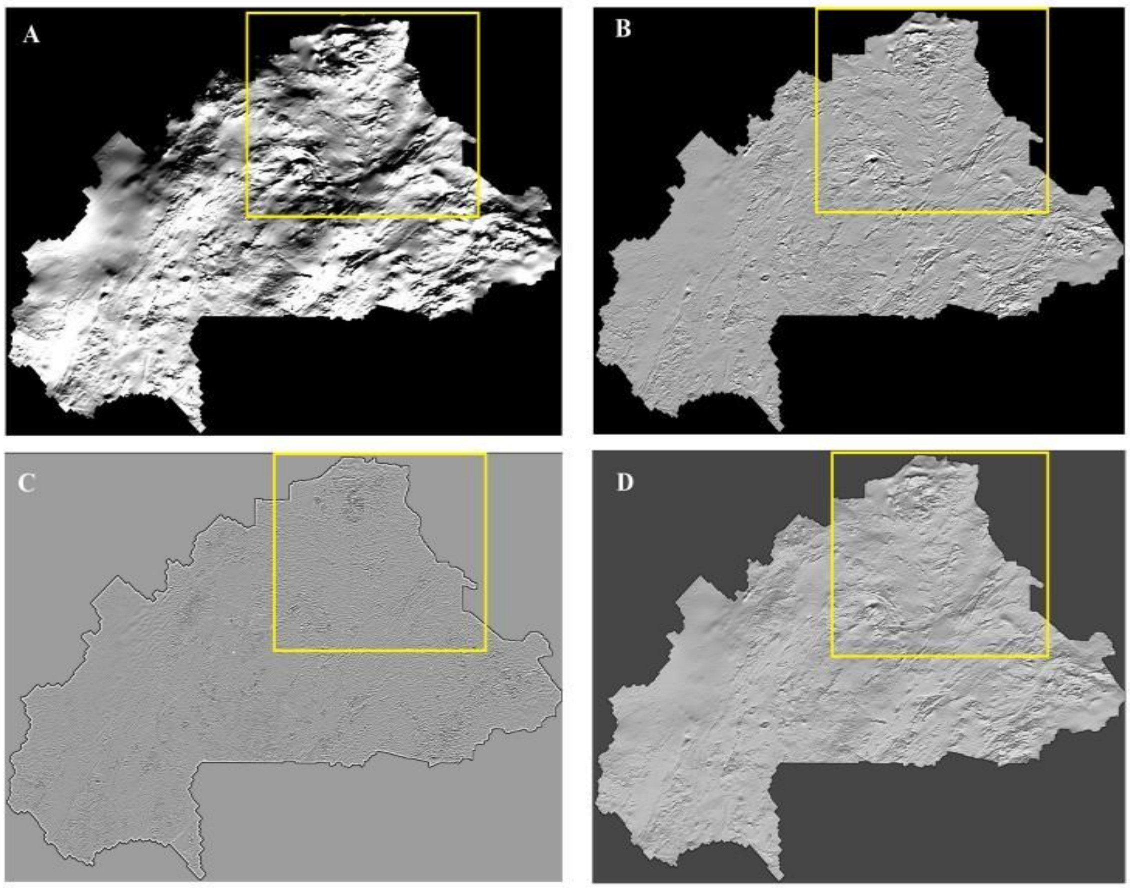


Figure 3.2: Aeromagnetic data A, B, C with total magnetic intensity reduced to the pole 1st vertical derivative. D-represents overlay of the three magnetic data (A, B and C).

3.1.4 Radiometric data

Total K-Th-U RGB data for NE Burkina Faso was used. Due to the image being cut off only few parts of the image making the study area will be used. There are two images making the radiometric data (figure 4) and using CorelDraw X3 ® Software the two image in figure 4 A and C were inverted.

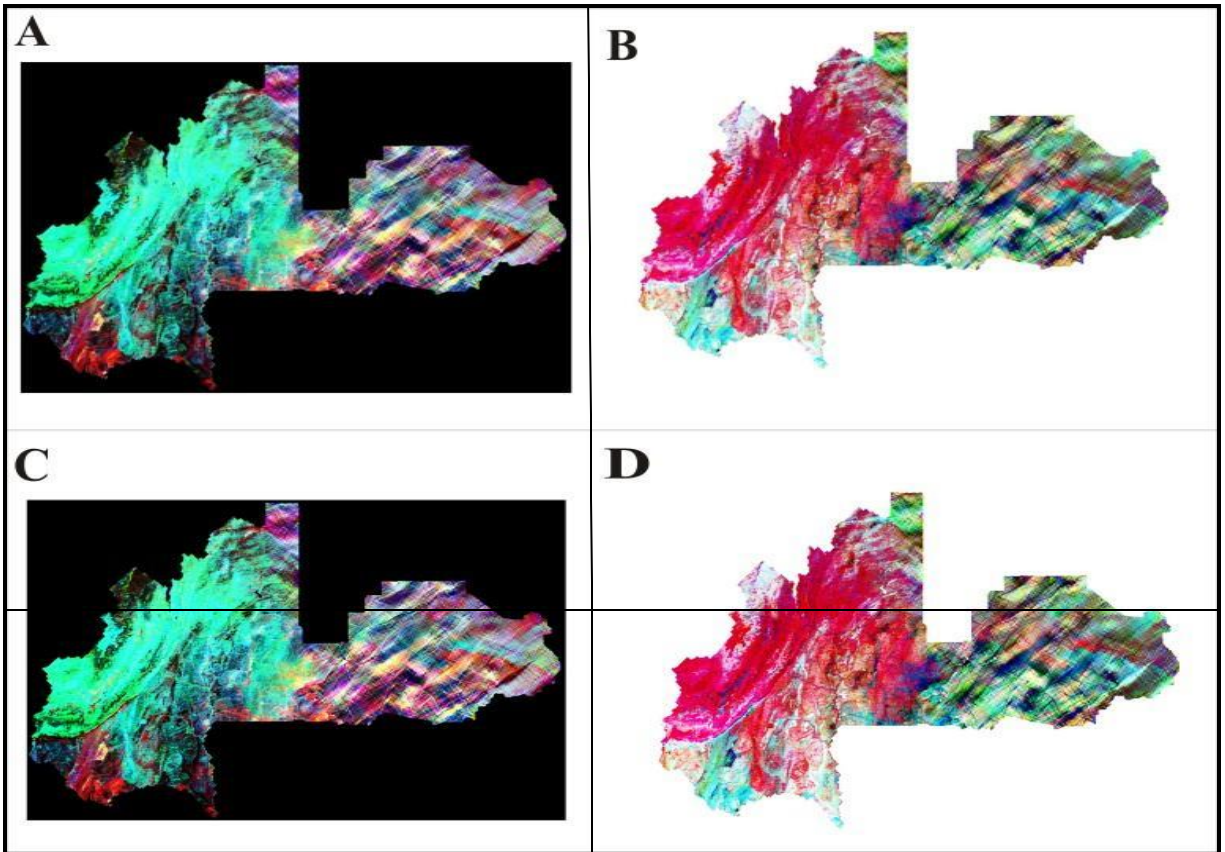


Figure 3.3: A and C show radiometric data and B and D show inverted radiometric data.

3.2. Image processing and classification

3.2.1 Bands combinations

The Landsat imagery bands of p194r050, p194r051, p194r052, p195r050, p195r051 and p195r052 were used for band combinations. RGB colour combination images using Landsat data were selected primarily on the basis of reflectance spectra of dominant rock types. The original image bands were displayed in an RGB colour composite in order to detect the best combination that shows more information of geological features of the study area (Fig. 1). The band combination 321 (RGB) were displayed for true colour visual analysis of geological features (Figure 5). The false colour composite 742 in an RGB was displayed in order to enhance the interpretation and visual analysis of geological structures shown by the band combination 321. The false colour composite 742 (Figure 6) has the advantage of preserving morphological features as well as displaying different lithological units in different colours because of the use of near and mid infrared portion of the electromagnetic spectra (Peña and Abdelsalam, 2006). A false colour composite with band combination (RGB) 7 3 1 was used to display differences in rock types (Figure 1). False colour composite with band combination (RGB) 432 was used to delineate the human geography. False colour composite with band combination (RGB) 753 can be used to find textural and moisture of soils and can be useful for geological studies. All the band combinations were created using IDRISI Kilimanjaro software package by running Composite from the display menu and assigning the bands to RGB composite.

True colour composite (RGB) 321

In a True Color composite, the visible bands are selected and assigned to their corresponding colours to obtain an image that approximates true color. The visible bands approximate the range of vision for the human eye, and hence they appear to be close to what we would expect to see in a normal photograph. True color tends to appear flat and have low contrast due to the Electromagnetic (EM) radiation in the blue visible region being more susceptible to atmospheric scattering.

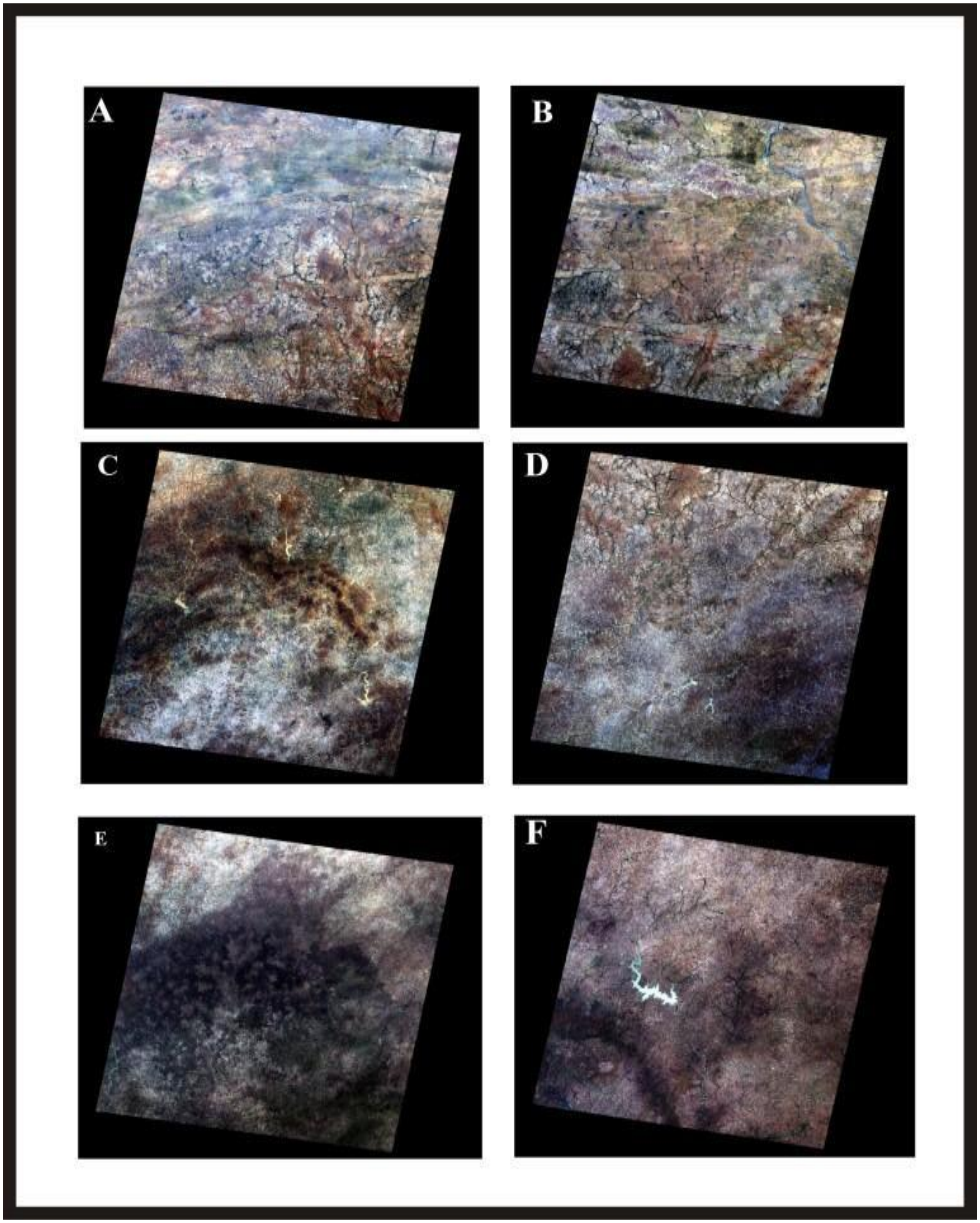


Figure 3.4: True colour composite image (RGB) 321

False colour composite 742

This band combination provides imagery for desert regions and for the purpose of the project it will be used to extract sand dunes. Sands, soils and minerals are highlighted in different colours. Areas with bright green indicate healthy vegetated areas while area in light green represents grass lands. Pink areas represents barren soil, urban areas are represented in magenta.

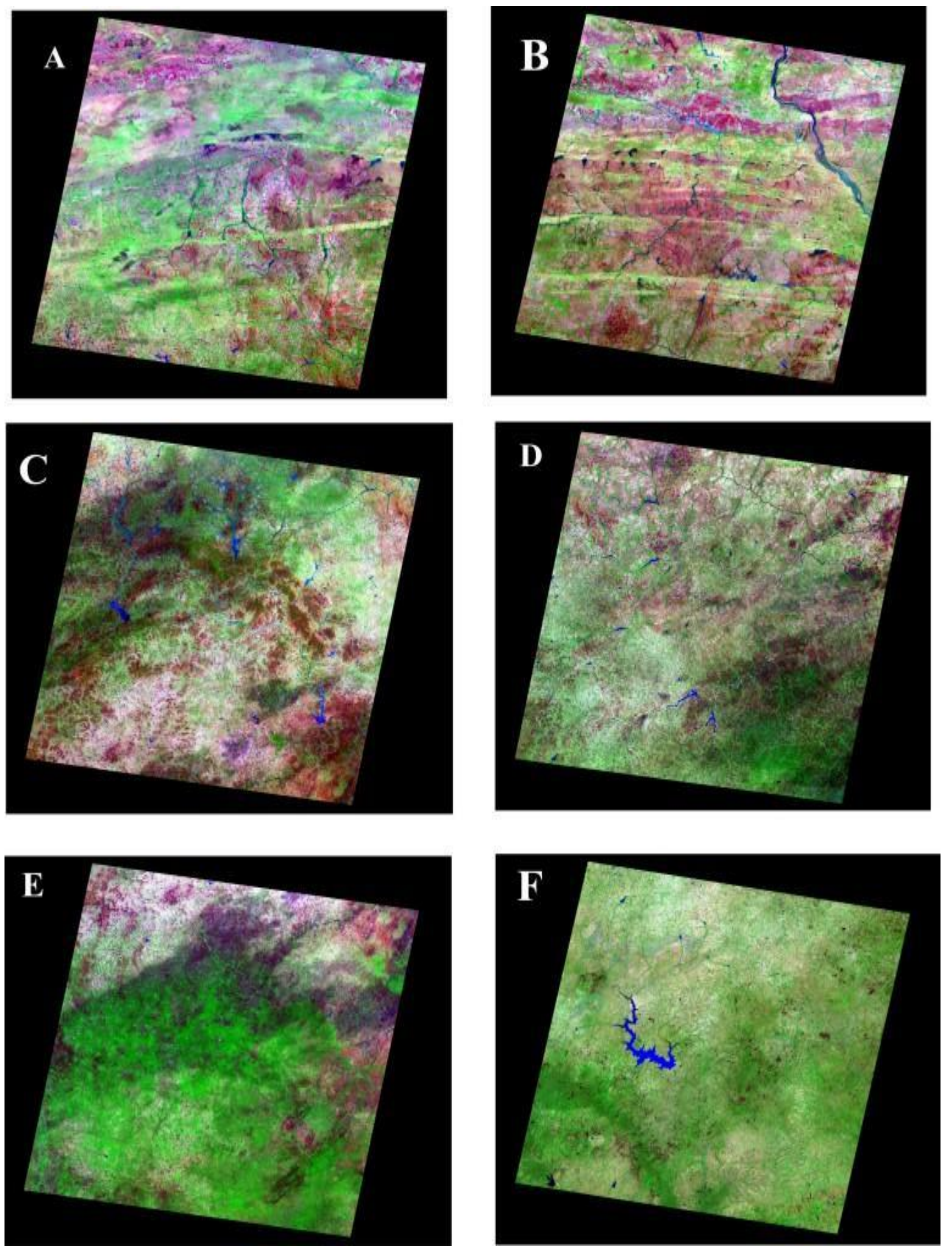


Figure 3.5: False colour composite 742 with rivers in blue, sand, minerals and soils in various colours and bare land in pink. Green show area of vegetation.

3.3 Extraction of geological features

CorelDraw X3 ® software was used to extract different features including lineaments, shear zones, sand dunes, plutons, granodiorites and greenstone belts. Six images from the study area with False Colour Composite and RGB 731 band combination were combined to form a mosaic using CorelDraw X3 ® software. The extraction process took five weeks to complete because of the large size of the images and time was needed to zoom to features to see them clearly. Magnetic and radiometric data were also used in this process. Three images of the aeromagnetic data were overlain in CorelDraw to extract large geological features. The two images making the radiometric data were also used for this process of extraction but due to the fact that only a portion of the study area is covered by the currently available radiometric data, few features could be extracted.

CHAPTER 4: EXTRACTION

The extraction process for NE Burkina Faso helped in constraining the position of plutons, dykes, lithologies, lineaments, laterites and shears in the study area. LANDSAT 7 data provided useful constraints on surface lineaments, the distribution of laterites, drainage systems and human geography.

4.1 Extraction of geological features using LANDSAT 7 (RGB) 731 FCC

Plutons

Plutonic rocks surround the greenstone belts, and are pink in image colour. There is no development of shears on the plutonic rocks. It can be concluded that the plutons postdate shearing. The plutons have almost circular shapes and their boundaries were easy to define.

Lineaments

A lineament analysis using LANDSAT 7 731 FCC and to a limited extent, aeromagnetic data, was completed to establish the dominant trend of lithologies, and shears. The lineaments were extracted from river drainages were the river was flowing in a straight line, since the river doesn't flow in a straight line there must have been a linear feature making it to flow in a straight line or causing it to change its course of flow. Most of the rivers in the imagery have the same trends as the lineaments. The lineaments trends (Fig 4.1).

1. East to ENE,
2. North to NNW
3. NEasterly

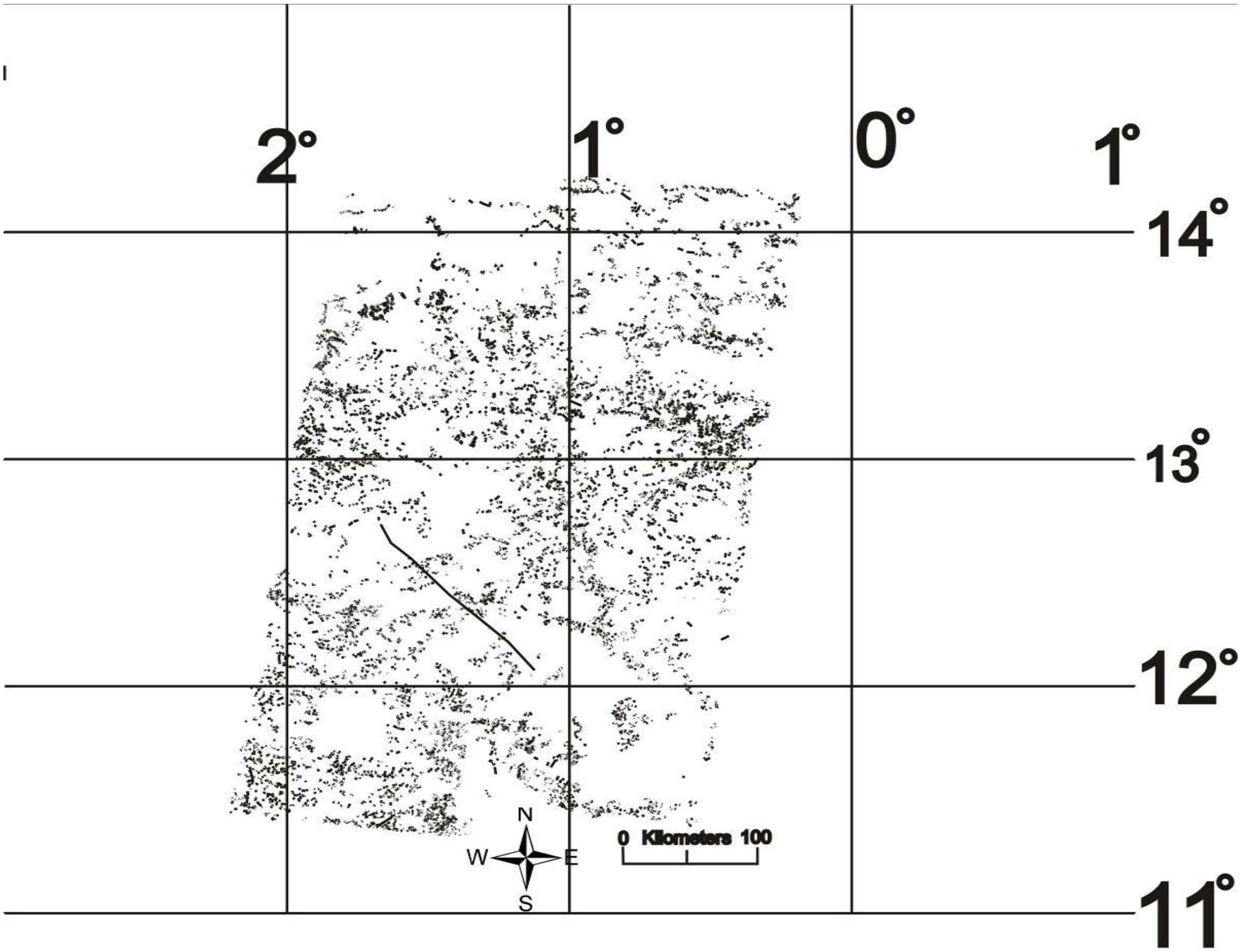


Figure 4.1: Lineaments interpreted from 731 FCC, lineaments trend east to ENE, north to NNW and NE.

Laterite (Ferricrete)

An extensive residual laterite cap exists in the study area. Dykes north of the Burkina Faso are skirted by laterite. Laterite covers greenstone belts. Age of the laterite is cretaceous.

Shear zones and greenstone belt

The NNE trending MSZ clearly mark the boundary of the OGGB as interpreted by Tshibubudze et al., (2009). The OGGB is surrounded by plutonic rocks as documented by Tshibubudze et al., (2010. The shear zones are marked in red (Fig. 4.2). The NE trending SSZ cuts the GGB and the Bouroum greenstone belt is cut by the BSZ which is NW trending as shown on fig 4.2 and fig. 4.3. All the greenstone belts on the image have an orange-brownish colour and have laterite caps. The GGB is cut by major joints with different trends. The greenstone belts extracted are larger in dimension than those documented on Figure 1.2, and this can help in increasing Gold exploration since most of the major discoveries of gold are found on the greenstone belts. New greenstone belts were found, these have the same signature (colour and laterite caps) as the already known greenstone belts.

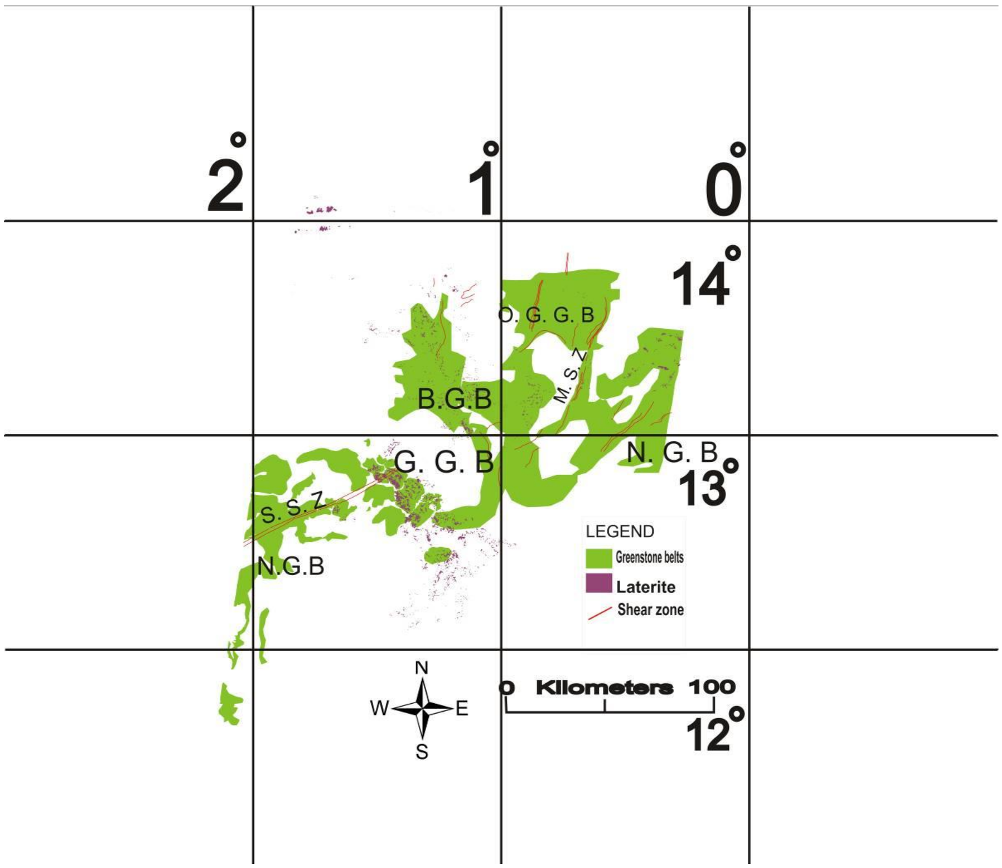


Figure 4.2: Distribution of greenstone belts, laterites and shear zones (Greenstone belts-green, laterites-purple and shear zones in red).

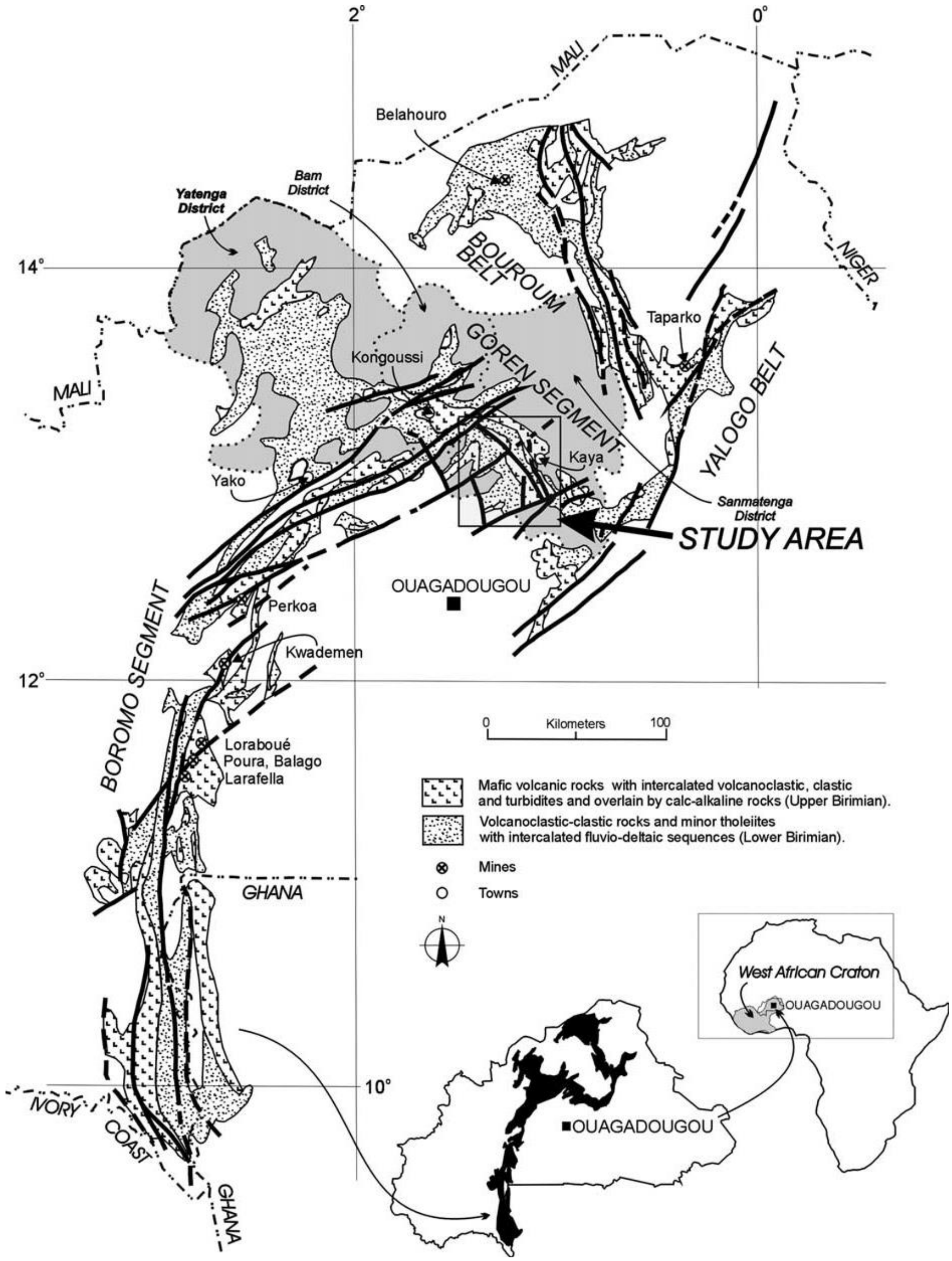


Figure 4.3: The Boromo–Goren Greenstone Belt (BGGB) of Burkina Faso, together with the Bouroum and Yalogo greenstone belts Hein et al. (2004).

Dykes

The dykes are predominantly NW-trending and are inferred to be dolerite in composition. The dykes are not continuous and hard to trace.

Sand dunes

Two images (p194r050 and p195r050) from the false colour composite 742 were used to delineate sand dunes (Fig. 4.4). On the image they are light green since they occur in areas with less vegetation. The sand dunes only cover the northern part of Burkina Faso, they form part of the Sahara desert.

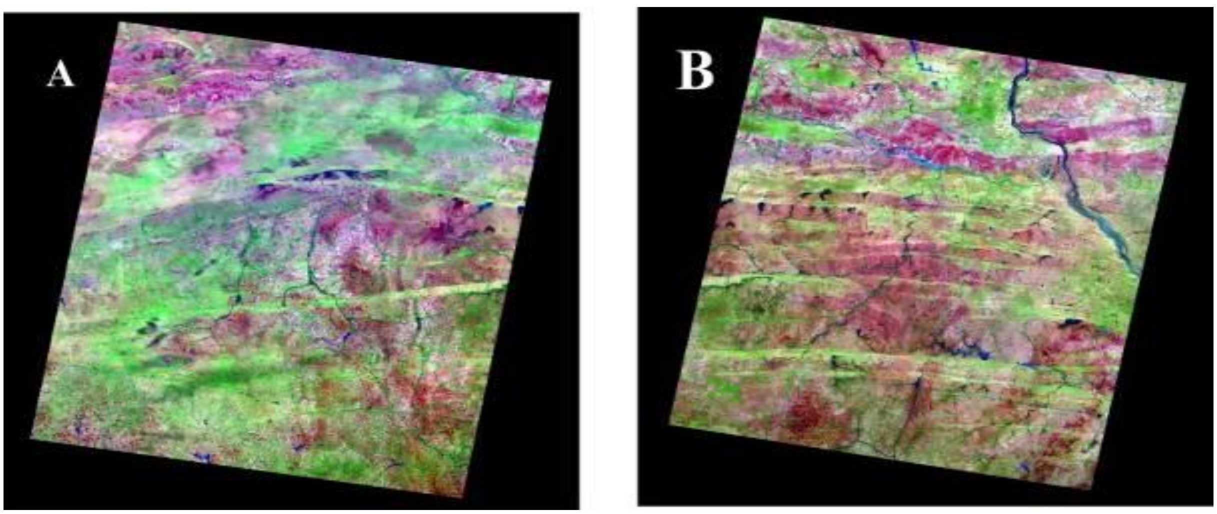


Figure 4.4: RGB 742 showing sand dunes in light green on the image.

Lithologies

Lithological trends were established wherever possible. There were sharp lithological contacts on the imagery were no mapping was done (fig.4.6). Near the GGB there was folding in the meta-conglomerate observed by Tshibubudze et al., (2009). Most of the eastern part of the image is covered by sand dunes and alluvium occurs in areas near the river this is marked by a light yellowish colour on the imagery. Other lithologies observed include volcanic intrusions e.g. TTG, granite which have a pink colour on the imagery.

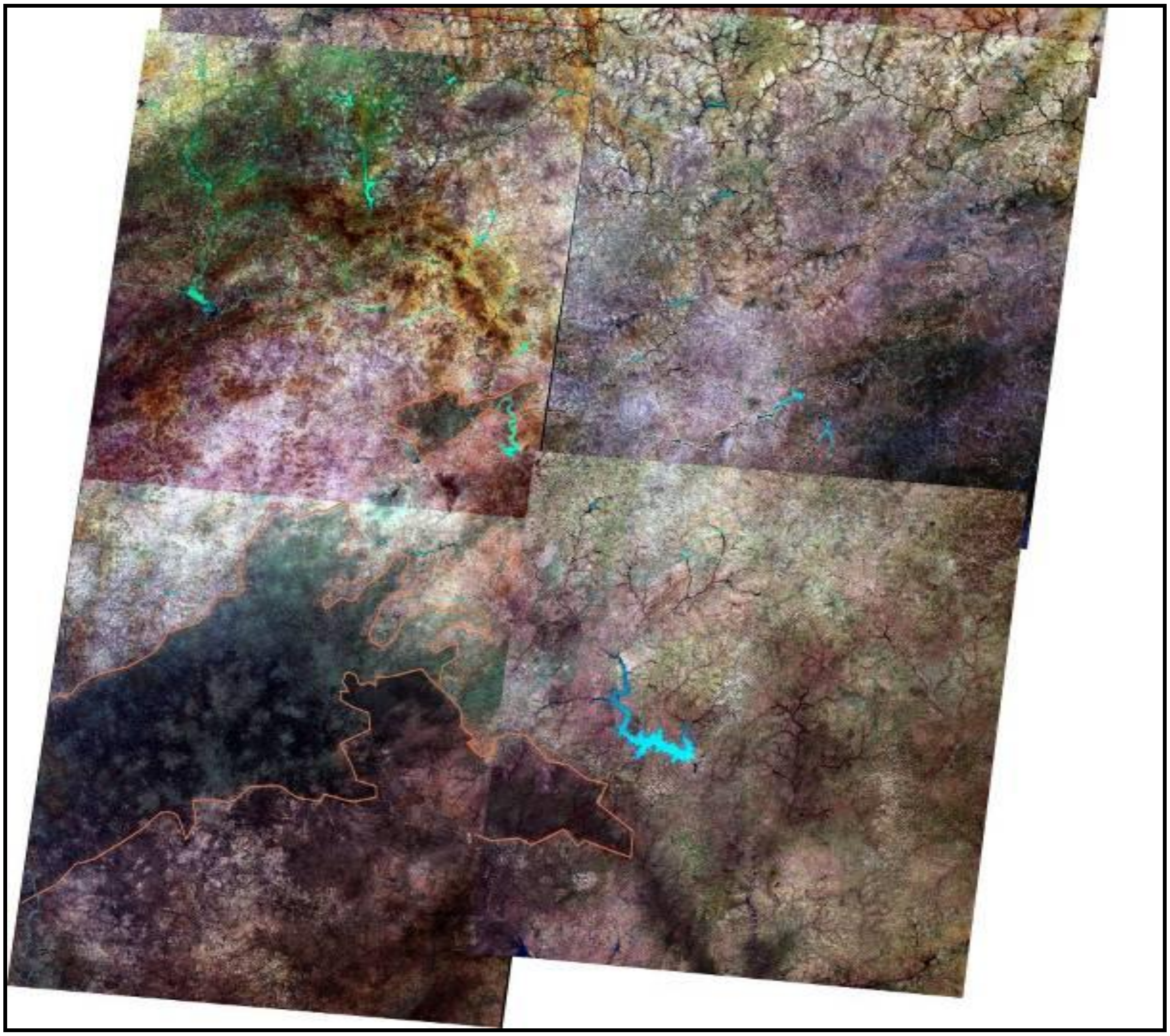


Figure 4.6: Sharp lithological contacts (orange)

4.2 Extraction of geographic/ physical features using LANDSAT 7 (RGB) 432 false colour composite.

RGB 432 colour composite was used to delineate the human geography these includes roads, cities and villages and drainage systems (fig. 4.7). This was done on a large scale. This RGB 432 band combination highlights the following:

Vegetation has shades of red, deep red shows healthy vegetation while light red shows grasslands and/or sparsely vegetated areas. Urban areas have a cyan blue. Soils have light to dark brown colours. Coniferous trees are darker red than hardwoods.

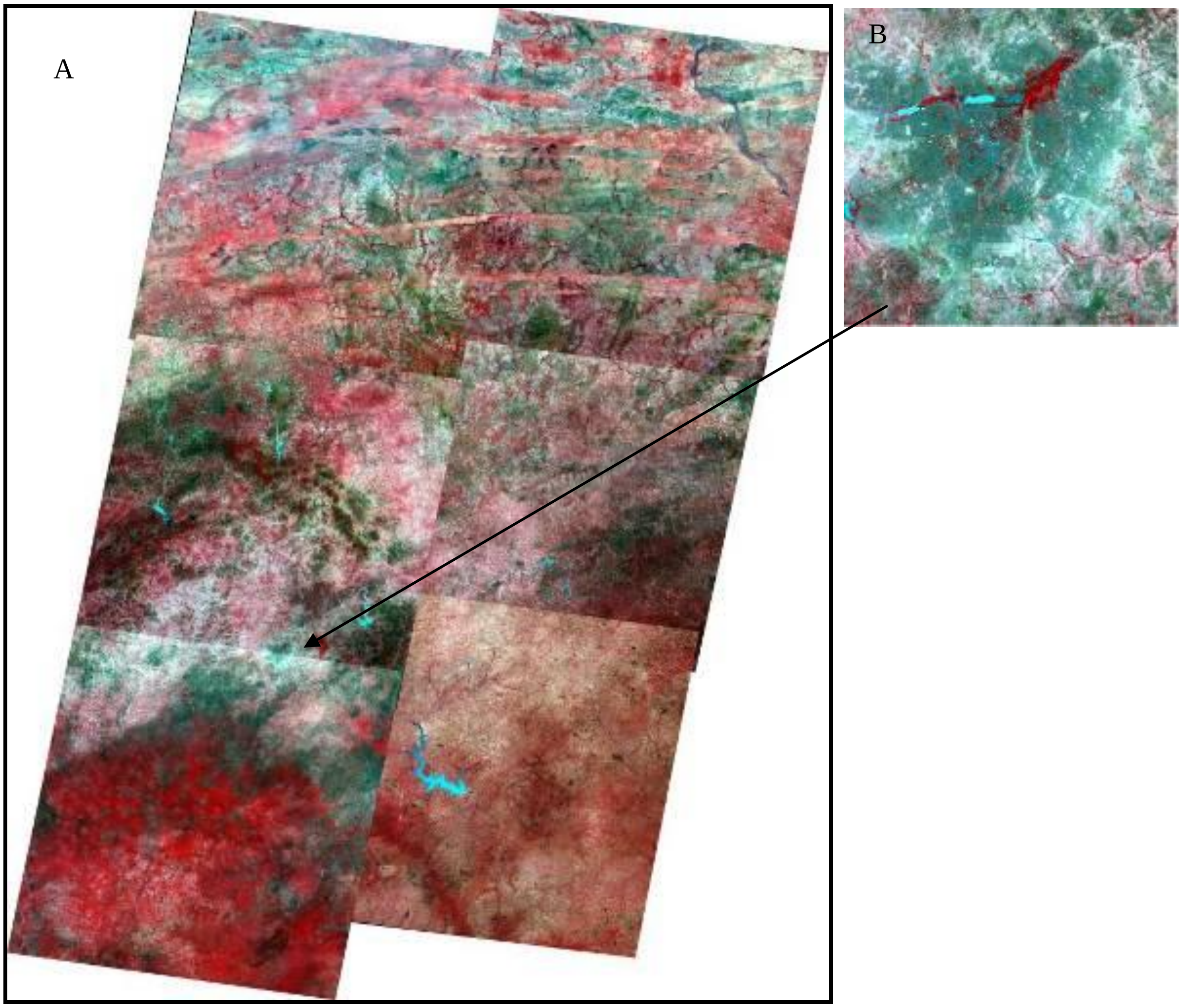


Figure 4.7: A-RGB 432 false colour composite with areas of healthy and dense vegetation shown in red and areas of less vegetation shown in light red. Rivers are marked in blue and cities (City of Ouagadougou) in cyan blue (B) and drainage systems are shown in red indicating that there is vegetation along the river (B).

Using the image above, a map showing locations of roads and cities as well as small villages was made using CorelDraw X3 ® Software (Fig. 4.8).

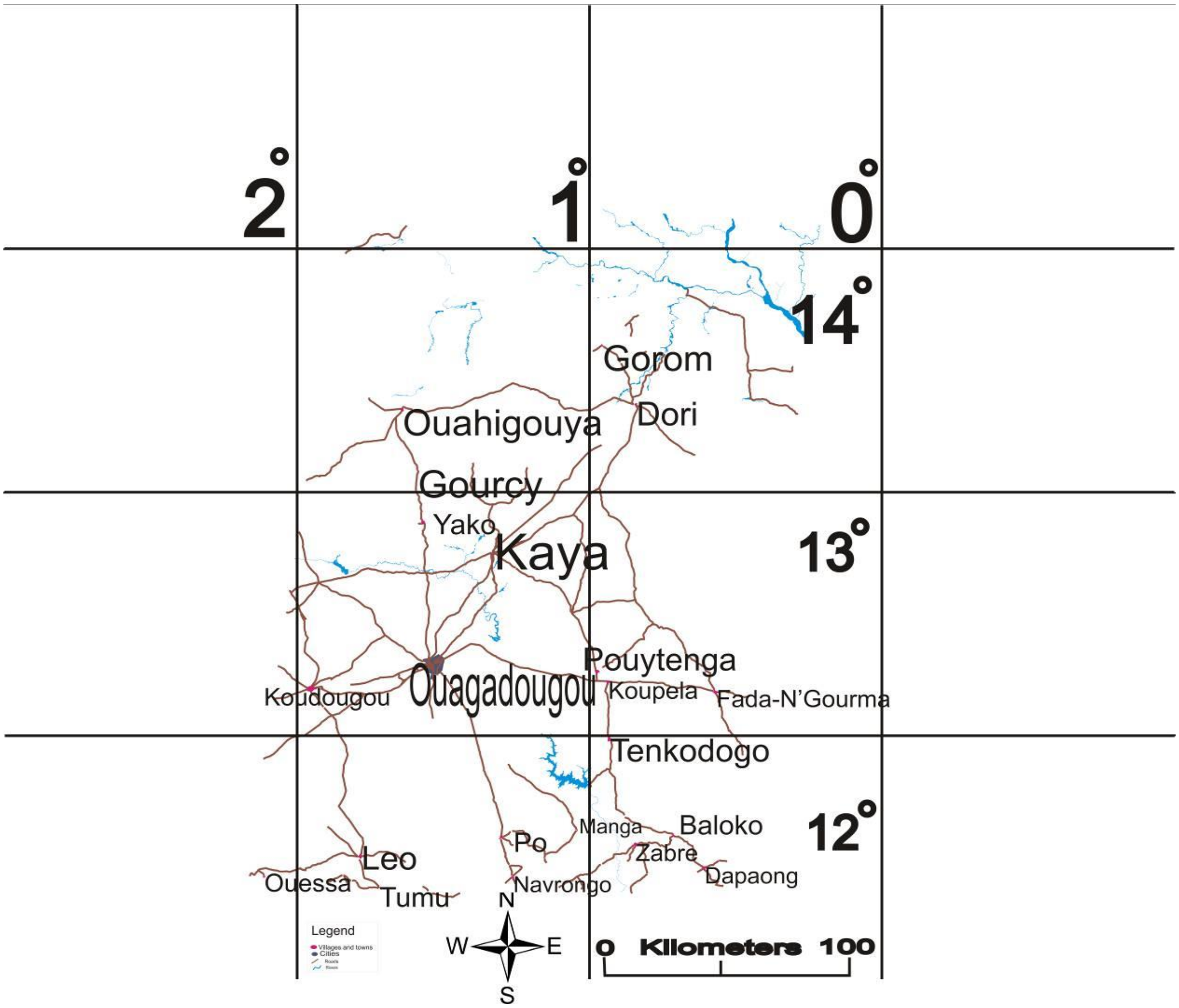


Figure 4.8: Locality map of Burkina Faso showing cities (dark blue), towns and villages (pink) and roads (brown)

4.3 Extraction of geological features using Magnetic data

The interpretation of magnetic data was done using figure 3:D which was the combination of A, B and C. from the data there were dominant NW trending lineaments (green) and areas of shear (black) were NE trending (Fig. 4.9).

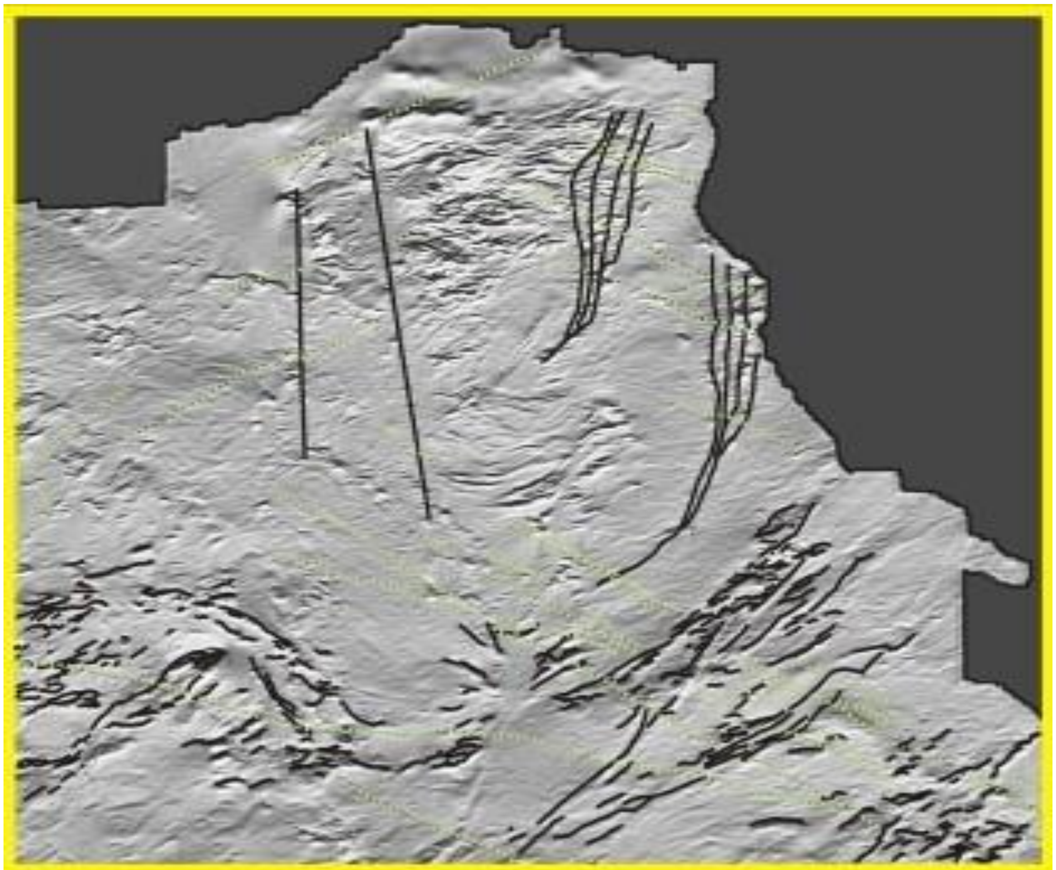


Figure 4.9: interpretation of magnetic data. Green- Lineaments and black-areas of shear.

4.4 Extraction of geological features using radiometric data

The normal (A) and inverted (B) radiometric data were used for the extraction. Since parts of the study area is cut off, only limited extraction was done. A few lineaments and areas of shear were extracted. The lineaments are NE-NW trending and the shears are NE trending (fig. 4.10).

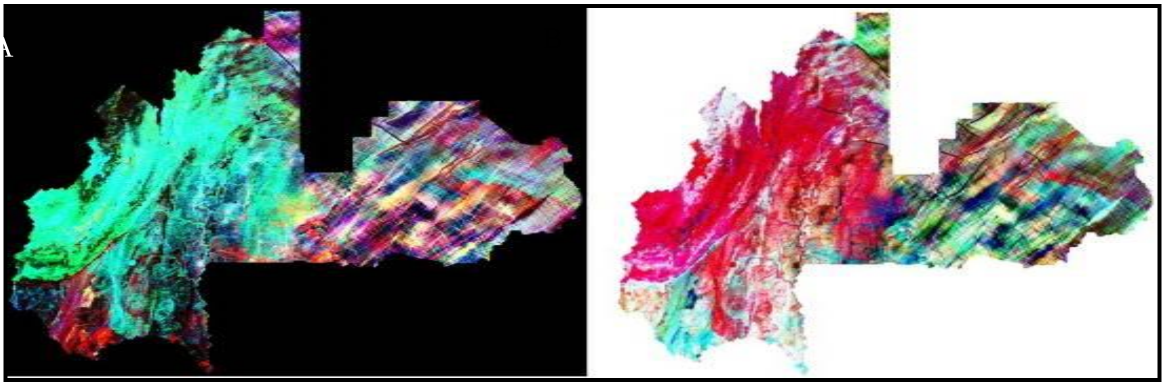


Figure 4.10: A- normal radiometric data and B- inverted radiometric data. Black- Lineaments, Red- areas of shear.

CHAPTER 5: DISCUSSION

5.1 Observations

From the Landsat 7 imagery, Magnetic and radiometric data a number of features were extracted including lineaments, Greenstone Belts, laterite, dykes, joints sets, shear zones. Lineaments in all the data sets had east to ENE, north to NNW and NEasterly trends. Most of the major lineaments as seen on the data sets had NW-NE trends. The areas of shear investigated in all data set were dominantly NNE trending with a few trending NW. The four greenstone belts studied in literature could only be extracted clearly from the Landsat 7 imagery. The greenstone belts were covered by laterite caps which followed the orientation of the greenstone belts throughout the images. Areas of greenstone belt occurrences were easily identified by looking at occurrences of the laterite caps. The Landsat with (RGB) 731 FCC used for extraction of geological features was very helpful because the band combination has an advantage of distinguishing different rock types. The greenstone belts had a brownish to orange colour; volcanic had a grey colour, granodiorites had a pinkish colour and sand dunes had a yellowish colour. The laterites have a dark brown to purple colour and were easy to distinguish from the imagery. The drainage systems on the imagery were used for lineament identification and major drainages were classified as major joints because they show area of weakness which the river penetrated and could flow through. The major joint sets had the same orientation as the lineaments. The extraction of human geography was done using 432 FCC because of the advantages that this band combination has as documented in the methodology. Roads, rivers, vegetation, drainage systems, towns, cities and villages were easy to identify and these was more useful for creating a locality map and thus for land use and land cover classification. From the magnetic and radiometric data lineaments with same orientation found in both Landsat and Aster imagery were also found, as well as areas of shear. Since the Radiometric data was cut off limited extraction was done on the data.

5.2 Geological mapping

Shear zone and dyke

From the extraction done previously the interpretation of the shear zones and NW trending dolerite dykes found are in accordance with observations made by Tshibubudze et al 2009 for the NNE trending Markoye and Takabangou shear zones(fig.5.1) which were also extracted using Landsat imagery followed by field mapping to ground truth the shear zones and the dykes. SSZ which is a major shear zone cuts the Goren greenstone belt and the BSZ cuts the OGGB and this is in accordance with what has been documented in literature.

Greenstone belts and laterite profiles

Since no GIS work has been done on the greenstone belts, there is no confirmation of association of greenstone belts with laterite profiles found throughout the study area. From the interpretation it was found that the laterite profiles have the same orientation as the greenstone belts and cover most of the study area where greenstone belts are located. Studies by Hein, (2008) show that dykes in northern Burkina Faso have laterite skirts and from the interpretation done in this study most of the dolerite dykes interpreted had the laterite skirts. The four greenstone belts Goren, Bouroum, Oudalan-Gorouol, and Yalogo greenstone belts locations were defined. A Goren Greenstone Belt is cut by a series of NE trending joint sets and the SSZ.

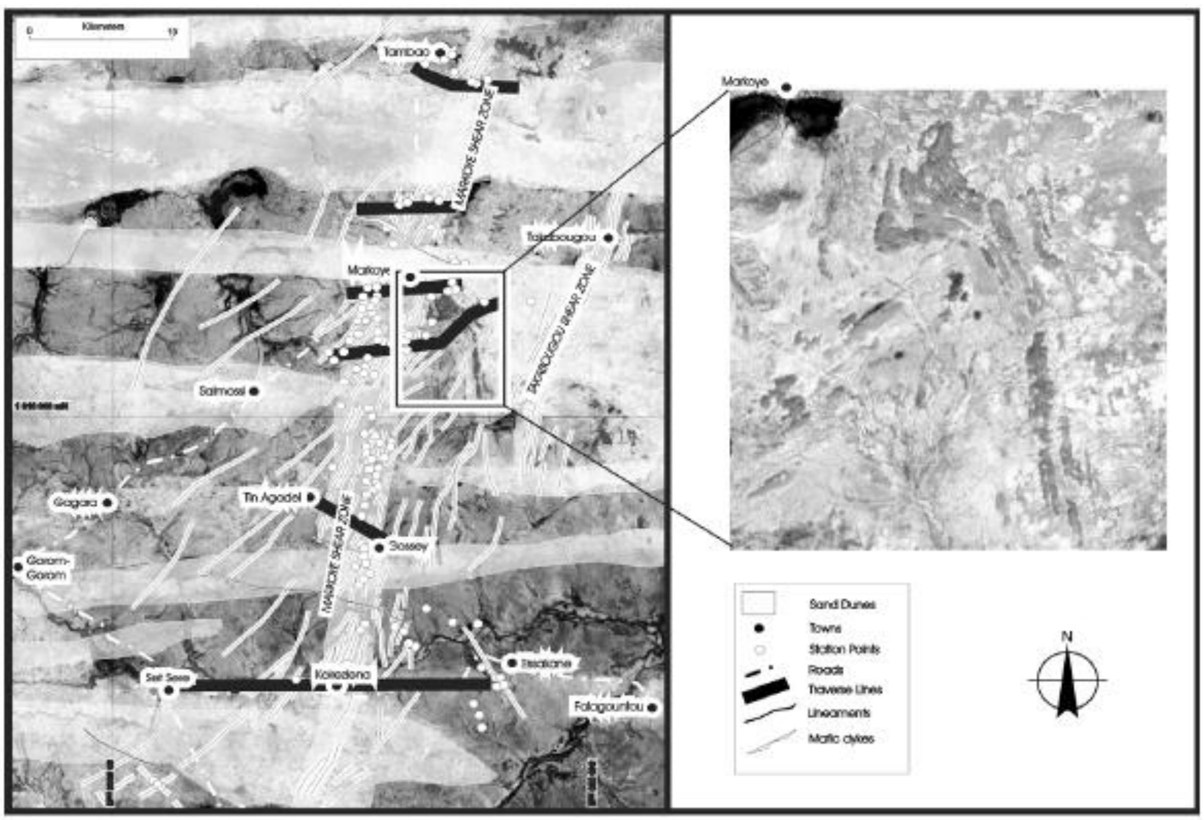


Figure 5.1: Interpretative geology map of the Markoye Shear Zone based on combined regional magnetic data (RTP and RTP 1st vertical derivative), Landsat imagery, with Landsat image p194r050_741 as underlay (Tshibubudze et al., 2009).

5.3. Is GIS and/or Remote sensing good for geological mapping and is it effective?

The results obtained from the study show that GIS is a very useful tool for geological mapping. GIS interpretation can be done before going to the field for ground truth. This use of GIS can decrease the cost of mapping. From the study it is evident that Landsat 7 band 7 is very useful for geological studies since it helps in distinguishing different rock types. The different band combinations generated in remote sensing using different bands is very helpful in differentiating features depending on the area of study. RGB 321 which is a true colour composite can be generated and since it's a representation of what in reality (ground) it can also be used for ground truth. From this study 731 and 742 FCC band combinations were very helpful for geological mapping and extraction of features; both bands have different advantages in highlighting different features. For land use and land cover analysis RGB 432 colour composite was used. Image classification which involves two classification systems (supervised and unsupervised) can be done for land use studies.

The use of GIS and remote sensing is very effective for geological studies. Different case studies that went this route were successful and this is a new effective tool that is been used and will continue to be used for mapping and for geographic studies. The results obtained using GIS are similar to what has been done previously (previous maps) and highlight other featured that are not documented on previous maps these was evident from this study.

Recommendations

From the study it is evident that the use of GIS is effective in that it agrees with what has been done before in previous studies and can also help in discovering things that might be missed on the field. This method of mapping though it is time consuming it reduces cost of mapping and buying aerial photographs which have become costly over the years. Using GIS and remote sensing improves mapping techniques.

5.4 Comparison

The map done by Hottin & Ouedraogo (1992) is missing a lot of structures such as lineaments, dykes, shear zones compared to the map created. The map by Hottin & Ouedraogo (1992) doesn't show sand dunes that cover most of the NE Burkina Faso. The new map (Fig. 5.2) has more details but more ground truth in the form of mapping needs to be done to confirm some of the features that are not covered in literature or haven't been mapped.

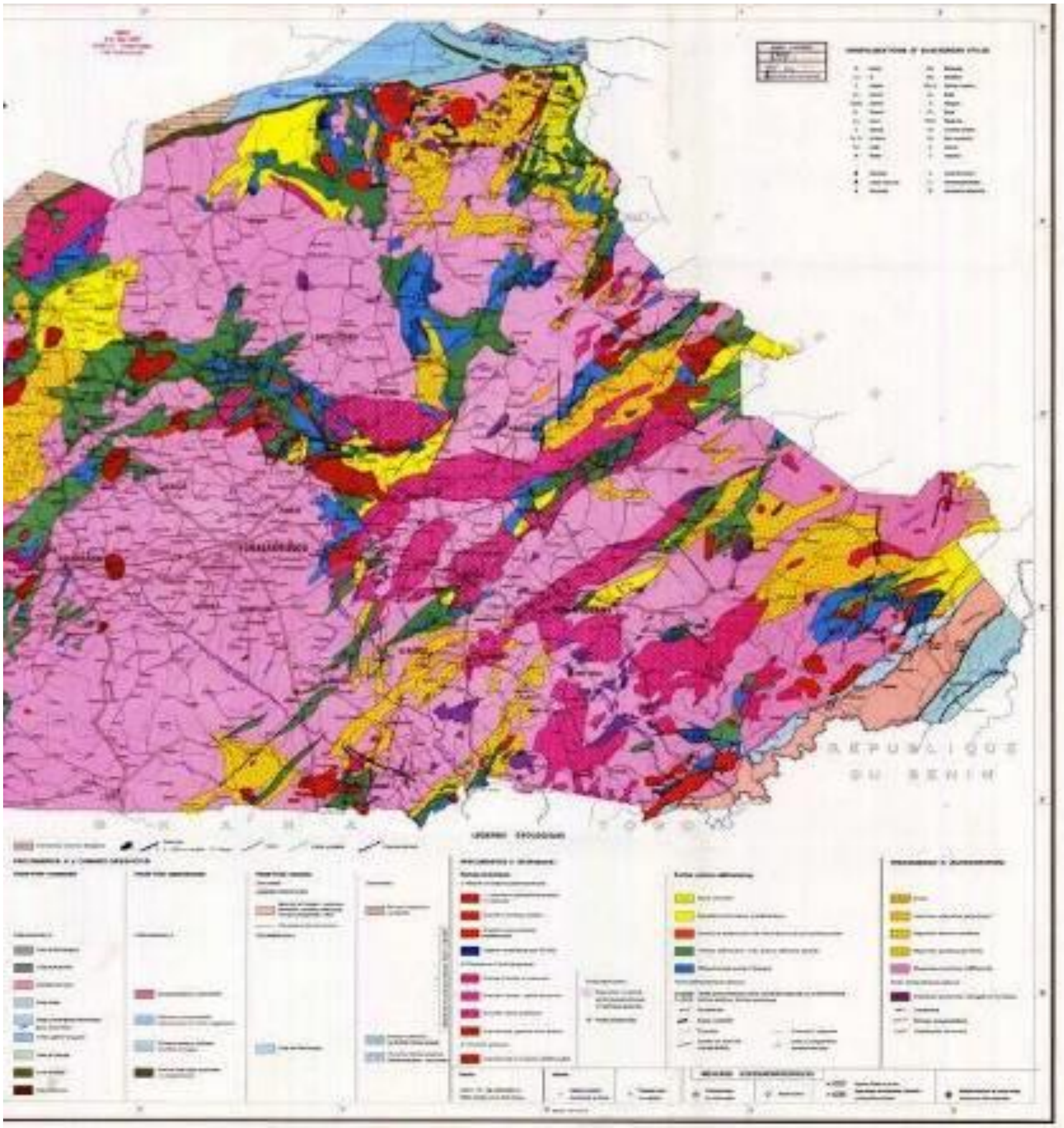


Figure 1.2: Geological map of Burkina Faso showing study area (Hottin & Ouedraogo, 1992)

Figure 5.2: Strato-tectonic-magmatic map of Burkina Faso with distribution of structures and lithology.

CHAPTER 7: CONCLUSION

This research is the first attempt that has utilized LANDSAT data, magnetic and radiometric data for geological mapping and production of a 1:100 000 geological map for the study area. Advantages of LANDSAT images for geological mapping lie in their high spectral band characteristics. Four different false colour composite images were generated and evaluated for extraction purposes. The first FCC 731 in RGB image was generated and evaluated for extraction of geological features. The second FCC 432 in RGB image was generated for human geography. The third FCC 742 in RGB image was also used for extraction of geological features, since the FCC 742 imagery has the same advantage as 731 FCC it was used to extract features that were not easy to extract like sand dunes on the 731 FCC image. The last FCC image was used for the location of outcrops. The prepared 731 FCC imagery (Fig. 3.1) obtained from the Landsat 7 data, was used in constructing the detailed strato-tectonic-magmatic map of NE Burkina Faso (Fig. 5.2) which illustrates the following:

1- The greenstone belts with a brownish to orange colour covered by purple laterite caps, plutonic rocks which had a pinkish colour surrounding the greenstone belts which were clearly discriminated.
2- The shear zones which had NNE- NW trends and dykes with laterite skirts trending NW.
3- The lineaments with East to ENE), North to NNW and NEasterly trends and major joints created by the drainage system in the area.

The prepared 432 FCC was helpful in extraction of human geography and a locality map for the study area was created (Fig. 4.8). The 742 FCC was used for extraction of sand dunes and 753 FCC was used for locating outcrops. The map created shows the validity and usefulness of applying GIS and remote sensing techniques for geological mapping. Comparing the constructed strato-tectonic-magmatic map of NE Burkina Faso (Fig. 5.2) with the previously published maps (Fig 1.2), the study shows the following:

1- The strato-tectonic-magmatic map in the present work shows more detailed information about structural features and lithologies than the previous mapping.
2- The FCC images gave additional information helping in improving the previous geological maps of the study area.
3- This new strato-tectonic-magmatic map in this study (Fig. 5.2) needs more field investigations and verifications to construct the detailed geological map of NE Burkina Faso. This study showed the important use of colour composite images constructed from the LANDSAT 7 bands combined with the magnetic and radiometric data and for geological mapping improves mapping.

REFERENCES

Abouchami, W., Boher, M., 1990. A major 2.1 Ga event of mafic magmatism in West Africa: and early stage of crustal accretion. Journal of Geophysical Research 95 (B11), 17605-17629.

Attoh, K., 1982. Structure, gravity models and stratigraphy of an early Proterozoic volcanic-sedimentary belt in northeastern Ghana. Precambrian Research 18, 275–290.

Béziat, D., Bourges, F., Debat, P., Lompo, M., Martin, F., Tollon, F., 2000. A Paleoproterozoic ultramafic-mafic assemblage and associated volcanic rocks of the Boromo greenstone belt: fractionates originating from island-arc volcanic activity in the West African craton. Precambrian Research 101, 25 47.

Béziat, D., Dubois, M., Debat, P., Nikiéma, S., Salvi, S., Tollon, F., 2008. Gold metallogeny in the Birimian craton of Burkina Faso (West Africa). Journal of African Earth Sciences 50, 215–233.

Boher, M., Abouchami, W., Michard, A., Albarede, F., Arndt, N.T., 1992. Crustal growth in West Africa at 2.1 Ga. Journal of Geophysical Research 97 (B1), 345-369.

Bourges, F., Debat, P., Tollon, F., Munoz, M., Ingles, J., 1998. The geology of the Taparko gold deposit, Birimian greenstone belt, Burkina Faso, West Africa. Mineralium Deposita 33, 591–605.

Brown, E.T., Bourlès, D.L., Colin, F., Safno, Z., Raisbeck, G.M., Yiou, F., 1994. The development of iron crust lateritic systems in Burkina Faso, West Africa examined with in-situ-produced cosmogenic nuclides. Earth and Planetary Science Letters 124, 19-33.

Castaing, C., Billa, M., Milési, J.P., Thiéblemont, D., Le Mentour, J., Egal, E., Donzeau, mM. (BRGM) (Coordonnateurs) et Guerrot, C., Cocherie, A., Chevremont, P., Tegyey, M., Itard, Y. (BRGM), Zida, B., Ouedraogo, I., Kote, S., Kabore, B.E., Ouedraogo, C. (BUMIGEB), Ki, J.C., Zunino (ANTEA), 2003. Notice explicative de la Carte géologique et miniére du Burkina Faso à 1/1 000 000.

Dequincey, O., Chabaux, F., Leprun, J.C., Panquet, H., Clauer, N., Larque, P., 2006. Lanthanide and trace elements mobilization in a lateritic toposequence: inferences from the Kaya laterite in Burkina Faso. European Journal of Soil Science 57, 816-830.

Ducellier,J. 1963. Contribution á l'étude des formations cristallineset métamorphiques du Centre et du Nord de la Haute-Volta.Mém BRG 10, Ed Technip, 320 p

Drury, S.A 2001, Image interpretation in geology, Blackwell science Inc. London. p199.

Feybesse, J.L., Milési, J.P., Ouedraogo, M.F., Prost, A., 1990. La ‘‘ceinture” protérozoïque inférieur de Boromo–Goren (Burkina Faso): un exemple d’interférence entre deux phases transcurrentes éburnéennes. Comptes Rendus de L’Académie des Sciences 310 (II), 1353–1360.

Hein, K.A.A. 1997. The geology and structure of the Sanmatenga Joint Venture Concession, Burkina Faso, West Africa. Report No QB98/04S, North Ltd, 110p.

Hein, K.A.A., Morel, V., Kagoné, O., Kiemde, F., Mayes, K., 2004. Birimian lithological succession and structural evolution in the Goren segment of the Boromo–Goren greenstone belt, Burkina Faso. Journal of African Earth Sciences 39, 1–23.

Hein K. A.A.,2008.. Report on the Karma project (KPA), Yatenga District, Burkina Faso. Summary Report to Riverstone Resources Inc, November 2008.

Hein, K.A.A., 2009. Structural chronologies in the Goren Greenstone Belt (Burkina Faso); implications for West African tectonics. Journal of African Earth Sciences.

Hirdes, W., Davis, D.W., Lüdtke, G., Konan, G., 1996. Two generations of Birimian (Paleoproterozoic) volcanic belts in north-eastern Côte d'Ivoire (West Africa): consequences for the 'Birimian controversy'. Precambrian Research 80, 173– 191.

Hottin G, Ouedraogo, O.F.,1976. Carte géologique du Burkina Faso au 1/1 000 000 éme, 2 éme édn, 1992, Bureau des mines et de la géologie du Burkina Faso.

Hottin, G., Ouedraogo, O.F., 1992. Carte Géologique du Burkina Faso (2nd edition). Bureau de Recherches Géologique et Miniéres, Burkina Faso.

Junner, N.R., 1935. Gold in the gold coast, Ghana Geological Survey Memoir, No. 4, 67pp.

Junner, N.R., 1940. Geology of the gold coast and Western Togoland (with revised geological map). Gold Coast Geological Survey Bulletin, No. 11, 40pp.

Konecny, G., 2002. Geoinformation: Remote Sensing, Photogrammetry and Geographical Information systems. Taylor and Francis, Inc, London.

Leube, A., Hirdes, W., Mauer, R., Kesse, G.O., 1990. The early Proterozoic Birimian Supergroup of Ghana and some aspects of its associated gold mineralisation. Precambrian Research 46,139-165.

Leube, A., Hirdes, W., Mauer, R., Kesse, G.O., 1990. The early Proterozoic Birimian Supergroup of Ghana and some aspects of its associated gold mineralization. Precambrian Research 46, 139–165.

Lillesand, T.M and Keifer, R.W., 1994. Remote sensing and image interpretation. John Wiley and Sons, Inc, New York.

Mambo, J and Archer, E., 2007. Assessment of land degradation in the save catchment of Zimbabwe. Royal geological society (with the institute of British Geographers). 39, 380-391.

Middleton, R. and Hein, K.A.A., 1997. Report on An assessment of gold prospectivity in the Pissila region Burkina Faso, West Africa. November 1997.

Milési, J.P., Feybesse, J.L., Ledru, P., Dommanget, A., Ouedraogo, M.F., Marcoux, E., Prost, A., Vinchon, Ch., Sylvain, J.P., Johan, V., Tegyey, M., Calvez, J.Y., Lagny, P., 1989. West African gold deposits, in their lower Proterozoic lithostructural setting. Chronique de la Recherché Minière 497, 3–98.

Milési, J.P., Ledru, P., Ankrah, P., Johan, V., Marcoux, E., Vinchon, Ch., 1991. The metallogenic relationship between Birimian and Tarkwaian gold deposits in Ghana. Mineralium Deposita 26, 228–238.

Milési, J.P., Ledru, P., Feybesse, J.L., Dommanget, A., Marcoux, E., 1992. Early Proterozoic ore deposits and tectonics of the Birimian orogenic belt, West Africa. Precambrian Research 58, 305–344.

Naba, S., Lompo, M., Debat, P., Bouchez, J.L., Béziat, D., 2004. Structure and emplacement model for late-orogenic Palaeoproterozoic granitoids: the Tenkodogo-Yamba elongate pluton (Eastern Burkina Faso). Journal of African Earth Sciences 38, 41–57.

Oberthür, T., Vetter, U., Davis, D.W., Amanor, J.A., 1998. Age constraints on gold mineralization and Paleoproterozoic crustal evolution in the Ashanti belt of southern Ghana. Precambrian Research 89, 129-143.

Ottichilo, W and Ekhamala E., 2002. Map updating using High Resolution satellite images: A case of the Kingdom of Swaziland. International Archives of the Photogrammetry Remote Sensing and spatial Information sciences, vol xxxiv.part6/w6.p141-158.

Pandey, S.N., 1987. Principles and applications of photo geology. John Wiley and sons, Inc, New York.

Pawlig, S., Gueye, M., Klischies, R., Schwarz, S., Wemmer, K., Siegesmund, S., 2006. Geochemical and Sr-Nd isotopic data on the Birimian of the Kedougou–Kenieba Inlier (Eastern Senegal): implications on the Palaeoproterozoic evolution of the West African Craton. South African Journal of Geology 109, 411–427.

Péna, S. and Abdelsalam, M., 2006., "Orbital Remote Sensing for Geological Mapping in Southern Tunisia: Implication for Oil and Gas Exploration", Journal of African Earth Sciences, 44, pp. 203–219.

Pons, J., Barley, P., Dupuis, D., Léger, J.M., 1995. Mechanisms of pluton emplacement and structural evolution of a 2.1 G.a juvenile continental crust: the Birimian of south western Niger. Precambrian Research 70, 281–301.

Prost, G.L., 2001. Remote sensing for geologists: a guide to image interpretation. Taylor and Francis, Inc, London.

Qari, M.H.T., Madani, A.A., Matsah, M.I.M., and Hamimi, Z., 2008. Utilization of Aster and Landsat data in geologic mapping of basement rocks of Arafat area, Saudi Arabia. The Arabian Journal for Science and Engineering, 33, 99-116.

Sawadogo J (1983). Etude géologique du sillon birimien de Yalogo dans la région de Gangaol (Nord de la Haute Volta). Thése de la Faculté des Sciences et Techniques de l'Université de Franche-Comté 165 p.

Schluter, T., 2006. Early Proterozoic Cratonic Basins and mobile belts. Springer Berlin/ Heidelberg. Geological Atlas of Africa, Vol 40, 50-51.

Serwan, M. J. B and Kamaruzaman, W. Y., 2001. Mapping land use/ cover distributions on a mountainous tropical island using remote sensing and GIS. Yusof International Journal of Remote Sensing, 1366-5901. Vol 22, 1909-1918.

Tshibubudze, A., Hein, K.A.A., Marquis, P., 2009. The Markoye Shear Zone in NE Burkina Faso. Journal of African Earth Sciences 55, 245–256.

Tunks, A.J., Selley, D., Rogers, J.R., Brabham, G., 2004. Vein mineralization at the Damang gold mine, Ghana: controls on mineralization. Journal of Structural Geology 26, 1257–1273.

Williams, D., 2009. Landsat 7 Science Data user’s handbook. NASA website, http://landsathandbook.gsfc.nasa.org. Last update on August 4, 2009.

Zonou S (1987) Les formations leptyno-amphibolitiques et le complexe volcanique et volcano sédimentaire du ProtérozoõÈque in-feÂrieur de Bouroum-nord (Burkina Faso, Afrique de l'Ouest).Etude pétrographique, geÂochimique, approche pétrogénétique etévolution géodynamique. Thése de l'Universitéde Nancy I 294 p.

Zonou S, Karche JP, Lapierre H, Lemoine S, Rossi M (1985) Volcanisme tholéiitique et calcoalcalin dans les formations du Birimien Supérieur de Bouroum (NE du Burkina Faso). C R Acad Sci Paris 301: 309-314.