

UNIVERSITY OF THE
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**THE GEODYNAMIC EVOLUTION OF THE FERKÉ SHEAR ZONE (FSZ):
RELATIVE TIMING OF THE ASSOCIATED TECTONIC AND
MAGMATIC EVENTS, NORTH-CENTRAL IVORY COAST, WEST
AFRICA.**

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Dissertation submitted in fulfilment of the requirements for the degree of Master of Science in
Geology to the Faculty of Science, at the University of the Witwatersrand.

DECLARATION

I declare that “The geodynamic evolution of the Ferké Shear Zone (FSZ): relative timing of the associated tectonic and magmatic events, north-central Ivory Coast, West Africa” is my own, unaided work. It is being submitted for the Degree of Master of Science at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University and that all the sources used or quoted have been indicated and acknowledged as complete references.

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.....Day of.....2019 in Johannesburg

ABSTRACT

The Palaeoproterozoic Baoulé-Mossi domain of the West African Craton in north-central Ivory Coast is crosscut by a north-northeast trending Ferké Batholith, confined by first-order crustal-scale Ferké Shear Zone (FSZ). To present a geodynamic evolution of the FSZ, incorporation of strato-tectonic, geophysical, geochemical, geochronological revisions is pivotal. In the study region, crosscutting relationship resolved that the oldest unit is formed by gneiss that is uncomfortably overlain by volcano-sedimentary sequences which are intruded by post-basin granitoids, i.e. Ferké Batholith. Volcano-sedimentary sequences consist of conglomerate-sandstone-siltstone-mudstone succession and meta-volcaniclastic greywacke unit. Intrusive units making up Ferké Batholith include granodioritic gneiss, granodiorite, granite, tonalite, diorite and pegmatite. U-Pb zircon analysis of samples from the orthogneiss gave a crystallization age of the orthogneiss at 2282 ± 4 Ma, and these were affected by D_{ext} extensional phase around 2132 ± 12 Ma that resulted in basin formation. Fining-upwards volcano-sedimentary sequences were deposited in the extensional-subsiding setting between 2109–2079 Ma. At 2097 Ma, Ferké Batholith emplacement was coeval with the formation of the FSZ. Four main deformational events were recognised crosscutting these rock units.

D_1 is a progressive deformation event that is dominated by ductile-brittle structures that formed at ~ 2097 Ma, and is responsible for development of north-northeast trending sinistral shear zones, steeply dipping foliation (S_1 and S_{1-C}), sub-horizontal L_1 lineation and tight F_1 folds. Ferké Batholith emplacement is constrained between 2097 and 1842 Ma U-Pb ages supported by crosscutting relationships. U-Pb age of 2097 Ma constrains D_1 and minimum age for deposition of metasedimentary units. Late D_1 structures are defined by northwest trending sub-vertical displaced fractures. Northwest trending dilational jogs and sigmoidal en-echelon fractures were formed during late D_1 . D_1 event is related to north-northwest and south-southeast directed principal compressive strain axis. The D_2 structures comprise northwest trending F_2 folds and foliation (S_2) from refolding of D_1 structures S_1 and F_1 . Dextral sense of displacement from north-northeast trending shear zones and L_2 lineation along the Ferké-Bandama branch developed during D_2 . West, northwest and west-northwest trending veins (V_2) are associated with D_2 deformation. Kinematic analysis indicated that the principal compressive strain axis was north-northeast or northeast directed during D_2 deformation.

Brittle fractures, including the northwest to west trending fractures and faults formed the third generation of structure (D_3). The traces of D_3 structures crosscut those of D_1 and D_2 features throughout the study area. Northwest sinistral en echelon structures and northeast trending displaced fractures correlate with D_3 characteristics i.e. overall north-northeast to northeast maximum shortening direction.

Geochemical data show that various granitoids making up the Ferké Batholith are true granites. These intrusive units geochemical character shows calc-alkaline affinities with a very high-K character, mostly I-type and peraluminous composition. Tectonic discrimination diagrams confine the batholith within syn-collision fields.

Gold mineralisation associated with FSZ occurs in the metasedimentary units to the southwest (Tortiya region) and northeast (north of Kouloukorosso) of the Ferké Batholith. These regions are structurally controlled and spatially associated with FSZ and hydrothermal veins that formed in response to the regional extensional stress field. The shape of the batholith and/or shear zone sense of displacement permits releasing bends (normal faults) to develop in the regions of Tortiya and Kouloukorosso.

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1 INTRODUCTION

1.1 Preamble

The majority of Ivory Coast is underlain by Archaean and Palaeoproterozoic rocks belonging to the West African Craton (WAC), with the exception of a narrow south-eastern coastal strip of Late Cretaceous to Neogene sediments ([Wozazek and Krawinkel, 2002](#); [Camus et al., 2008](#); [Murray et al., 2019](#)). The WAC is composed of Archaean-Palaeoproterozoic basement shields, the Reguibat shield in the north and the Leo-Man shield in the south ([Jessell and Liégeois, 2015](#)). The Reguibat shield is made up of two major Archaean and Palaeoproterozoic domains. The Palaeoproterozoic domains consist of juvenile formations structured by the Eburnean megacycle ([Bonhomme, 1962](#); [Tagini, 1971](#); [Yacé, 1984](#), [Tempier, 1986](#), [Lemoine, 1988](#); [Abouchami et al., 1990](#); [Boher et al., 1992](#); [Feybesse and Milési, 1994](#)). The Leo-Man shield is divided into the Archaean (3.6-3.5 Ga) Kénéma-Man domain ([Rollinson, 2016](#)) and the Palaeoproterozoic (2.3-1.8 Ga) Baoulé-Mossi domain ([Feybesse et al., 2006](#); [Jessell et al., 2016](#)). Numerous first-order crustal-scale structures are recognised across the Palaeoproterozoic Baoulé-Mossi domain, mainly, Sassandra Fault (SF), Gagnoa Shear Zone (GSZ), Senegal-Mali Shear Zone (SMSZ), Brobo-N’Zi Shear Zone (BNSZ), Wango-Fitini Shear Zone (WFSZ), Boromo-Poura Shear Zone (BPSZ), Markoye Shear Zone (MSZ), Bole-Nangodi Shear Zone (B-NSZ), Fada-Gourma Shear Zone (FGSZ) and Tano River Tectonic Zone (TRTZ) ([Vidal et al., 2009](#), [Ouattara et al., 2013a](#); [Tshibubudze and Hein, 2013](#); [Baratoux et al., 2015](#); [Masurel et al., 2015](#); [Chudasama et al., 2016](#); [Block et al., 2016](#); [Sehloho, 2017, unpub.](#); [Murray et al., 2019](#)). One of the transecting structures includes the Greenville-Ferkéssédougou-Bobo-Dioulasso Shear Zone (GFBSZ) ([Lemoine, 1988, 1990](#)) here designated as Ferké Shear Zone (FSZ). FSZ is a north-northeast trending shear zone that transects from Liberia, central part of Ivory Coast to Burkina Faso ([Figure 1.1](#)) ([Baratoux et al., 2011](#)). In the north-central Ivory Coast, the FSZ confines the Ferké Batholith from the adjacent volcano-sedimentary sequences. The case of shear zones interrelated with granitoid emplacement dominates across the Baoulé-Mossi domain ([Ouattara, 1998](#); [Feybesse et al., 2006](#); [Vidal et al., 2009](#); [WAXI, 2013](#); [Amponsah et al., 2016](#)). Therefore, this interrelationship will be taken into consideration for the geodynamic interpretation of the north-central Ivory Coast.

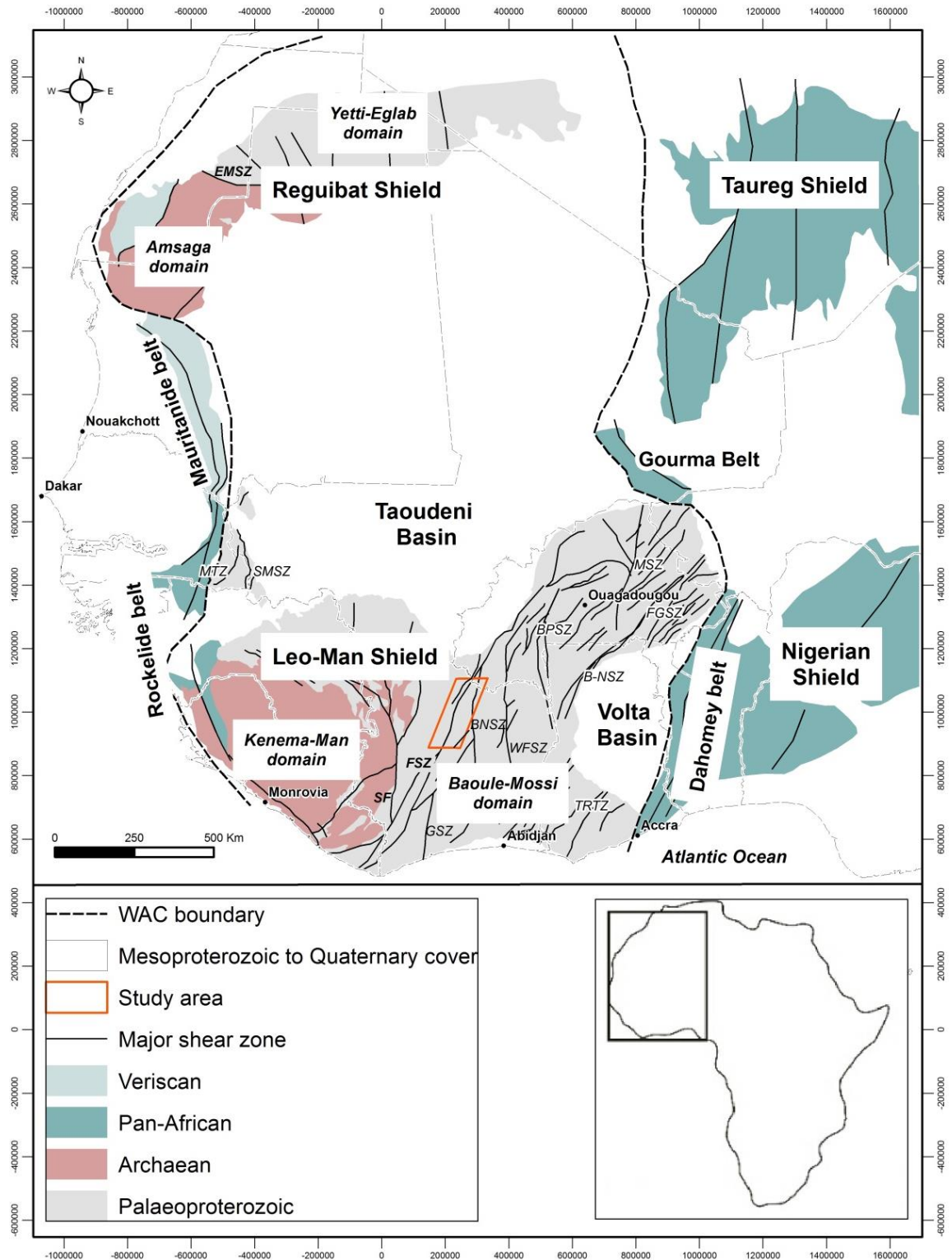


Figure 1.1: The geological schematic map of the West African Craton and of the surrounding geological terranes (modified after Feybesse et al., 2006; Block, 2015). The map shows Archaean-Palaeoproterozoic domains surrounded by progressively younger orogenic belts. The boundaries between these are commonly delineated by major thrust or shear zones. The study area is represented by the red box. The insert outlines African map with a black box representing West African region.

According to [Ouattara \(1998\)](#), [Doumbia et al. \(1998\)](#), [Pouclet et al. \(2006\)](#) and [Vidal et al. \(2009\)](#) the Birimian volcano-sedimentary sequences in Ivory Coast were intruded and metamorphosed by the syn-kinematic leucogranites of the Ferké Batholith, which extend more than 500 km along the FSZ ([Figure 1.2](#)).

In the north-central Ivory Coast, the Ferké Batholith margins are defined by two shear zone i.e. FSZ branches. The western branch is herein designated as the Ferké-Bandama branch and the eastern is Yédandiekaha-Niakaramandougou branch. The study by [Baratoux et al. \(2011\)](#) in Burkina Faso referred to FSZ as a dextral shear zone whereas studies by [Doumbia et al. \(1998\)](#), [Ouattara \(1998\)](#), [Pouclet et al., \(2006\)](#) and [Vidal et al. \(2009\)](#) in central Ivory Coast recognised sinistral regime.

The majority of the previous studies related to FSZ are based on petro-geochemical studies of the wall rocks including studies by [Yobou \(1993\)](#), [Hirdes et al. \(1996\)](#), [Doumbia et al. \(1998\)](#), [Hirdes and Davis \(2002\)](#) and [Coulibaly et al. \(2008\)](#). Few studies have considered the structure and tectonics ([Lemoine, 1988, 1990](#); [Vidal et al., 2009](#); [Baratoux et al., 2011](#)) and in places have been limited to geophysical data interpretations ([Ouattara et al., 1995](#), [Murray et al., 2019](#)). The geophysical data interpretations were introduced due to combined thick vegetation, lateritic cover and scarcity of outcrops.

Regardless of these studies, a geodynamic study of the evolution of the FSZ has never been completed. This study will use geometric, kinematic and dynamic analyses to constrain the dynamic history. The Palaeoproterozoic terranes of West Africa are well known to host numerous occurrences of economic gold mineralisation ([Coulibaly et al., 2008](#); [Kadio et al., 2010](#); [Robertson and Peters, 2016](#); [Amponsah et al., 2016](#); [Fougerouse et al., 2017](#); [Murray et al., 2019](#)) that are temporally and spatially related to structures formed during the polycyclic Eburnean Orogeny ca. 2.13 - 1.98 Ga ([Milési et al., 1991; 1992](#); [Boher et al., 1992](#); [Allibone et al., 2002](#); [Feybesse et al., 2006](#); [Perrouy et al., 2012](#); [Ouattara et al., 2013b](#), [Traoré et al., 2016](#); [Feng et al., 2018](#)).

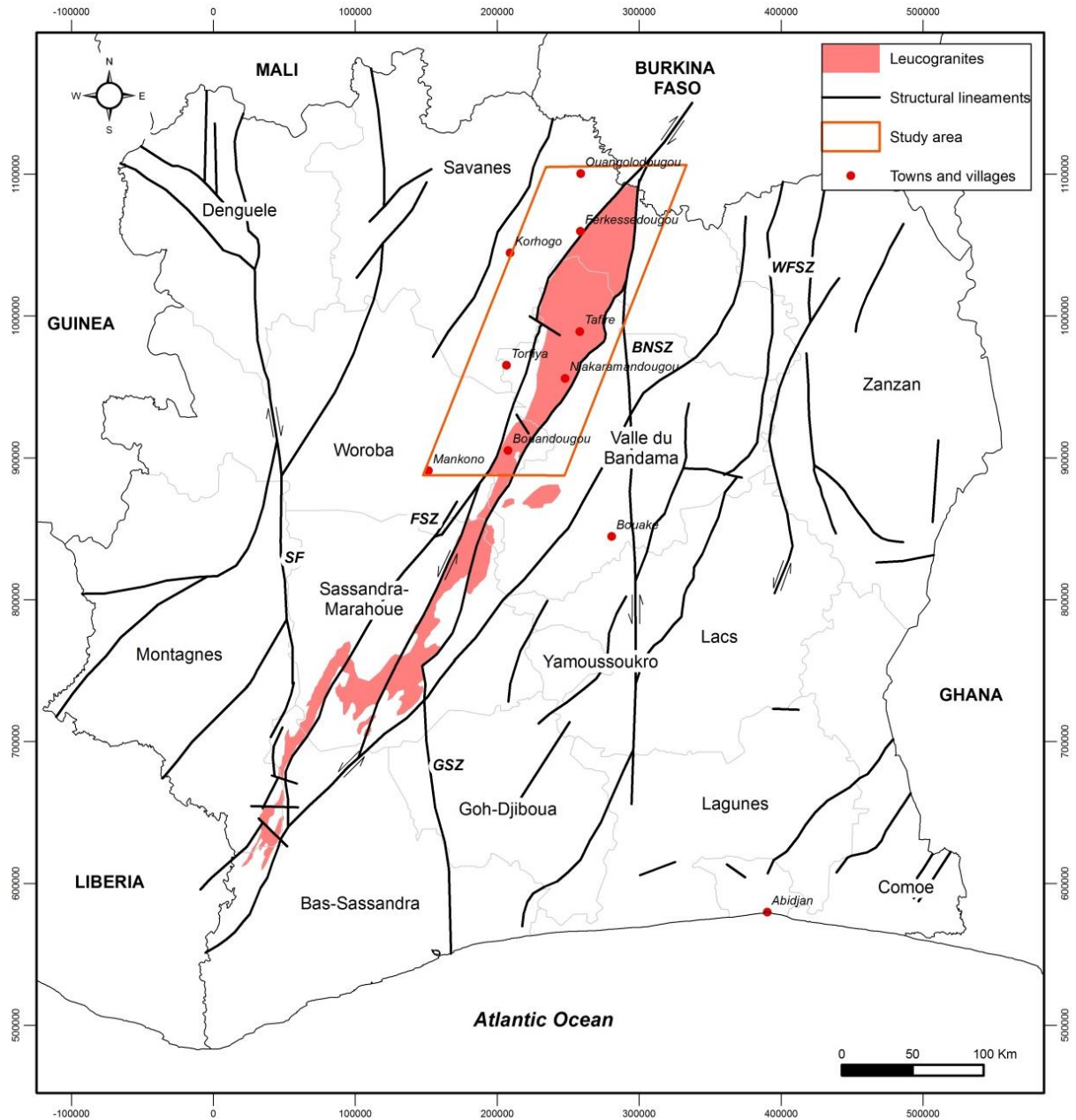


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Gold production in Ivory Coast is mainly produced from Bonikro, Agbaou, Hiré, Ity, Tongon, and Yaouré Mines. Gold is also produced from informal artisanal mining which have taken place for centuries in West Africa ([Robertson and Peters, 2016](#)). Mineral resources located along and/or proximal to FSZ include:

- Yaouré (Angovia) gold project in central Ivory Coast (Yédandiekaha-Niakaramandougou branch) ([Coulibaly et al., 2008](#)).
- Tortiya-Katiola-Séguéla diamond fields in central Ivory Coast (Ferké-Bandama branch) ([Teeuw, 2002](#); [Chirico and Malpeli, 2013](#)).
- The informal artisanal mining is predominantly along the FSZ.

Understanding the geodynamic history and the distribution of gold along the FSZ in the north-central Ivory Coast will contribute to mineral exploration in WAC. Therefore, the metallogenic potential of the north-central Ivory Coast will also be assessed in this study.

Other natural resources across the country include petroleum, natural gas, diamonds, manganese, iron ore, cobalt, copper, nickel, tantalum, silica sand, clay, bauxite, uranium, lithium and colombo-tantalite and hydropower ([Aregheore, 2009](#); [Chirico and Malpeli, 2013](#)).

1.2 Location and physiography

The detailed study of this poorly documented zone was conducted between latitudes 8° - 9° north and longitudes 4° - 6° west. This area is located in the north-central portion of the Ivory Coast. Ivory Coast is situated in West Africa where it is bordered by Guinea and Liberia in the west, Burkina Faso and Mali in the north, and Ghana in the east ([Figure 1.2](#)). It is a coastal country that covers an area of 322,463 km² ([Bassey, 2014](#)). The study area is located in three adjoining districts or provinces, namely Savanes, Vallée du Bandama and Woroba ([Figure 1.2](#)). The FSZ transects in the midst of the towns of Ferkéssédougou, Kogbala and Yédandiekaha in the Savanes district and Niakaramandougou in the Valle du Bandama district.

The landscape of Ivory Coast is characterised by mostly flat to undulating plains with mountains in the northwest. The plateaus are tilted at a gently southward slope to the Gulf of Guinea (lowest point) at no more than 460 m above sea level ([Howstuffs.com, 2008](#)). Significant

highlands commonly occur along the western borders, where Mount Nimba (highest point) reaches 1 752 m above sea level ([Howstuffs.com, 2008](#)).

The climate in Ivory Coast is close to equatorial, with an annual rainfall ranging from 1500 to 1800 mm, characterised by two rainy seasons and two dry seasons ([Durand and Skubich, 1982](#); [Aregheore, 2009](#); [Koné et al., 2010](#)). Dry seasons include, the high dry season extends from January to March and the low dry in September to October. Rainy seasons include, the high rainy season from early April to late July and the low rainy season from October to December ([Koné et al., 2010](#)). Temperatures are high in the south but may exceed 35 °C in the far north. According to [Lacaux \(1995\)](#) the northern Ivory Coast is part of the West Sudanian Savanna ecoregion of the Tropical and subtropical grassland, savanna and shrub land biomes. It is a zone of lateritic or sandy soils, with vegetation decreasing from south to north ([Menaut, 1996](#); [Aregheore, 2009](#)).

The population consists of more than 60 ethnic groups which are divided into 7 principal cluster groups, the Akan, Krou or Kru, Lagoon, Nuclear-Mande, Peripheral-Mande, Senoufo and the Lobi ([Grimard, 1997](#)). Other ethnic settlers include groups from neighbouring countries such as Burkina Faso, Mali, Ghana and Guinea. Additionally, Lebanese and French settlers exist in relatively smaller numbers. The official language is French, although there are approximately 60 local African languages spoken throughout the country with the four principal ones being Agni, Baoule, Senoufo and Malinke-Bambara-Dioula (Jula) ([Gordon, 2005](#); [Collett, 2006](#)). Religiously, majority of the population practise local native tribal beliefs while 20% are Muslims and 20% are Christians, of which the Roman Catholics represent 15% and the remainder are Protestants ([Nordås, 2014](#)).

The majority of the land in Ivory Coast is cultivated ([Rosenberg, 1997](#)) and the country is a major producer of cocoa beans, coffee, coconuts and rubber ([Traoré, 1990](#); [Papalexandratou et al., 2011](#)). To the north, crops such as cotton, rice and yams are cultivated. [Ounissi \(2008\)](#) listed cassava, plantain, sugarcane and corn as other staple foods grown locally.

1.3 Project aims

The outcomes of the project will be achieved by investigation of the stratigraphy, structure, metamorphism and metallogenesis of the study area. The aims and key objectives of this project are as follows:

- To establish the regional geology proximal to the FSZ; this includes the sedimentary and volcano-sedimentary sequences as well as producing updated geological map and cross-sections.
- To establish the relative timing of structural events and metamorphic grade along the FSZ. This will be achieved by mapping deformational structures and sampling the granitoids, sedimentary and volcano-sedimentary sequences for petrographic studies.
- To investigate the relationship between the FSZ and the Ferké leucogranite batholith.
- To complete absolute geochronology analysis on key units that will help to constrain the relative timing established.
- To investigate the spatial and temporal relationship of gold mineralisation associated with the FSZ, and fingerprint the timing of gold metallogenesis.

1.4 Conventions and acronyms used in this dissertation

Convention used for measuring structural readings:–

Planar readings: strike/dip/dip direction, for example, 021°/82° W. The northern hemisphere of the compass was used to record the strike values (270°-090°).

Linear readings: Plunge and trend/azimuth (plunge direction), for example, 13°→253°. The value 253° represents the (trend/azimuth) plunge direction, herein, southwest.

The conventions and acronyms used in this thesis include:

- % - Percentage
- ® - Registered sign
- µm – Micro meters
- 2SE – Two standard errors

- °C - Degree Celsius
- A – Ampere
- B1 - Birimian 1
- B2 - Birimian 2
- B-NSZ - Bole-Nangodi Shear Zone
- BSE - Backscattered electron
- CHBr₃ - Bromoform
- BPSZ - Boromo-Poura Shear Zone
- BNSZ - Brobo-N’Zi Shear Zone
- BSZ - Bonikro Shear Zone
- Ca and/or ~ - approximately
- Cid_F – Côte d’Ivoire_ Ferkéssédougou
- CL - Cathodoluminescence
- CMA - Compagnie Minière d'Afrique
- Cm – Centimetre
- Cm² – Square centimetre
- CRMs - Certified Reference Materials
- D₍₁₋₄₎ – Deformation events
- EM - Electromagnetic
- FBB - Ferké-Bandama branch
- Ferké - Ferkéssédougou
- FGSZ - Fada-Gourma Shear Zone
- FSZ - Ferké Shear Zone
- g - grams
- Ga – Giga-annum, billion years
- GFBSZ - Greenville-Ferkéssédougou-Bobo-Dioulasso Shear Zone
- GIS - Geographic Information Systems
- GPS - Geographic Positioning System
- GSZ - Gagnoa Shear Zone
- Hz - Hertz

- IOCG - Iron Oxide-Copper-Gold
- Jcm⁻² - Joules per square centimeter
- KKI - Kédougou-Kéniéba Inlier
- Km - Kilometre
- Km² - Square kilometre
- KSZC - Kargouna Shear Zone Complex
- LOI - Loss on ignition.
- m - Metre
- Ma - Mega-annum, million years
- Min - minutes
- Mm - Millimetre
- MSWD - Mean Square of the Weighted Deviates
- MSZ - Markoye Shear Zone
- MT survey - Magnetotellurics survey
- Nm – nanometres
- OGB - Oudalan-Gorouol (volcano-sedimentary) Belt
- Pb–Pb ages – Lead-Lead ages
- S₍₁₋₄₎ – foliation “*schistosité*” (*fabric*)
- S-C – foliation “*schistosité-cisaillement*” (*fabric*)
- Sec – seconds
- SEM - scanning electron microscope
- SMSZ - Senegal-Mali Shear Zone
- SF- Sassandra Fault
- TRTZ - Tano River Tectonic zone
- TTG - Tonalite-Trondhjemite-Granodiorite
- U-Pb zircon - Uranium-Lead zircon
- Unpub - Unpublished
- UTM - Universal Transverse Mercator
- WAC - West African Craton
- WAXI - West African Exploration Initiative

- WFSZ - Wango-Fitini Shear Zone
- WGS - World Geodetic System
- wt. % - weight percentage
- XRF - X-ray Fluorescence
- YNB - Yédandiekaha-Niakaramandougou branch

1.5 Thesis Organisation

This thesis is divided into seven chapters including the introductory chapter. **Chapter 1** provides introduction of the basis, background and aims of the study and the main problems in the study area.

Chapter 2 provides a review of the tectonic history, pluton emplacement and gold mineralisation of West Africa. Specific focus is given to the tectonics and pluton emplacement in Ivory Coast and ultimately the study area.

Chapter 3 provides a detailed description of the methodologies used in this study. It includes field work techniques, laboratory processes and data analyses. Some of these processes include structural geology, petrographic, geochemical and geochronological studies. This chapter also provides the detailed description regarding the use of ArcGIS[®], Google Earth[®], Adobe Illustrator[®] and CorelDraw[®]. The chapter further explains the use of geophysical and remotely sensed data that was used to extract geological, geographical and geomorphological attributes. The extracted data was used during the field mapping.

Chapter 4 presents field results including the description of the lithological units associated with the FSZ. These results contain field relationships and characteristic features of the units. This chapter also presents the results of petrographic studies of selected samples of intrusive rocks, sedimentary and volcano-sedimentary rocks including their textures, modal abundances and mineralogy (metamorphic mineralogy and alteration mineralogy). This chapter also includes geochemical classifications of the key intrusive rocks and establish their absolute chronology.

Chapter 5 describes the structural geology of the study area. This chapter relates geological and structural elements associated with FSZ. The structural timing and/or evolution of the FSZ are also described in this chapter.

Chapter 6 presents the Discussion. The FSZ in relation with Ferké batholith and volcano-sedimentary sequences from north-central Ivory Coast is contextualised within a regional and global framework.

Chapter 7 is the summary of the key findings of the study, followed by References and Appendices.

2 REVIEW OF REGIONAL GEOLOGY OF WEST AFRICAN CRATON (WAC) AND THE LOCAL GEOLOGY ASSOCIATED WITH THE FERKÉ SHEAR ZONE (FSZ).

2.1 Geological overview of the West African Craton (WAC)

The West African Craton (WAC) extends across 14 countries in the western Africa and composed of Archaean and Palaeoproterozoic basement shields, the Reguibat shield in the north and the Leo-Man shield in the south (Thiéblemont et al., 2004; De Waele et al., 2015; Jessell et al., 2016; Rollinson, 2016) (Figure 1.1). The shields are separated by the intracratonic Neoproterozoic to Palaeozoic Taoudeni basin (Albert-Villanueva et al., 2016). Two Palaeoproterozoic inliers crop out in the central west of the Taoudeni basin, namely the Kédougou-Kéniéba (KKI) and Kayes Inliers (Assie, 2008; Masurel et al., 2016), and one Palaeoproterozoic inlier in the central east termed the Ansongo inlier (Hein and Tshibubudze, 2015).

The Leo-Man shield consists of two domains, namely the Archaean Kénéma-Man domain (3.6-3.5 Ga, U-Pb zircon, Rollinson, 2016) in the southwest and the Palaeoproterozoic Baoulé-Mossi domain (2.3-1.8 Ga) in the east (Feybesse et al., 2006) (Figure 2.1). The Archaean Kénéma-Man domain is a granite-greenstone terrain consisting of layered tonalite-trondhjemite granodiorite (TTG) gneiss and supracrustal rocks containing greenstone sequences (Rollinson, 2016). The margins of the greenstone sequences were intruded by granites, and ultramafic to mafic igneous intrusions ca. 2910–2800 Ma (Kouamelan et al., 1997; Barth, et al., 2002; Thiéblemont et al., 2004; Rollinson, 2016).

The Palaeoproterozoic terrain consists of the Baoulé-Mossi domain in which the study area is situated (Figure 2.1). The domain is composed of granite-gneiss terranes, dominated by gneisses and tonalite-trondhjemite-granodiorite (TTG) plutons, which alternate with narrow greenstone belts, wide volcano-sedimentary basins and younger fluvio-deltaic sedimentary basins (Feybesse et al., 2006; Pawlig et al., 2006). Davis et al. (1994), Lüdtke et al., (1998) and Lüdtke et al., (1999) completed radiometric dating of the volcanic units which places the main peak of the Birimian volcanism ca. 2190–2160 Ma. The detrital zircons from the sedimentary basins yield ages as young as 2130 Ma (Lüdtke et al., 1999) or 2107 Ma (Doumbia et al., 1998). The

supracrustal rocks of greenstone belts and of the volcano-sedimentary basins belong to the Birimian Supergroup which underwent reworking during the Eburnean Orogeny ca. 2.1 Ga (Milési et al., 1991, 1992; Baratoux et al., 2011; Tshibubudze and Hein, 2013).

The late metasedimentary basins, collectively known as the Tarkwa Group unconformably overlie the Birimian Supergroup (Milési et al., 1991; Leube et al., 1990; Feybesse et al., 2006) and characterised by conglomerate, quartzite and shale units (Perrouy et al., 2012; Block et al., 2016). The Tarkwa sediments were deposited at 2107-2097 Ma and are interpreted to represent syn-orogenic to late-stage basins (Davis et al., 1994; Perrouy et al., 2012).

The Palaeoproterozoic Baoulé-Mossi domain was intruded by several generations of granitoids, which indicate a large span of ages, from about 2.2 to 2.0 Ga (Hirdes et al., 1996; Doumbia et al., 1998; Hirdes and Davis, 2002; Pawlig et al., 2006; Gueye et al., 2008; Vidal et al., 2009; Lompo, 2009). Granitoids make up approximately 70% of the Birimian terrane (Doumbia et al., 1998) and form as structural-controlled ovoid intrusions or composite batholiths (Pons et al., 1995; Jessell et al., 2012) that range in composition from TTGs to leucogranites (Hirdes et al., 1992).

The case of the stratigraphy of the WAC was initially reported by Junner (1935, 1940), Ledru et al. (1991) and Milési et al. (1989, 1991) who subdivided WAC into older volcano-sedimentary sequence (Lower Birimian/B1) and younger metavolcanic sequence (Upper Birimian/B2). On the contrary, Vidal and Alric (1994), Hein et al. (2004), Hein (2010) and Baratoux et al. (2011) presented complications with regards to correlating this sequence across the WAC. Work by the WAXI (2013) described the deposition of the dominantly volcanic, volcano-sedimentary and pyroclastic sequences of B1 in an oceanic arc to back-arc setting, in contrast to the dominantly volcano-sedimentary to sedimentary sequences of B2 which were deposited during a period of arc accretion synchronous with the Eburnean Orogeny. This suggested that the stratigraphy of each belt, volcano-sedimentary series or terrane is distinctive from others across the WAC.

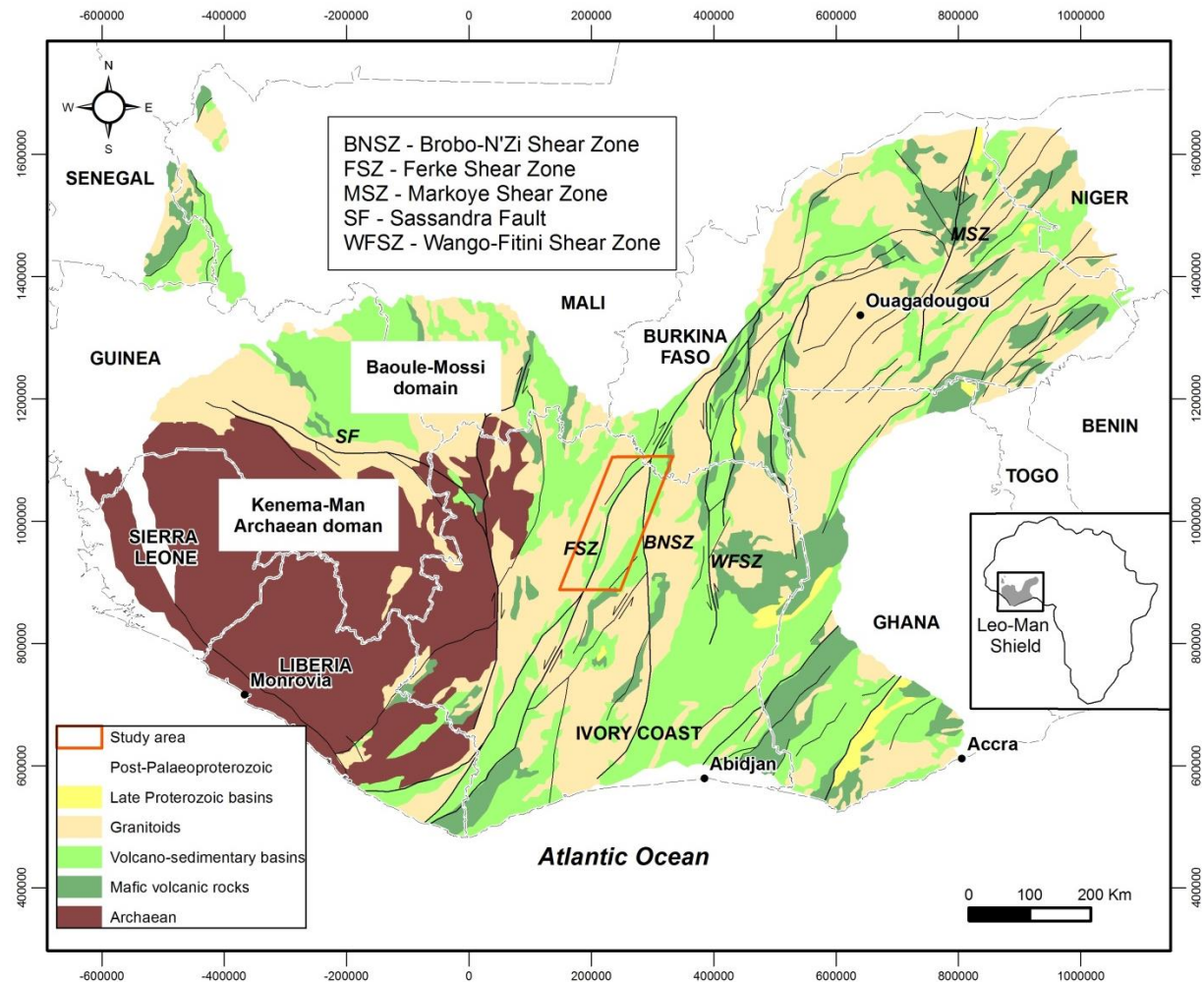


Figure 2.1: Simplified geological sketch map of Leo-Man shield (modified after [Milési et al., 2004](#); [Vidal et al., 2009](#), [Block et al., 2016](#)). Leo-Man shield is made up of Archaean Kenema-Man and Palaeoproterozoic Baoulé-Mossi domains that are crosscut by several structural lineaments. The location of the study area indicated by the red box, located in Ivory Coast (see [Figure 2.2](#)). Projection: Universal Transverse Mercator (UTM) Zone 30 World Geodetic System (WGS) Datum.

2.1.1 Geological overview of Ivory Coast

Ivory Coast is located in the central part of the Leo-Man Rise in the south of WAC. The oldest rocks are part of the Archaean Kénéma-Man domain constrained at 3.5-3.6 Ga (U-Pb zircon, [Rollinson, 2016](#)) and occur in the west of Ivory Coast ([Camil et al., 1983](#); [Kouamélan et al., 1997](#)) ([Figure 2.2](#)). The Palaeoproterozoic Baoulé-Mossi domain characterised by undifferentiated granites, gneisses as well as north-northeast trending rock sequences of the Birimian Supergroup with predominantly volcano-sedimentary rocks and granitoids ([Wright et al., 1985](#)) underlie most the Ivory Coast in the east ([Figure 2.2](#)). The volcano-sedimentary

sequences mainly consist of meta-gabbro, meta-dolerite, meta-basalt, meta-andesite, meta-rhyolite, meta-rhyodacite, meta-dacite, amphibolite, volcaniclastite, various schists and quartzite (Assie, 2008). The granitoids are represented by granite, granodiorite and tonalite (Yacé, 2002). Milési et al. (1991) reported that the Tarkwa Group unconformably overly the Birimian sequences at limited places in the southeast of the country. In places, conglomerates and fine-grained detrital sediments of Tarkwa Group are interbedded within calc-alkaline sequences and were ascribed to the Birimian volcano-sedimentary series (Vidal et al., 1996; Doumbia et al., 1998; Pouclet et al., 2006).

Moreover, the central Ivory Coast comprises of dissected greenstone belts, narrow volcano-sedimentary basin formations and generations of leucogranites (batholiths) striking north-northeast (Doumbia et al., 1998; Pouclet et al., 2006; Vidal et al., 2009). Some of the granitoid bodies cut the greenstones belts whereas others cut both the greenstones (together with earlier granitoids) and the sedimentary basins. The greenstone belts are dated at 2195 ± 10 Ma (Delor et al., 1995) and consist of meta-basalts, basaltic meta-tuffs, meta-dolerites and coarse grained layered meta-gabbros. The first generation of granitoids, mainly of TTG composition, were emplaced between 2123 Ma and 2108 Ma (Doumbia et al., 1998; Castaing et al., 2003; Gasquet et al., 2003). The volcano-sedimentary basins formed between 2108-2094 Ma consist of metamorphosed arkosic sandstones including large lenses of conglomerates, sandstones and shales (Pouclet et al., 2006). In places the sedimentary units are interbedded with lavas together with a sequence of pyroclastites (Ouattara, 1998; Doumbia et al., 1998; Vidal et al., 2009). Second generation of granitoids, mainly of peraluminous composition, were emplaced ca. 2097 Ma (Daouda-Yao, 1998; Doumbia et al., 1998; Adou, 2000; Castaing et al., 2003).

2.2 Tectonic history of the WAC

The volcanic, volcano-sedimentary and sedimentary rocks of the Birimian Supergroup were deformed during the polyphase orogenic events (Davis et al., 1994; Feybesse et al., 2006; Markwitz et al., 2015). The polyphase deformation character of the Baoulé-Mossi domain has been recognised by various researchers including Hirdes et al. (1996), Vidal et al. (1996), Allibone et al. (2002), Feybesse et al. (2006), Pouclet et al. (2006), Vidal et al. (2009), Hein (2010) and Tshibubudze et al. (2015).

The major deformation events have been sub-divided into D₁, D₂ and D₃. D₁, Tangaeen Event constrained between 2170-2130 Ma, resulted in northwest-trending dextral reverse shear zones, folds and an S₁ foliation from southwest-northeast shortening (Tshibubudze et al., 2009; Hein, 2010; Tshibubudze and Hein, 2013). D₁ is recognised in northern Ghana by de Kock et al. (2011) and southern Ghana by Perrouty et al. (2012) as the Eoeburnean.

D₂ or Eburnean Orogeny occurred around 2130-2110 and 2090-1980 Ma (U-Pb and Pb-Pb zircon ages on rhyolites and granitoids) is characterised by northeast to north-northeast-trending shears, folds and an S₂ foliation parallel to axial planes of the folds, developed from northwest-southeast compression (Milési et al., 1989; Feybesse et al., 2006; Hein, 2010; Baratoux et al., 2011; Murray et al., 2019). This event is synchronous with the emplacement of several intrusions across the Palaeoproterozoic domains of the WAC (Pons et al., 1992).

D₃ or the Wabo-Tampelse event resulted in west-northwest trending shears and folds crosscutting D₂ structures. An associated S₃ foliation formed during north-south compression. There is no age constrain for this deformation phase (Hein et al., 2004; Hein, 2010; Baratoux et al., 2011; Metelka et al., 2011).

2.2.1 Tectonic overview of Ivory Coast

In Ivory Coast, strike-slip faults and/or ductile shear zones are dominant and mostly striking north to northeast (Figure 2.2). Excluding the FSZ, the other main structural features in the country include the Brobo-N'Zi Shear Zone (BNSZ), Wango-Fitini Shear Zone (WFSZ) and Sassandra Fault (SF). The north trending BNSZ transects the eastern portion of the study area and controls the emplacement of both the Brobo-N'Zi leucogranite and the Karpélé porphyritic granite (Gasquet et al., 2003). The north trending WFSZ in the east of the country, corresponds to the eastern limit of granites and controls the transtensive sedimentary Wango-Fitini basin (Yao, 1998). The SF in the western Ivory Coast corresponds to the transition between the Archaean and the Palaeoproterozoic (Kouamélan, 1996; Ouattara et al., 2013a).

In central Ivory Coast, the north-northeast transcurrent shear-zones, southwest-northeast upright folds, high density of quartz veins and/or pegmatitic dykes and granitic magmatism correspond to a regional northwest-southeast crustal shortening approximately 2097 Ma (Vidal et al., 2009). Ouattara (1998) recognised sub-horizontal linear anisotropies that show two different

direction families (i) one striking southwest, also parallel to the measured stretching lineations, and (ii) striking perpendicularly and oblique to the cartographic north-northeast elongation of the Ferké Batholith. At the edges of the Ferké Batholith [Vidal et al. \(2009\)](#) recognised several ductile shear zones, defined by mylonites. Away from these regional-scale shear zones, layering of the volcano-sedimentary rocks is preserved and displays upright folds with axes striking northeast, parallel to the direction of the Ferké Batholith.

2.3 Metamorphism in the WAC

During the Tangaeen/Eoeburnean and during the progressive Eburnean Orogeny, the volcanic and sedimentary rocks underwent metamorphism ([Feybesse et al., 2006](#); [Tshibubudze et al., 2009](#); [Hein, 2010](#); [Baratoux et al., 2011](#); [De Kock et al., 2011](#); [Block et al., 2016](#)) with further metamorphism related to the intrusion of granitoids ([Ouattara, 1998](#); [Gasquet et al., 2003](#); [Pouclet et al., 2006](#), [Vidal et al., 2009](#)). At the regional scale, the Palaeoproterozoic domain displays metamorphic conditions from greenschist to lower amphibolites facies ([Tagini, 1971](#); [Lemoine, 1988](#); [Pouclet et al., 1996](#); [Doumbia et al., 1998](#); [Block et al., 2016](#)).

The geology of WAC is characterised by low- to high-grade tectono-metamorphic terranes which are bounded by shear zones ([Block et al., 2016](#)). In relation to the deformation events, metamorphic grades during the Tangaeen (D₁) are generally characterised by greenschist to amphibolite facies, with upper greenschist to granulite facies restricted to shear-mylonite zones ([Pitra et al., 2010](#); [WAXI, 2013](#); [Tshibubudze, 2015](#); [Block et al., 2016](#)). Regional metamorphism in the Eburnean Orogeny (D₂) attained greenschist facies ([Milési et al., 1989, 1991](#); [Eisenlohr and Hirdes, 1992](#); [Bossière et al., 1996](#); [Hirdes et al., 1996](#)) with the development of chlorite-muscovite-epidote-actinolite mineral assemblages, and low to medium grade amphibolite facies with the introduction of hornblende ([Bossière et al., 1996](#); [Béziat et al., 2000](#); [Debat et al., 2003](#); [Naba et al., 2004](#)).

[Block et al. \(2016\)](#) have shown that amphibolite and higher grade assemblages occur in northwest Ghana. [Ganne et al. \(2011\)](#) reported blueschist metamorphism characterised by high pressure-low temperature assemblages along low-temperature granitoid-greenstone contacts in the Fada N'Gourma area, northeast Burkina Faso. Granulite facies have been reported in northeast Burkina Faso ([Tshibubudze and Hein, 2013](#)), mostly reported only in association with

the contact aureoles of granitic plutons as a result of the thermal effect during pluton emplacement. Granulite facies metamorphic rocks also crop out in the Pissila batholith in the Saaba region (Simoko, 2012). The basin sediments in central Ivory Coast underwent a very low grade prehnite-pumpellyite facies metamorphism, but metamorphosed to spotted schists near the granitoid plutons (Doumbia et al., 1998).

2.3.1 Metamorphism overview in Ivory Coast

In the Ivory Coast the metamorphic rocks are folded and strike north-northeast to south-southwest with a sub-vertical dip (Doumbia et al., 1998; Vidal et al., 2009). The regional metamorphism is mostly of greenschist facies (Assie, 2008). In the central Ivory Coast it has been noticed that contact metamorphism by the Ferké leucogranite is overprinting prehnite-pumpellyite facies wall rocks, forming biotite-staurolite-garnet hornfels and andalusite-bearing spotted schists (Doumbia et al., 1998). In the Ferké leucogranite the biotite retromorphosis gives either secondary muscovite or chlorite with Fe oxides mineral assemblages (Vidal et al., 2009).

2.4 Granitoid emplacement in WAC

The Palaeoproterozoic Birimian Supergroup was systematically intruded by a suite of TTG granitoids, diorite and leucogranite plutons (Pons et al., 1995; Naba et al., 2004; Vidal et al., 2009). TTG and diorite emplacement at 2200 Ma and 2160-2130 Ma preceded the Eburnean Orogeny, while granite-leucogranite emplacement at 2100-2070 Ma was concurrent with the Eburnean Orogeny (Leube et al., 1990; Hirdes and Davis, 2002; Pawlig et al., 2006; Gueye et al., 2008). According to Pawlig et al. (2006) and Gueye et al. (2008) the emplacement of tonalite-trondhjemite-granodiorite (TTG) plutons and granites in the WAC is restricted to 2200, 2160-2130 and 2100-2070 Ma.

Jessell et al. (2015) recognised over 20 sets of dolerite dykes crosscutting Palaeoproterozoic basement in West Africa. Ernst (2014) considered these dolerite dykes to be parts of much larger systems of mafic dyke swarms which are part of the plumbing system for Large Igneous Provinces (LIPs) and may be therefore used for the reconstruction of Precambrian supercontinents. Dyke swarms in Niger, Senegal, Burkina Faso and Ghana yielded ages of ca. 1790, 1764, 1575; 1520, 870 Ma, respectively (Baratoux et al., 2016).

2.4.1 Granitoids in central Ivory Coast

The granitoids in central Ivory Coast are associated with greenstone belts and/or sedimentary basins. [Doumbia et al. \(1998\)](#) conducted a study showing two stages of granitoid emplacement in the Katiola-Marabadiassa area. Furthermore, [Pouclet et al. \(2006\)](#) supported [Doumbia et al. \(1998\)](#) by stating that i) the first generation of granitoids (2123-2108 Ma) intruded and metamorphosed the greenstone belts, whereas ii) the second generation (2108-2097 Ma) intruded the sedimentary sequences and volcano-sedimentary basins unconformably overlying greenstone belts. The second generation granitoids are predominately peraluminous in nature and were generated from large batholithic volumes of granitic magma ([Doumbia et al., 1998](#)). It is considered that the second generation granitoids were emplaced during the regional crustal shortening that evolved into deformation along transcurrent shear zones ([Doumbia et al., 1998](#), [Ouattara, 1998](#); [Gasquet et al., 2003](#); [Pouclet et al., 2006](#); [Vidal et al., 2009](#)).

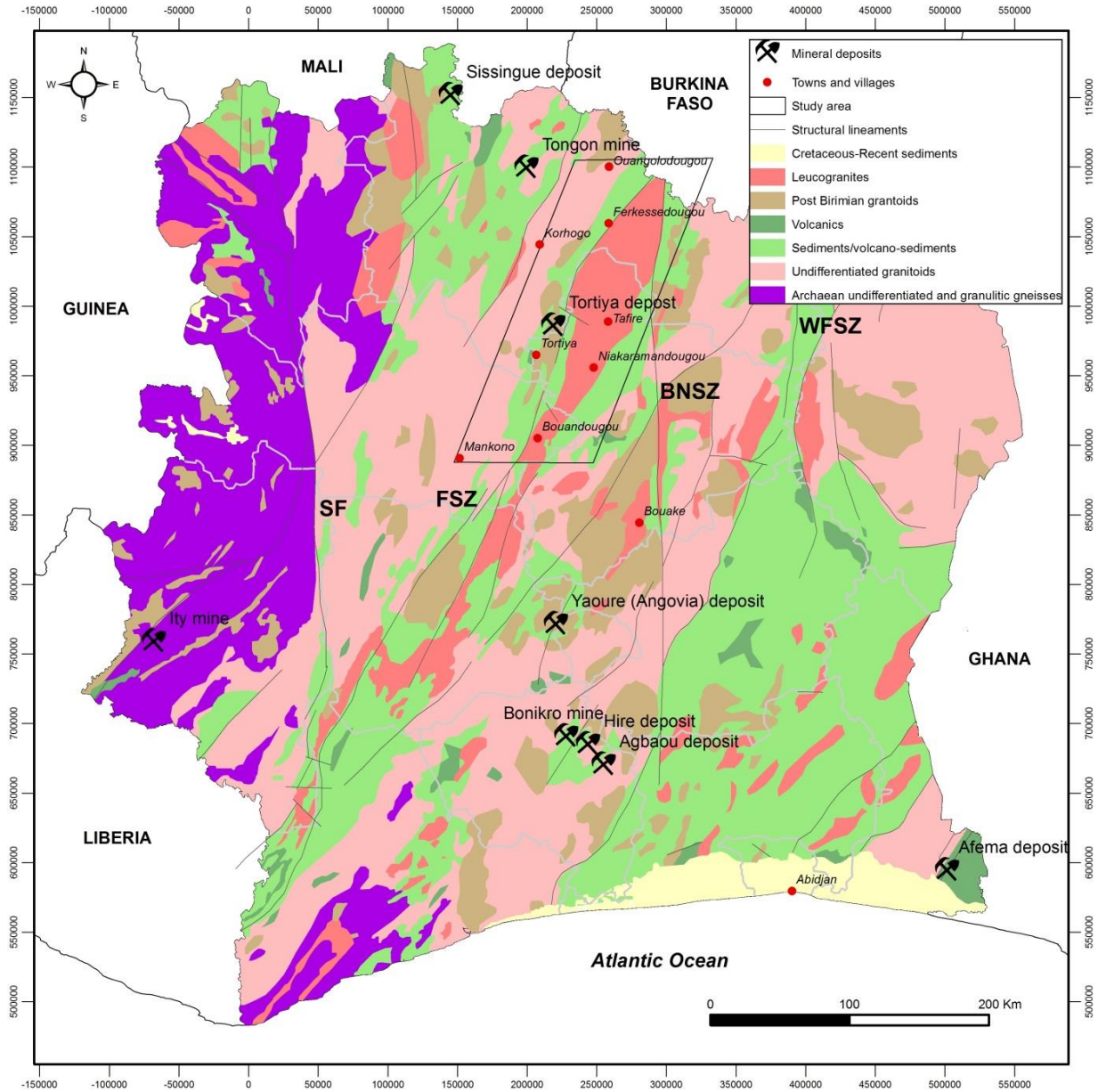


Figure 2.2: A simplified geology map of Ivory Coast showing gold mines / deposits and structural lineaments, redrawn after [Ouattara \(1998\)](#), [Ouattara et al. \(2013a\)](#), [Holliday \(2014\)](#), [Roux et al. \(2015\)](#) and [Robertson and Peters \(2016\)](#). The rectangle indicates the location of the study area. FSZ-Ferké Shear Zone, BNSZ- Brobo-N'Zi Shear Zone, SF-Sassandra Fault, WFSZ-Wango-Fitini Shear Zone. Projection: Universal Transverse Mercator (UTM) Zone 30 World Geodetic System (WGS) Datum.

2.5 Gold mineralisation in WAC

The gold potential of West Africa has long been known, with informal artisanal mining having taken place for centuries (Robertson and Peters, 2016). Over the last two decades West Africa has been an emerging gold producing region having attracted significant exploration interest from research programmes such as West African Exploration Initiative (WAXI). The most gold-endowed regions are spatially associated with the Baoulé-Mossi domain, the Archaean Kénéma-Man domain and the Kédougou-Kéniéba inlier, in the southwestern part of the West African Craton (Milési et al., 1992; Foster and Piper, 1993; Béziat et al., 2016). The majority of gold deposits on the West African Craton are hosted in Palaeoproterozoic rocks of the Birimian Supergroup and are temporally and spatially related to structures formed during the Eburnean Orogeny ca. 2.13 - 1.98 Ga (Milési et al., 1991; 1992; Boher et al., 1992; Allibone et al., 2002; Feybesse et al., 2006; Perrouy et al., 2012; Ouattara et al., 2013a; Ballo et al., 2016; 2015; Traoré et al., 2016; Augustin et al., 2017). Markwitz et al. (2015) recognised various gold deposit types, namely orogenic, intrusion-related, skarn-hosted, palaeoplacer, porphyry-hosted and gold contained within iron oxide-copper-gold (IOCG) deposits.

2.5.1 Gold mineralisation in Ivory Coast

In Ivory Coast, several deposits are associated with greenstone belts, plutons and shear zones (Coulbaly et al., 2008; McFarlane et al., 2011; Lawrence et al., 2013b, 2016; Treloar et al., 2014; Hein et al., 2015; Béziat et al., 2016; Masurel et al., 2016; Le Mignot et al., 2017). Most gold deposits occur within “locally extensional” secondary and tertiary structures associated with the first order shear zones (Cox, 1999; Murray et al. 2019). The Tongon mine is located in northern Ivory Coast within the north-northeast to northeast trending Birimian Senoufo greenstone belt (Figure 2.2). Senoufo greenstone belt host the Au skarn deposit exclusively in basaltic-andesitic crystal tuffs along a corridor of orogen-oblique east-northeast trending thrust faults and shear zones (Lawrence et al., 2017). Locally, in the stratigraphy all other rock units such as carbonaceous shales, siltstones, dacitic crystal and lapilli tuffs, are devoid of mineralisation (Robertson and Peters, 2016; Lawrence et al., 2017). The volcanoclastic sequence is intruded by a granodiorite-diorite pluton that postdates mineralisation. Lastly, all the lithology units are crosscut by late porphyritic and gabbroic dykes (Robertson and Peters, 2016).

The Bonikro gold project is located in the southern part of the Fettekro greenstone belt, south-central Ivory Coast (Gnanzou, 2006; Houssou et al., 2011; 2017; Houssou, 2013; Ouattara, 2015; Ouattara et al., 2015). This part is otherwise called Oumé-Hiré gold district, includes the deposits of Agbaou, Hiré and Bonikro aligned in a linear distance of 40 km (Ouattara et al., 2018). The Hiré deposit is located 12 kilometres southeast of Bonikro (Ouattara et al., 2018). The Bonikro geology is controlled by Bonikro Shear Zone (BSZ) and consists of felsic rocks, mafic rocks and sedimentary rocks associated with volcano-sedimentary deposits (Houssou et al., 2011; Houssou, 2013, Ouattara, 2015; Ouattara et al., 2015; Houssou et al., 2017; Ouattara et al., 2018). Gold mineralisation at the Bonikro Mine was reportedly in the granodiorite but also in relation with three single veins: sheeted, planar and transversal (Gnanzou, 2006). These mineralised veins are consistent with the influence of the hydrothermal activity in the formation of the deposit (Yacé, 2002, Coulibaly et al., 2017).

The Agbaou deposit is located in south-central Ivory Coast within the Birimian Oumé-Fettekro Greenstone Belt, which consists of a volcano-sedimentary succession developed along a northeast trending shear zone (Yacé, 2002). Roux et al. (2015) reported that the belt is surrounded by granodioritic intrusions and gold occurs in a pyrite-pyrrhotite assemblage associated with quartz veining.

The Ity gold mine is located in southwestern Ivory Coast in the Birimian rocks of the Toulépleu-Ity klippe within the Archaean portion of the West African Craton (Figure 2.2). Body et al. (2015) and Béziat et al. (2015) described the deposits Ity as skarns, structurally controlled and developed at the contact of the granodiorite with carbonates. Supergene gold mineralisation is hosted by saprolite that is overlain by a thick laterite horizon.

The Yaouré (Angovia) gold project is located in the Bouaflé Prefecture of the Marahoué Region in the central part of Ivory Coast. The geology consists of mafic volcanics, massive granodiorite and volcanoclastic unit is situated near the contact of the granodiorite (Coulibaly et al., 2008). The Yaouré (Angovia) deposit has been classified as a disseminated gold-sulphide-type deposit hosted by volcanic rocks (Milési et al., 1992; Coulibaly et al., 2008). The mineralisation is contained within two shallow dipping, north-south trending pits named Yaouré Central and Compagnie Minière d'Afrique (CMA), which are controlled by a thick zone of brittle-ductile shearing (Coulibaly et al., 2008; Perseus Mining Limited, 2017).

Yaouré (Angovia) gold project in central Ivory Coast ([Coulibaly et al., 2008](#)) ([Figure. 2.2](#)) and Tortiya-Katiola-Séguéla diamond fields in central Ivory Coast ([Teeuw, 2002](#); [Chirico and Malpeli, 2013](#)) are mineral deposits located proximal to the FSZ. The informal artisanal mining is predominant along the FSZ and some Orpillage workings were recognised in the Tortiya region.

3 RESEARCH METHODOLOGIES

3.1 Introduction

This section briefly details the different methods and techniques used to meet the defined objectives of this study. The principal methodologies of this research are outlined in this chapter; namely, desktop study, field work (data collection), data interpretation and analysis. These fundamental procedures incorporate geological mapping (November-December 2016), sampling for petrological, geochronological and geochemical studies. Samples collected in January 2016 are also incorporated in this research. The Geographic Information Systems (GIS) and remote sensing techniques were also incorporated in this research project, including the interpretation of geophysical data (Google Earth[®], Electromagnetic (EM), ASTER, LANDSAT imagery) from the study area (Figure 3.1).

3.2 Desktop study

A desktop study of the field area was completed prior to fieldwork by utilising previous geological maps (Ouattara, 1998; Doumbia et al., 1998; Pouclet et al., 2006; Vidal et al., 2009; Ouattara et al., 2013a; Holliday, 2014; Roux et al., 2015; Robertson and Peters, 2016) and high resolution geophysical data including Google Earth[®] (Figure 3.2), EM data, ASTER and LANDSAT imagery. The images were studied in order to determine the most effective approach to undertake field mapping and to outline possible traverse lines.

Previous researchers in the Palaeoproterozoic Baoulé-Mossi domain have presented deficiency in outcrop availability (Vidal et al., 2009; Baratoux et al., 2011; Tshibubudze, 2015). Laterite, saprolite-profile and vegetation extensively cover the majority of the study area; therefore, they limit the exposure of outcrops. The challenge of outcrop availability required a desktop study to target areas of possible outcrop exposure within the study area. This included extraction of geographical, geological and geomorphological attributes from previous maps and geophysics data. The accessibility to the targeted areas of good outcrop exposure was enhanced by the use of Google Earth[®] and topographic maps to locate tracks, roads, fences and inhabited areas. Interpretation of the geophysical data allowed extraction of geological attributes such as batholiths, plutons, sedimentary basins and structural lineaments. Accessibility routes facilitated

traverse lines to be delineated. The traverse lines were delineated to cross the targeted geological attributes of the study area.

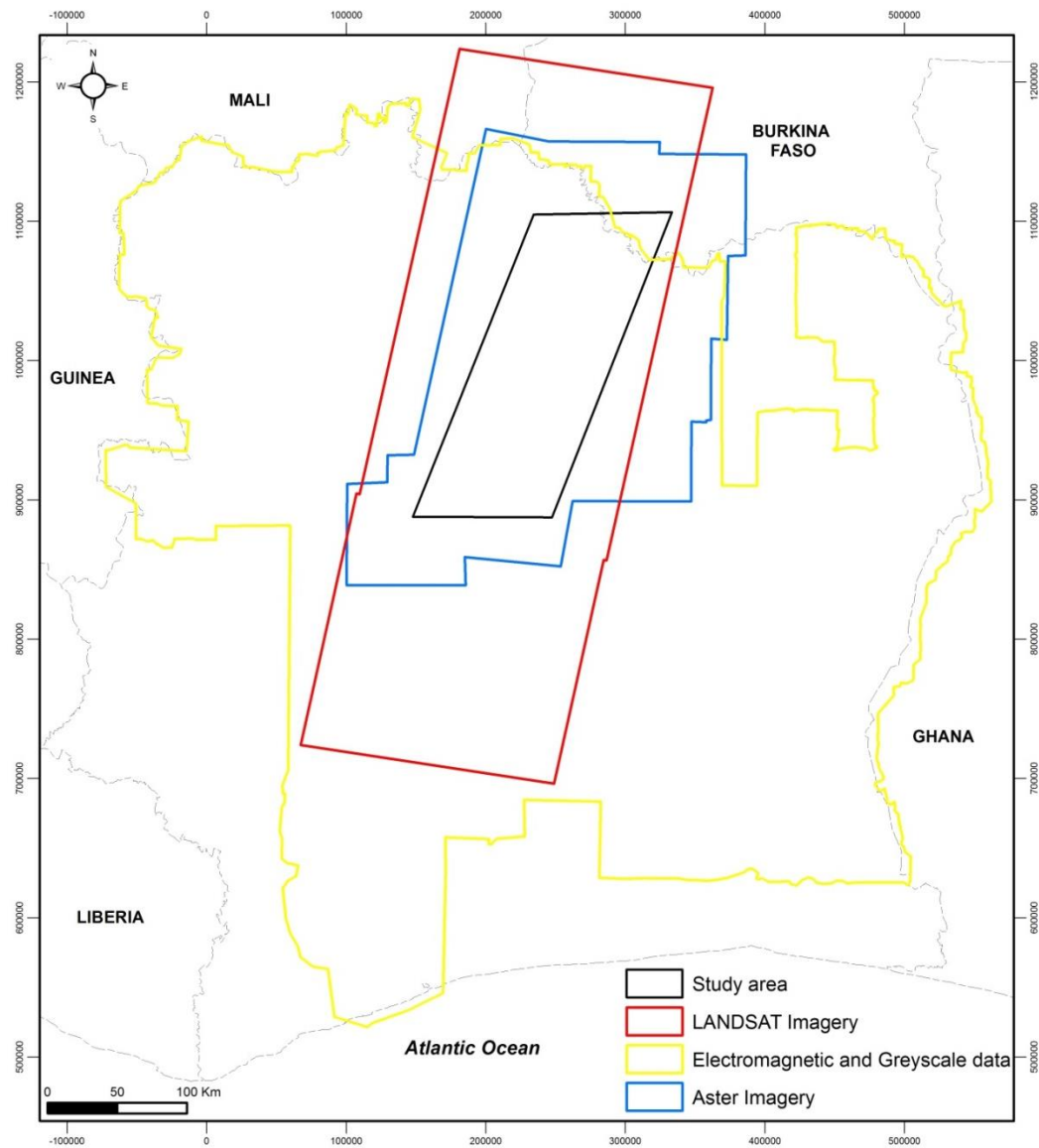


Figure 3.1: Outlines of the geophysical datasets overlaying the north-central Ivory Coast. The study area is covered by EM Greyscale data, LANDSAT imagery and ASTER imagery. Universal Transverse Mercator (UTM) Zone 30 World Geodetic System (WGS) Datum.

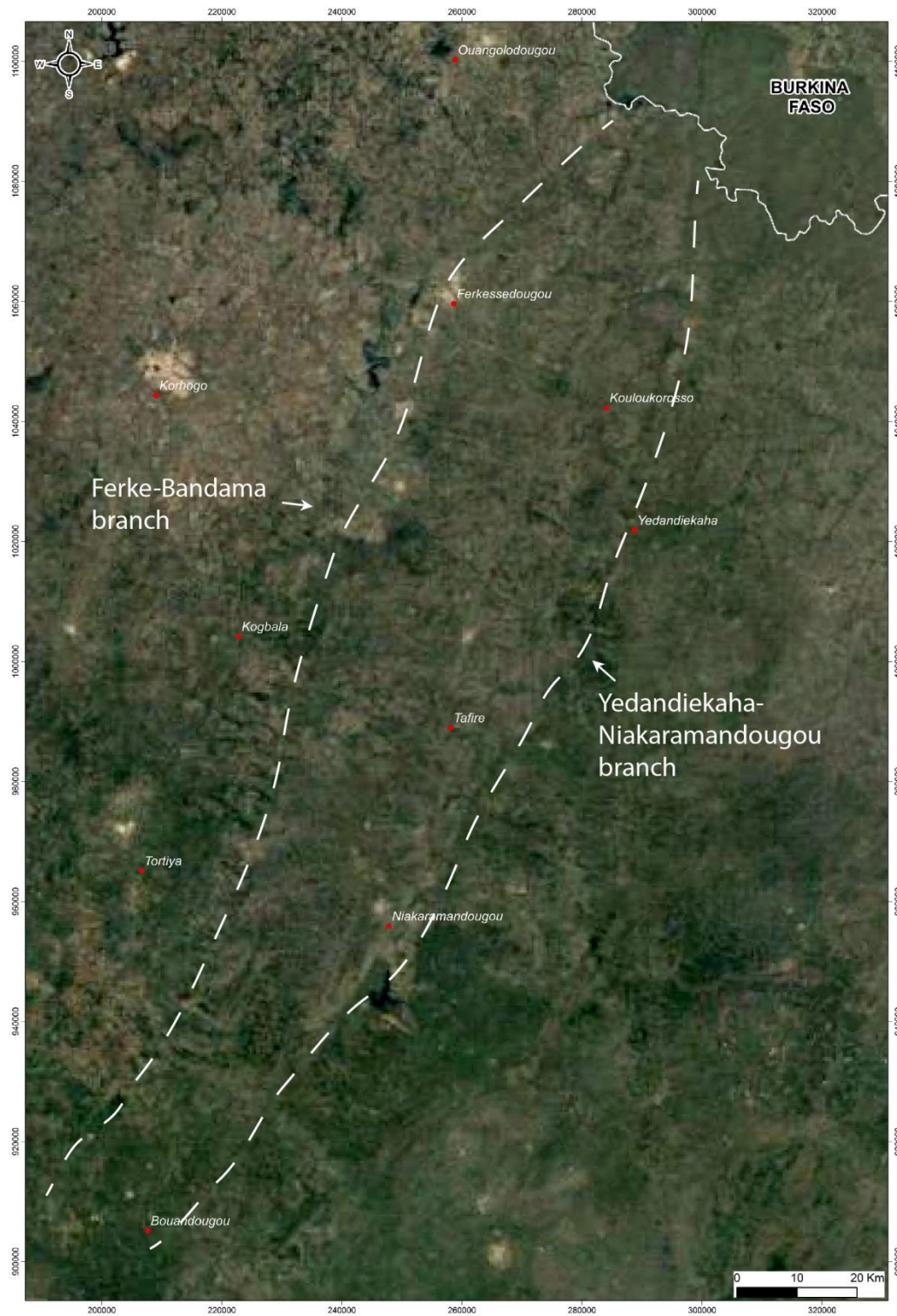


Figure 3.2: Google Earth® satellite image of the north-central Ivory Coast, showing FSZ and its branches (Ferké-Bandama and Yedandiekaha-Niakaramandougou). Note the elongated shape of the batholith between Ferké shear zone branches. Universal Transverse Mercator (UTM) Zone 30 World Geodetic System (WGS) Datum.

3.2.1 Data extraction and interpretation

Drury (2001) simplified the utilisation of remote sensing data in lithological and structural mapping. The process includes basic characteristics of an image, namely, tone, texture, pattern and shape of attributes to extract geologic data as much as possible. The attributes were extracted and interpreted from geophysical and remotely sensed data that include:

- Electromagnetic (EM) data in Figure 3.3.
- EM (greyscale) data in Figure 3.4.
- LANDSAT imagery in Figure 3.5.
- ASTER imagery in Figure 3.6.

These datasets cover most of the Ivory Coast including the north-central portion where the study area is located (Figure 3.1). The extraction and interpretation process of EM data was based on magnetic anomalies. The extraction and interpretation process of ASTER and LANDSAT imagery was primarily based on the characteristics of the attribute. The characteristics included size, texture, colour, and shape of the attribute. Previous maps were additionally used to improve the accuracy of the extracted and interpreted attributes. ArcMap® 10.3.1-10.4.1, Adobe Illustrator® CS6 and CorelDraw® 3X were the three software programs used during the extraction and interpretation of attributes.

3.2.1.1 Electromagnetic (EM) data interpretation

EM data enabled interpretation of attributes such as batholiths, structural lineaments, plutons, sedimentary and volcano-sedimentary sequences. Batholiths are represented in Figure 3.7a and characterised by medium to low magnetic anomalies. The central part of the study area is dominated by magnetic lows that are associated with linear magnetic highs, in places. The magnetic highs are defining the margins of the batholith or plutons and have been interpreted as structural lineaments. The magnetic lows in the central parts of the study area represent the Ferké Batholith. Ouattara (1998), Doumbia et al. (1998) and Vidal et al. (2009) stated that the batholith is made up of leucogranites. The volcano-sedimentary and sedimentary sequences are predominantly defined by magnetic highs (Figure 3.3 and 3.7b). The magnetic highs are associated with the volcanic rocks of the sequences. Structural lineaments are represented by linear magnetic highs and lows. In the study, the dominating orientation of the lineaments is the northeast or north-northeast (Figure 3.7c).

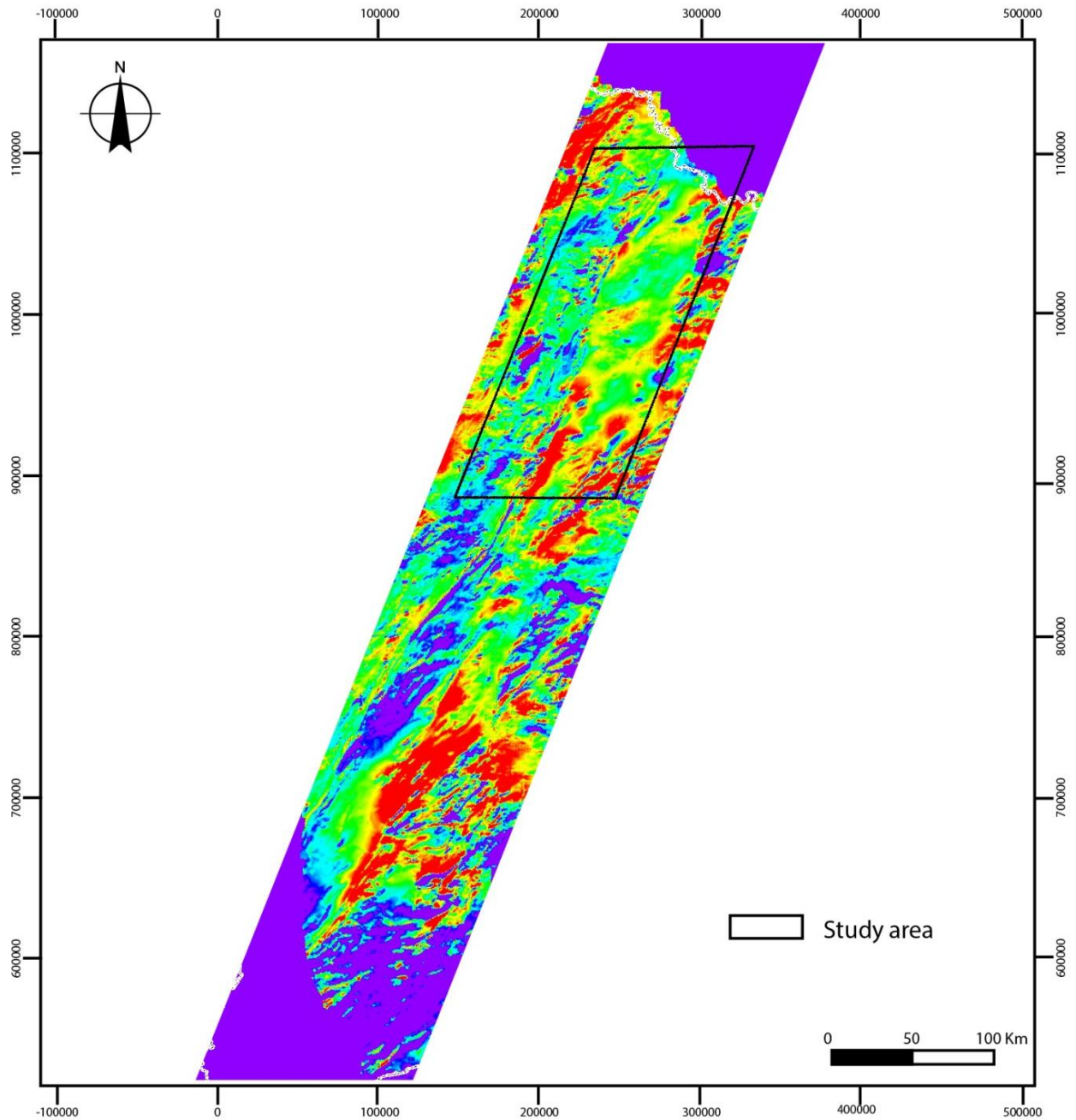


Figure 3.3: The Electromagnetic (EM) data covering a portion of FSZ in Ivory Coast including the study area. The parallelogram represents the study area. Universal Transverse Mercator (UTM) Zone 30 World Geodetic System (WGS) Datum.

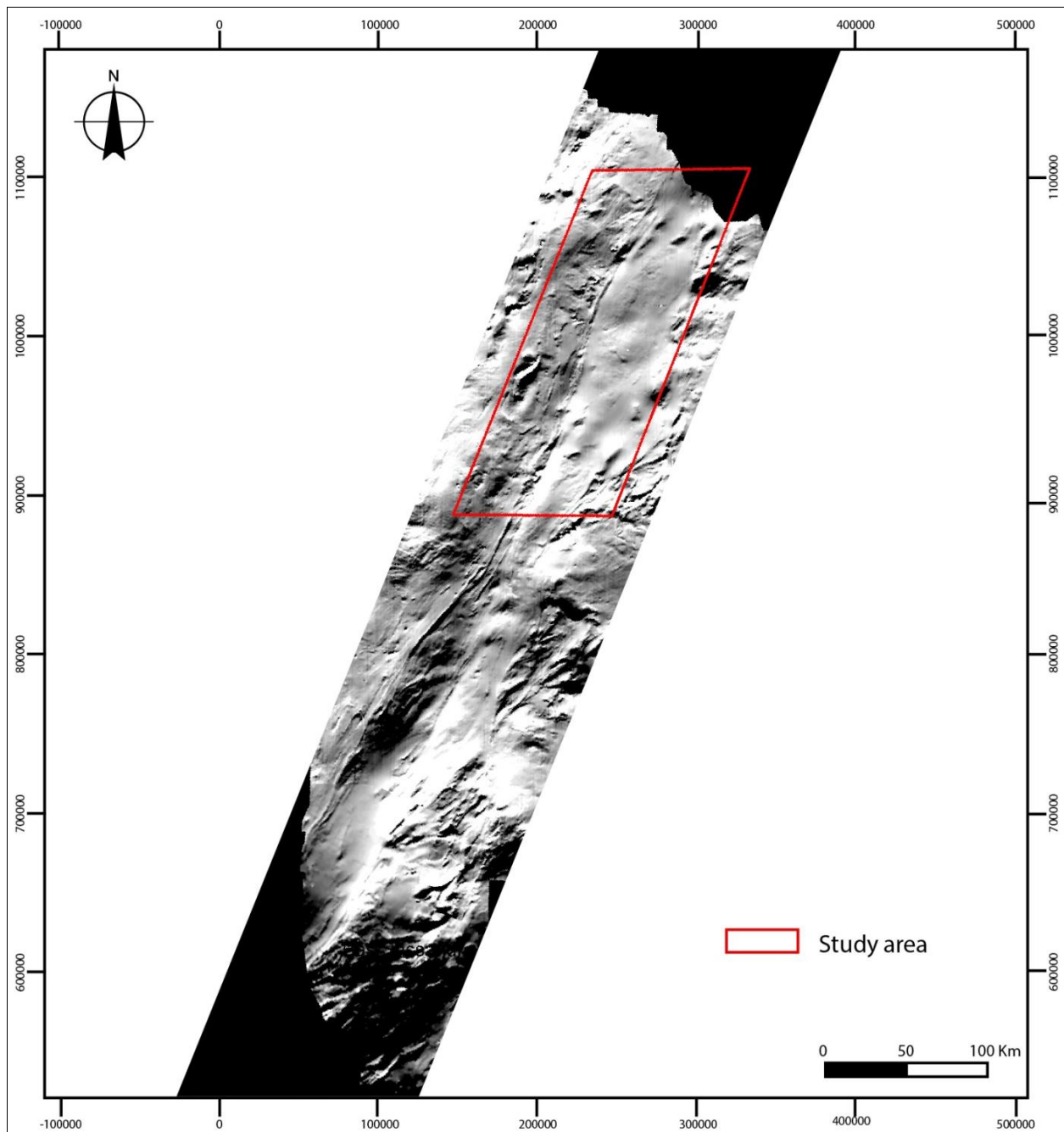


Figure 3.4: The EM greyscale data covering a portion of FSZ in Ivory Coast including the study area. The study area is represented by the parallelogram. Universal Transverse Mercator (UTM) Zone 30 World Geodetic System (WGS) Datum.

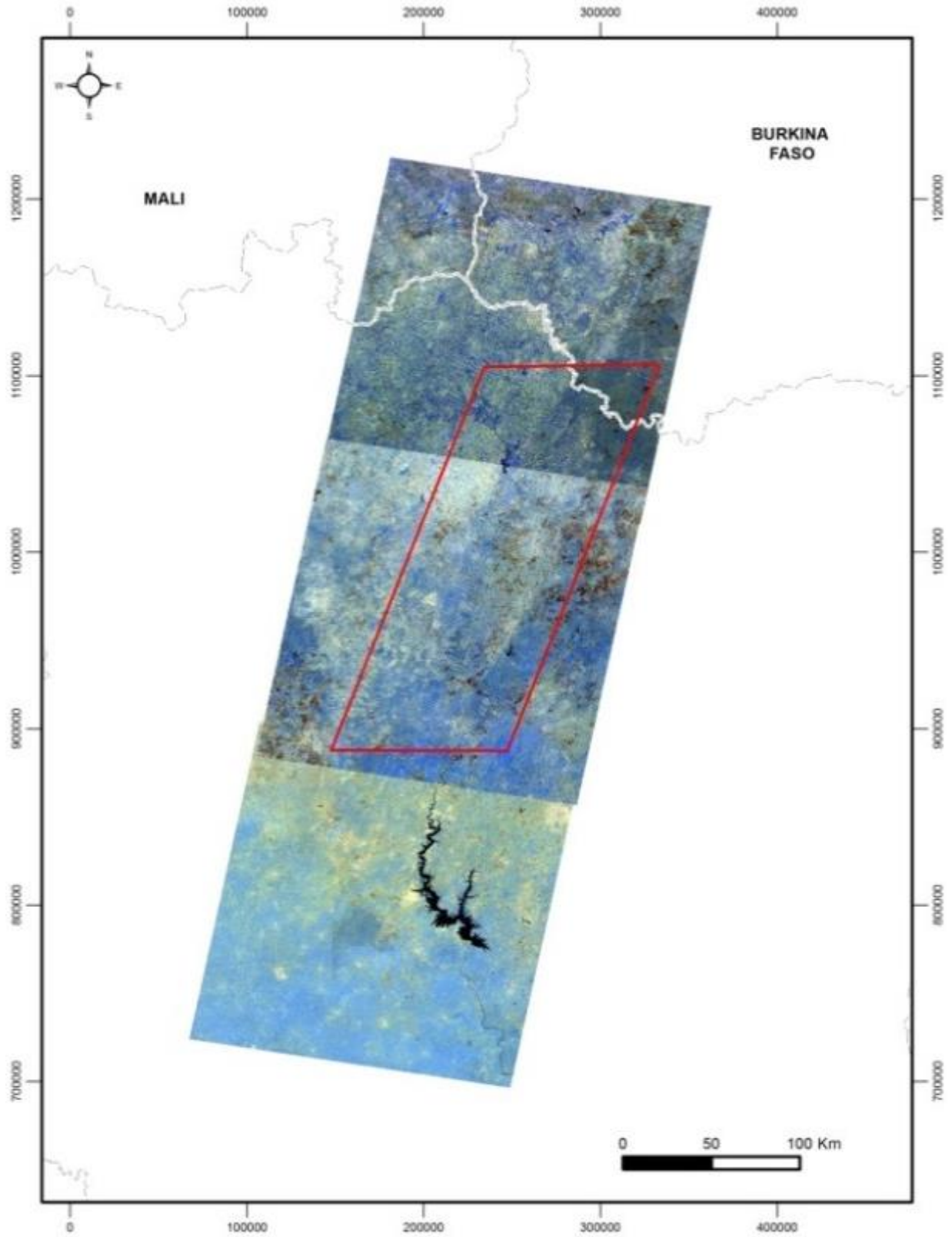


Figure 3.5: The images of LANDSAT ETM Bands 123 covering the portion of north-central Ivory Coast and the study indicated by the parallelogram. Universal Transverse Mercator (UTM) Zone 30 World Geodetic System (WGS) Datum.

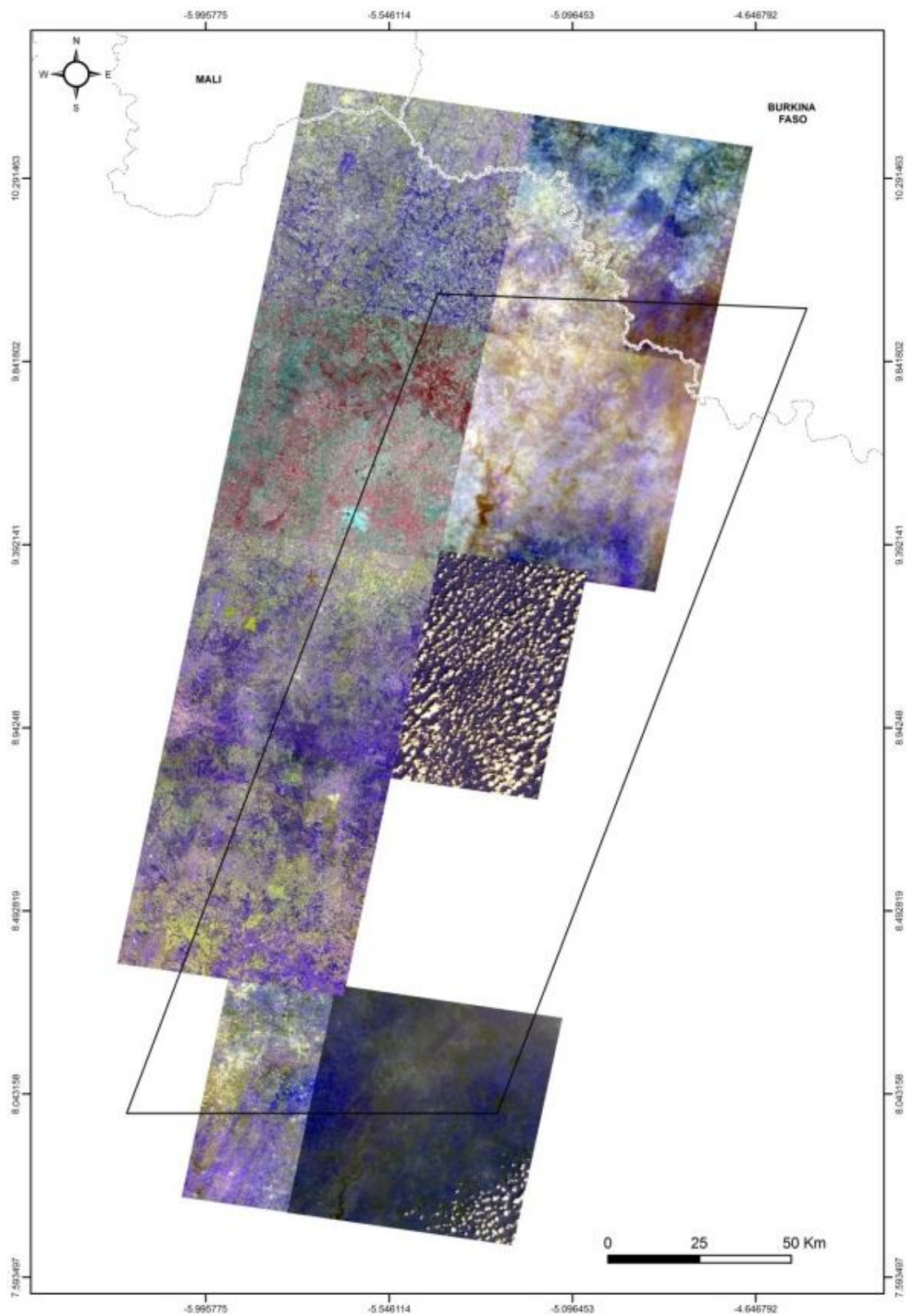


Figure 3.6: The study area represented by the parallelogram and partially covered by the images of ASTER's bands 1.1.1 in RGB.

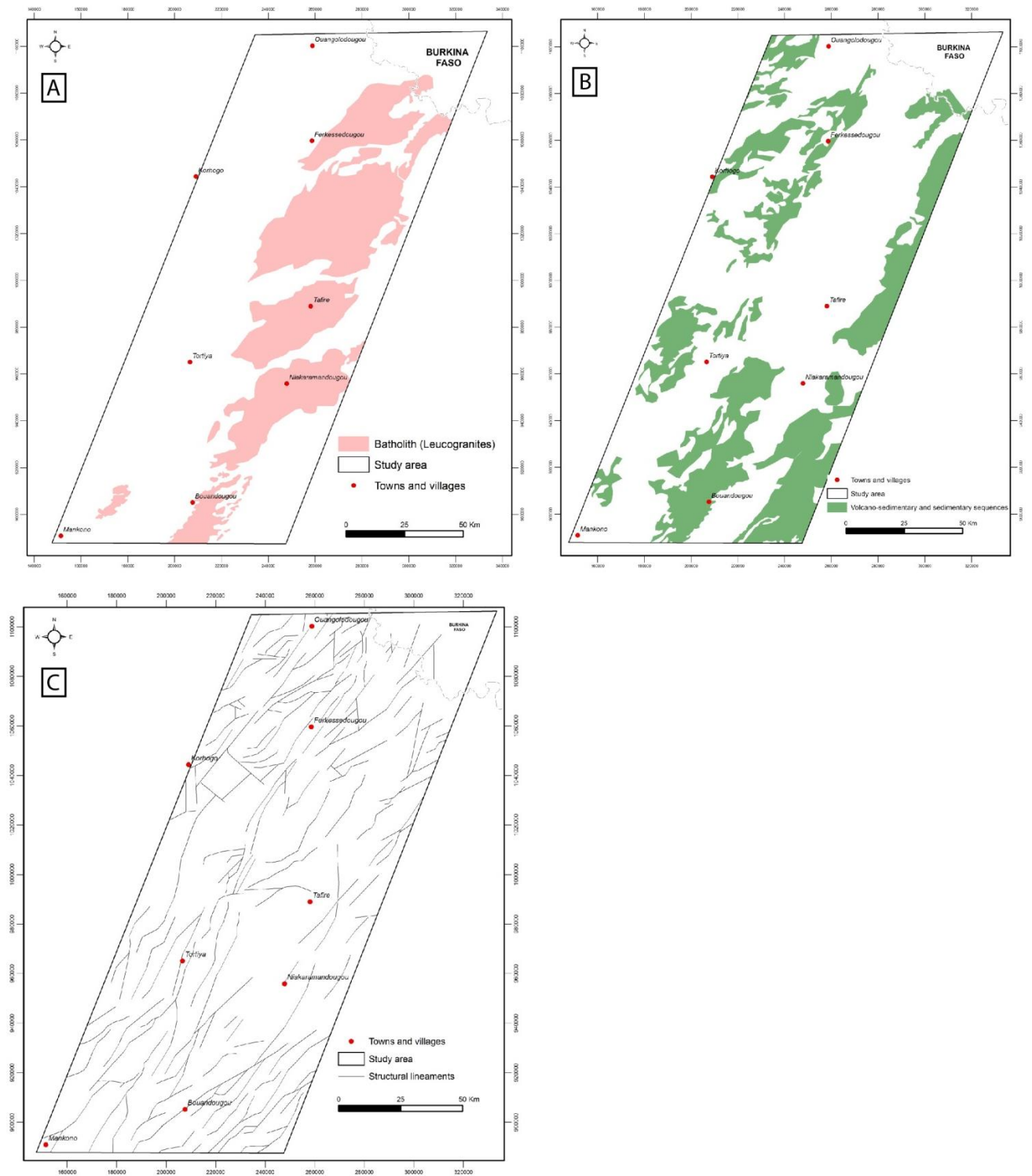


Figure 3.7: (a) The location of magnetic lows that are interpreted as Ferke Batholith and other leucogranite plutons from the EM data. **(b)** The location of magnetic highs that are interpreted as sedimentary and volcano-sedimentary sequences from the EM data. **(c)** Structural lineaments interpreted from EM and EM (greyscale) data. Universal Transverse Mercator (UTM) Zone 30 World Geodetic System (WGS) Datum.

3.2.1.2 *ASTER and LANDSAT imagery interpretation*

ASTER and LANDSAT image interpretation resulted in attributes such as regions of vegetation, regolith cover, towns, villages, drainage patterns, rivers, railways and roads. Major roads, railways, towns and villages are represented in [Figure 3.8](#). ASTER and LANDSAT images show that a large portion of the study area is covered or dominated by the brown to dark brown features. These features were interpreted as laterite piles or caps. Laterite piles were identified using LANDSAT ETM Band 123 and are shown in [Figure 3.9a](#). The batholiths and plutons were identified using LANDSAT ETM Band 123 and represented in [Figure 3.9b](#) due to their uniform texture on the imagery. The white to light green colour on the LANDSAT ETM Band 123 was used to identify the plutons. Ferké Batholith was easy to interpret due to the size and its structure-dominated margins. The structural lineaments are represented in [Figure 3.9c](#). The dominating trends of the drainage patterns are northeast and northwest.

The main rivers flow parallel to the trends of major lineaments and/or batholith margins. The river drainage patterns were identified using LANDSAT ETM Band 123 and LANDSAT ETM Band 541. The drainage patterns and rivers were used to interpret the structural lineaments because these attributes commonly conform to underlying geological features as shown in [Figure 3.9d](#). A map of the combined information extracted only from EM data, EM (greyscale) data, LANDSAT imagery and ASTER imagery is represented in [Figure 3.10](#).

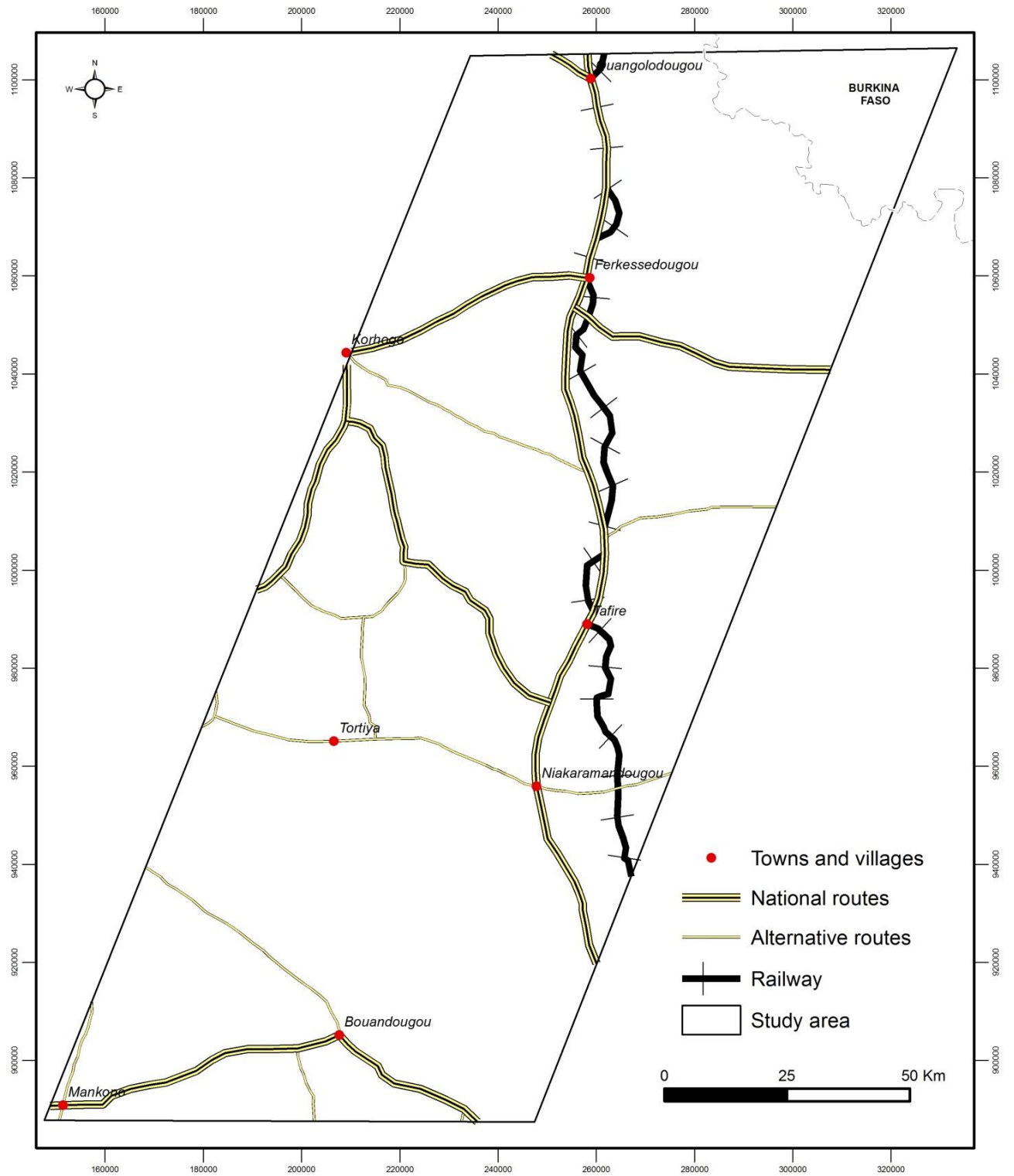


Figure 3.8: The geographic and man-made attributes including roads, towns, villages and railways. Universal Transverse Mercator (UTM) Zone 30 World Geodetic System (WGS) Datum.

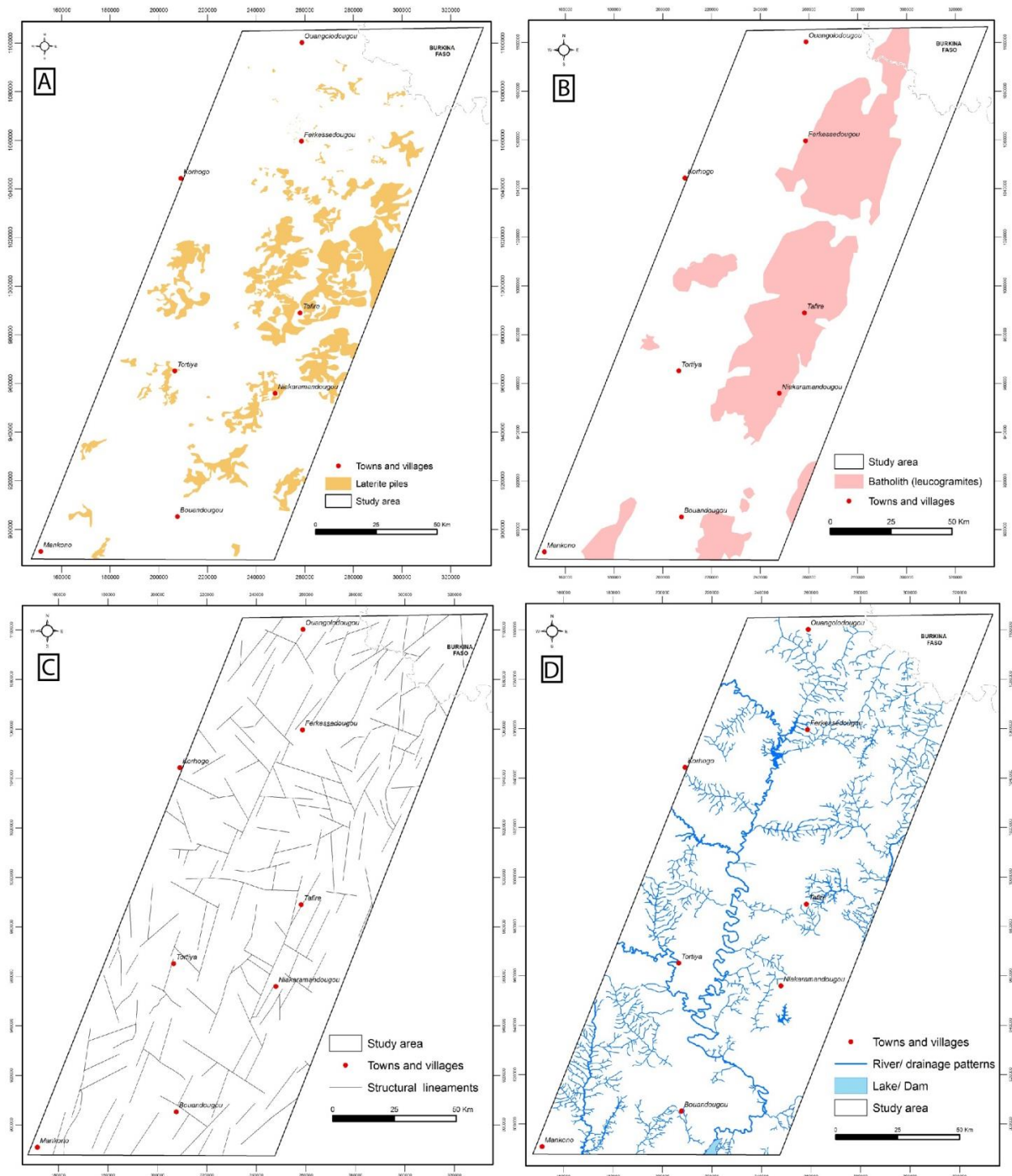


Figure 3.9: (a) The location of laterite piles or caps interpreted from the ASTER and LANDSAT images. (b) The location of batholiths and plutons interpreted from the ASTER and LANDSAT images. (c) The structural lineaments interpreted from the ASTER and LANDSAT images. (d) Location of attributes extracted for drainage patterns and rivers from the ASTER and LANDSAT images. Universal Transverse Mercator (UTM) Zone 30 World Geodetic System (WGS) Datum.

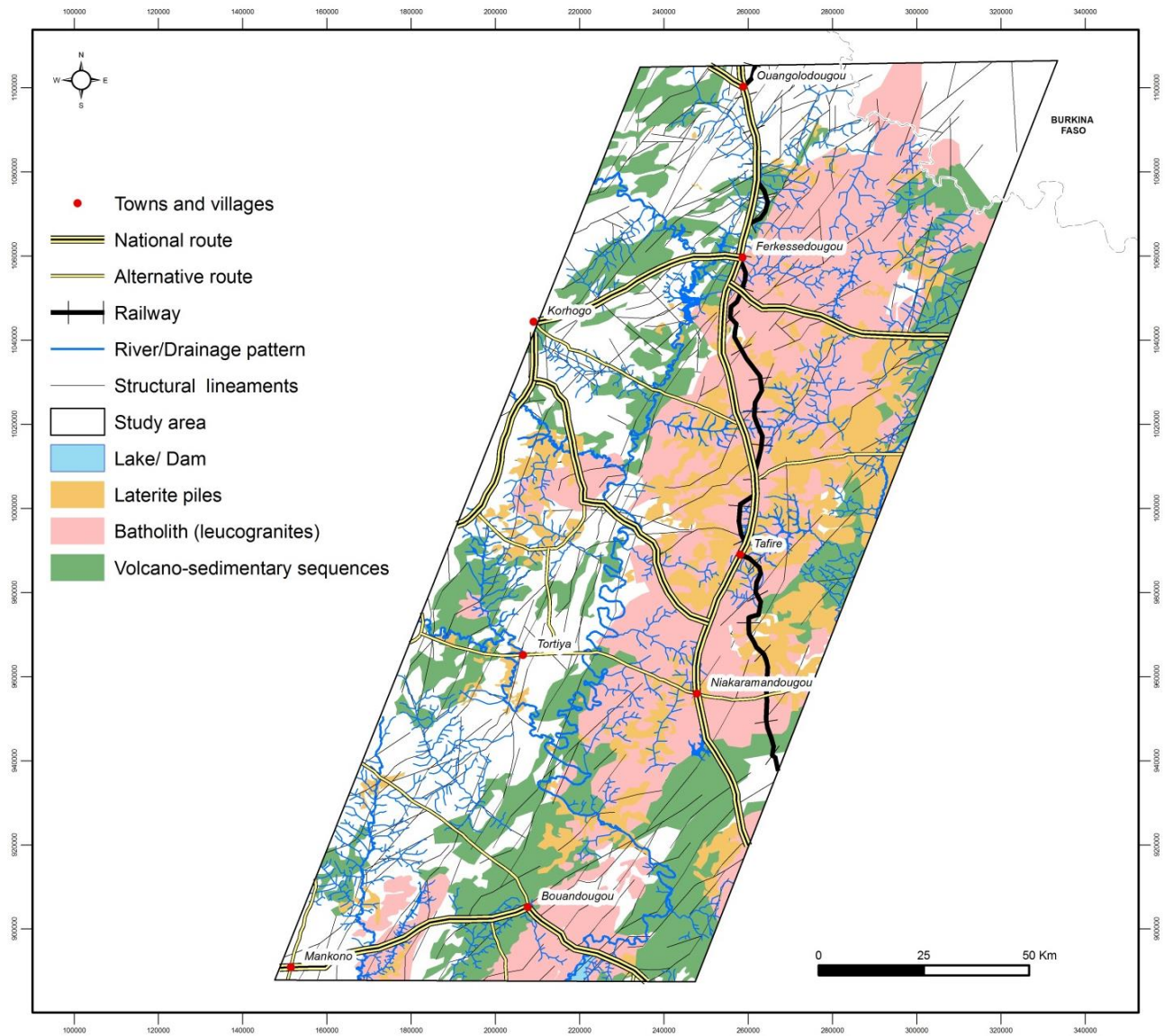


Figure 3.10: An interpretation map of the study area compiled from combined information extracted from EM data, EM (greyscale) data, LANDSAT imagery and ASTER imagery for the study area. Universal Transverse Mercator (UTM) Zone 30 World Geodetic System (WGS) Datum.

3.3 Field methods

The terrain of the north-central region of Ivory Coast is relatively flat. In the study area the elevations vary from 200-300 m above the sea level. The region is characterised by a thick laterite profile and vegetation that has limited good outcrop exposure. In West Africa due to various limiting factors (warfare, health scares, traditional owners, scarcity of outcrops and political landscape) the majority of the geological data have been interpreted from geophysical

information. However, field mapping is very important in order to reduce the possibility and degree of errors. For example, field mapping produce more accurate delineation of the boundaries between different lithology units.

Two field seasons were planned for November-December 2016 and November-December 2017 in order to be concurrent with the favourable climatic conditions of West Africa; however, only one was completed. The November-December 2017 field season was declared unnecessary as all the important data was collected in the November-December 2016 field season. The November-December 2016 field season included geologic reconnaissance study, detailed structural mapping and sampling. Mapping in this field season was conducted in the period of 20 days. The mapping commenced from the northern portion of the study area along traverses and was concluded in the southern parts of the study area. Essential field mapping tools included a hand lens for mineral identification, a compass clinometer to measure structural orientations, a geological hammer for sampling and a Geographic Positioning System (GPS) that recorded the coordinates of the station points. The coordinates recorded on the GPS correspond to the Universal Transverse Mercator (UTM WGS 84) grid coordinates system (Zone 30P). Photographs were taken at every station point to provide evidence of observations, textures and structures. Convention used for measuring structural readings includes strike/dip/dip direction for planar readings, for example, $021^{\circ}/82^{\circ}$ W. The strike is represented by the values on the northern hemisphere of the compass (270° - 090°). Plunge and trend/azimuth (plunge direction) were used to represent linear readings, for example, $13^{\circ}\rightarrow 253^{\circ}$. The value 253° represents the trend/azimuth (plunge direction), herein, southwest. Field data is presented in [Appendix A](#).

3.4 Data processing

The data collected during the field mapping was documented in a Microsoft Excel[®] 2010 spreadsheet. The data included the structural elements, lithological descriptions and the location of station points. ArcMap[®] 10.3.1 and 10.4.1 were used to create maps, diagrams and to plot all the station points, sample points and structural data. The creation of maps in ArcMap[®] included geo-referencing previous maps to the WGS84 UTM coordinate system and grid lines for UTM Zone 30P. Other maps and diagrams were created and edited using the vector graphics editor

CorelDraw® 3X. The structural data was analysed and plotted using stereographic software program GEORient® 9.2 on an equal area projection.

3.5 Petrography and geochemical studies

During fieldwork, fifty-three samples were collected from the outcrops in the study area. These rock samples were chosen to represent the main structural, lithological and mineralogical variations observed in the field. Furthermore, these samples were collected for petrographic (Appendix B), geochemical, geochronological and micro-structural analyses. In the collection, eleven samples were collected for geochronological studies (section 3.6) from specific locations across the study area.

The samples were transported from the field to the rock cutting Lab of the Université Félix Houphouët-Boigny, Cocody-Abidjan for trimming and packaging. The samples were trimmed and cleaned using a rock saw to reduce the weight prior to their transportation to University of the Witwatersrand, Johannesburg. Polished thin sections were prepared at the University of the Witwatersrand Earth Lab from selected samples for petrographic and microstructural analyses.

Optical techniques included the reflected light microscopy for the identification of sulphide and oxide minerals, their occurrences, relationship to silicate minerals, modal abundances and sizes. The use of transmitted light microscopy enabled:

- Mineral identification.
- Determination of modal abundances for each mineral.
- Classification of the sample according to its mineralogy and alteration.
- Identification of textures and mineral chemistry zonation
- Determination of the metamorphic grade using the mineralogy.

For geochemical analyses, representative samples of specific units were taken during systematic fieldwork mapping. Subsequent to extensive petrographic analyses, only fresh samples of the selected units were chosen for further geochemical analyses. Major and trace element analysis were determined by X-ray fluorescence (XRF) at the Earth Lab, University of the Witwatersrand. Geochemical classification and nomenclature of these samples was obtained

by plotting geochemical (XRF) data on various discrimination diagrams. Standards used for calibration of PW2404 XRFs for major element composition analysis are given in [Table 1](#).

Table 1: Standards used for calibration of PW2404 XRFs for major element composition analysis

		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	Cr ₂ O ₃	NiO	TOTAL	LOI
NIM-P		51.39	4.29	1.28	10.36	0.23	25.41	2.64	0.34	0.09	0.1907	0.03	3.5889	0.0764	99.92	-0.23
NIM-D		39.02	0.33	1.7	13.81	0.22	43.81	0.3	0.05	0	0.0255	0.01	0.4076	0.2708	99.95	-0.51
W2		53.09	15.53	1.1	8.9	0.17	6.49	11	2.22	0.63	1.0761	0.13	0.0288	0.0098	100.38	0.19
NIM-S		63.85	17.33	0.14	1.13	0.01	0.46	0.7	0.38	15.38	0.0413	0.12	0.0172	-0.0032	99.55	0.42
GSP2		67.25	15.08	0.5	4.01	0.04	0.98	2.14	2.83	5.45	0.6656	0.29	0.0185	0.0027	99.26	0.87
BCR2		54.98	13.73	1.4	11.31	0.2	3.67	7.24	3.21	1.81	2.2741	0.36	0.0164	0.0019	100.2	0.1
NIM-N		53.47	16.73	0.91	7.34	0.18	7.61	11.59	2.46	0.25	0.199	0.02	0.0159	0.0159	100.78	0.04
NIM-G		76.8	12.26	0.2	1.61	0.02	0.04	0.81	3.36	5.07	0.0953	0.01	0.0157	-0.0021	100.28	0.73
PCC1		44.03	0.74	0.86	7	0.12	45.81	0.58	0.07	0	0.0126	0.01	0.4131	0.3328	99.99	5.09
BHVO2		50.52	13.7	1.25	10.12	0.17	7.33	11.5	2.25	0.52	2.7659	0.27	0.0637	0.0158	100.48	-0.48
AGV2		60.54	17.29	0.68	5.54	0.1	1.83	5.3	4.3	2.93	1.0663	0.48	0.0193	0.0014	100.07	1.8
G2		69.57	15.44	0.27	2.18	0.04	0.78	1.96	4.12	4.54	0.4974	0.14	0.0129	-0.0008	99.54	0.64
DTS1		41.05	0.26	0.87	7.06	0.12	50.24	0.15	0.08	0	0.0137	0.01	0.5739	0.3204	100.76	-0.02

3.6 Geochronological study

Geochronological studies undertaken on the rocks from the northern to central Ivory Coast, the vicinity of FSZ and Ferké batholith, include [Yobou \(1993\)](#), [Hirdes et al. \(1996\)](#), [Daouda-Yao \(1998\)](#), [Doumbia et al. \(1998\)](#), [Ouattara \(1998\)](#), [Adou \(2000\)](#), [Hirdes and Davis \(2002\)](#), [Gasquet et al. \(2003\)](#), [Coulibaly et al. \(2008\)](#) and [Allialy et al. \(2018\)](#). Their main aim of conducting absolute geochronology is the same as this research project, which is to constrain the relative chronologies established from integrated field studies. Eleven samples were collected from specific locations, to primarily provide important data on: (1) timing of structural events, (2) crystallisation ages and (3) mineralisation. In total, only 6 whole-rock samples were chosen for zircon extraction with a specific end goal to conduct U-Pb geochronology. Extraction of zircon took place at the University of the Witwatersrand, Earth Lab. The extraction process followed standard procedure, namely, crushing, milling, sieving, use of light (water)-heavy liquids and Frantz magnetic separator ([Figure 3.11](#)).

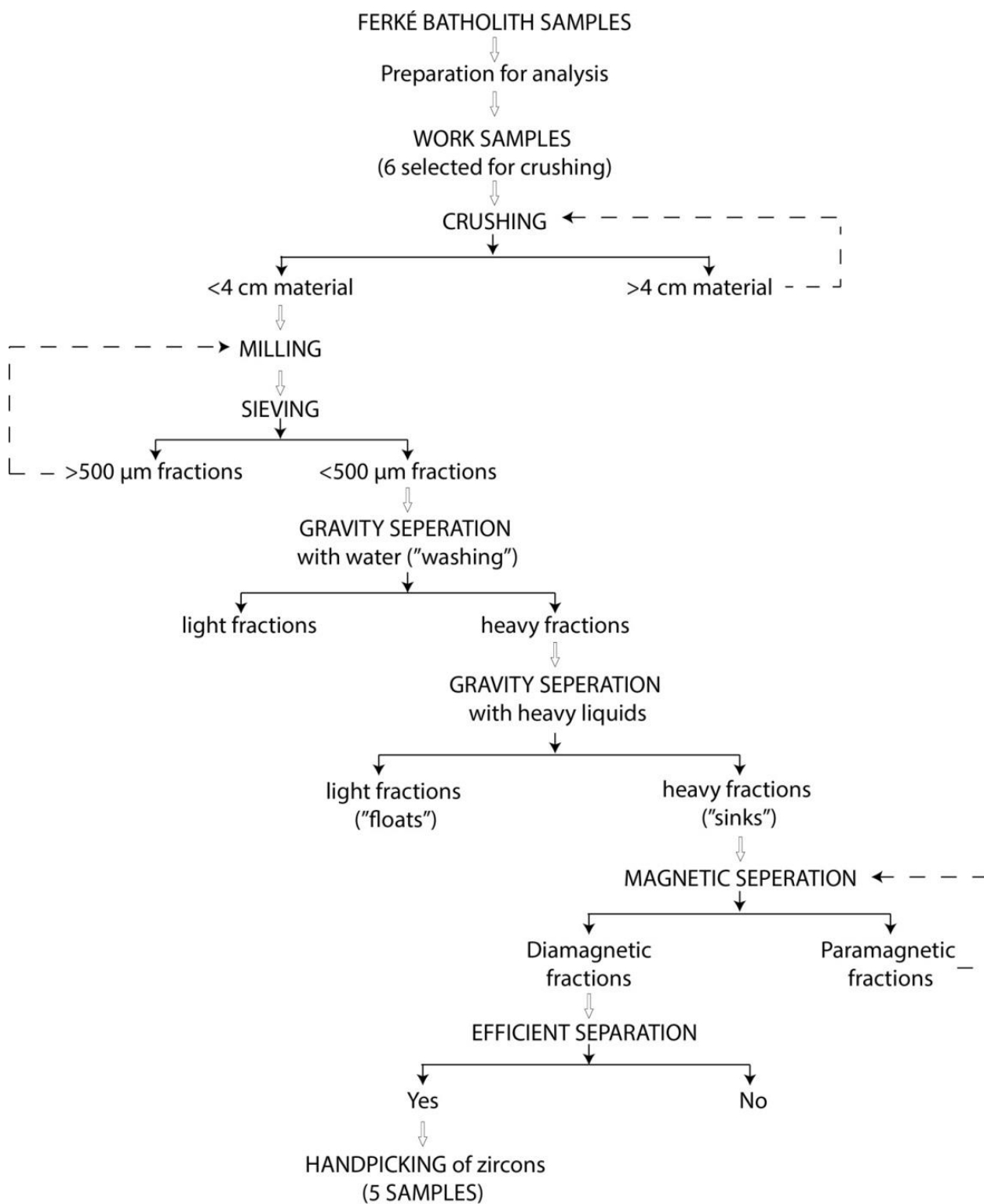


Figure 3.11: Flow chat representation of the steps and procedures followed during zircon extraction for U-Pb analysis from the selected samples.

3.6.1 Crushing

Selected samples were crushed using the carbon steel jaw crusher at the University of the Witwatersrand Earth Lab. The jaw crusher allowed feeding size of up to 10 cm (< 250g) which was crushed into a final material of approximately 2-4 cm. The crushing process included cautious setting of a collector tray and safety tray underneath the jaw crusher to keep away the final material from the laboratory floor. The final material from each sample was then transferred into plastic bags and labelled. Rigorous cleaning of the jaw crusher was compulsory before and after each sample to avoid contamination. Cleaning of the jaw crusher included utilization of a wire brush and acetone. The trays were washed with water and then dried with acetone. A vacuum cleaner was used to clean the equipment.

3.6.2 Milling

Crushed samples were further processed for milling into powder in a carbon steel pot in the refurbished Dickie and Stockler TS-250 MILL tungsten-carbide ring-mill. Approximately 50g of crushed material were transferred into the milling pots at a time. The pots were closed and inserted into the milling machine for roughly 10-30 seconds. The powder material from each sample was divided into two separate labelled plastic bags for geochronology and geochemical analyses.

Contamination was avoided by cleaning the milling machine before and after each sample. The milling pots and lids were washed with water and wiped with acetone. The rubber ring in the lids was washed with water as acetone could harm the rubber. A vacuum cleaner was also used to clean the inside of the equipment and the outside was wiped with a damp cloth.

3.6.3 Sieving

The powdery samples labelled for geochronology were sieved. The wire mesh sieve only collected material less than 500 μ m for mineral separation. Sample material larger than 500 μ m was milled again for 10-20 seconds to lessen the size. The sieved material was then put in plastic bags and labelled. The 500 μ m-wire mesh sieve was cleaned and washed with water, wire brush and toothbrush. The brushes were used to 'stab' at the sieve's holes with the bristles of the brush in a 'stippling' motion, dislodging any material stuck in the mesh. Furthermore, the sieve was

submerged in the Branson B-220 ultrasonic cleaner containing water for 10-20 seconds. The sieve was then wiped with acetone and dried using compressed air.

3.6.4 Gravity separation with water: “washing”

The sieved samples were too small for a Wilfley Shaker Table method, therefore were washed. The process included tap water, one litre beakers, five-litre bucket. Each sample was mixed with water in a beaker, stirred constantly and left for 30 - 40 sec to allow sample material to sink or float. The floating sample material was poured with into a bucket. The sinking material was considered ‘heavy’ and the floating material was ‘light’. For each sample, ‘heavy’ and ‘light’ materials were put into two separate beakers and labelled, these were then put into an oven to dry overnight. The following day, the samples were put into plastic bags and labelled. The cleaning process included the use of water to wash beakers, stirring rod and bucket, after each and every sample. These were then wiped with cloth and acetone.

3.6.5 Gravity separation with heavy liquids

The separation process using heavy liquids only included ‘heavy’ washed samples. The separation was conducted at the Witwatersrand University Earth Lab. The equipment was cleaned thoroughly before use. The heavy liquid, used in this density separation process is Bromoform (CHBr_3). This separation process required use of a fume cupboard where each sample was mixed with Bromoform and stirred in a separation funnel. The mixture was then left for 2-5 minutes to allow material to sink or float. The material at the bottom of the separation funnel was released by opening a stopcock into a filter paper over a beaker. The floating material was released into a separate filter paper. The sinking and floating materials were labelled ‘sinks (>2.85 density of Bromoform)’ and ‘floats (< 2.85 density of Bromoform)’, respectively. The ‘sinks’ on a filter paper were put into a beaker using acetone. This beaker was labelled, put into a UMC 5 ultrasonic cleaner (1 min) and oven to dry the material. The ‘floats’ were left on filter papers in the fume cupboard to dry off Bromoform overnight. The cleaning process required the use acetone on beakers that contained Bromoform. Separation funnel, other lab funnels, beakers and the stirring rod were also washed and wiped with acetone. The following day, both ‘sinks’ and ‘floats’ for each sample were put into separate plastic bags and labelled.

3.6.6 Magnetic separation

Highly magnetic material (e.g. magnetite, steel flakes from disc mill, pyrrhotite) from each sample was removed using a hand magnet. Sample grains were spread on a clean sheet of paper and a hand magnet (covered with tissue paper) was passed through the sample, attracting magnetic grains. These magnetic grains were stored in separate containers and labelled. The process was repeated numerous times until no further magnetic material was picked up. Weakly magnetic materials were separated by an isodynamic magnetic separator of “Frantz MODEL L-1” type. Only the ‘sinks’ from heavy liquid separation were used in the Frantz magnetic separator. The ramp was set at 25° angle forward and -10° angle to the side. Each sample was added to the feed shoe and two sample containers were placed at the end of ramps for magnetic and non-magnetic material. The strength of magnetic field was adjusted using the current knob, magnetic material from each magnetic current (0.1A -1.2A) was collected and labelled.

Minerals such as xenotime and monazite have moderate magnetic susceptibilities (paramagnetic at ~0.4-0.7A), titanite is slightly lower (paramagnetic at ~0.7-1.0A) and rutile, apatite and zircon are very low (paramagnetic at >1.0A to diamagnetic). The separated mineral fractions were microscopically analysed on the binocular magnifier for zircon hand-picking.

3.6.7 Preparation of mounts

Zircon concentrates were purified by hand-picking under binocular microscope. Pure zircon concentrates of each sample were mounted and labelled accordingly. The mount preparation was conducted at the Witwatersrand University, Thin section Lab, Geosciences building. The hand-picking procedure for each sample included transfer of previously prepared diamagnetic fractions into 11cm² paper sheets. Paper sheets allow (a) spread of mineral fractions and (b) refraction of light under binocular microscope. Zircon population of all sizes, colour, and shape were hand-picked then pasted on a double-sided tape. The hand-picking tools include tweezers and pins or needle-probes. A double-sided tape for each sample had been stuck to a glass plate. The glass plate was thoroughly cleaned using acetone before marking (25 mm diameter circle), sticking and labelling each double-sided tape. Pure zircon concentrates on a double-sided tape were then covered with a clean Petri dish lid and placed in a clean area to avoid contamination.

All zircon grains were located at the inner area of the circular markings, therefore, mounting cups were placed and aligned with circular markings. Well-prepared epoxy was then poured slowly into the side of mounting cup. This will allow the epoxy to flow over the zircon grains and the bottom surface evenly without creating air bubbles. The epoxy preparation included mixing of Epofix epoxy resin and hardener until the mixture was smooth and uniform. The resin was then checked under the microscope for (a) air bubbles around the zircon grains, (b) along the inside edge of the mounting cup where it is attached to the tape and (c) any entrapped fibres. The remainder of the epoxy was then poured up the thickness of ~ 20 mm. It was left over night to cure and hardened.

Once the mount has fully cured, it was removed from the mounting cup and the sample number was marked on the side of the resin cylinder. The mount was cut to the preferred thickness of ~1 cm. This preference is due to multiple factors, mainly to properly fit into the mount holder of the polishing/coating machine. The face of the mount was grinded and polished to achieve the best possible optical surface.

3.6.8 Mount carbon coating and scanning electron microscope (SEM) imaging

The surface of the mount was thoroughly cleaned with acetone prior to carbon coating for either cathodoluminescence (CL) or backscattered electron (BSE) detectors in SEM. Carbon coating was required to improve the imaging of samples, because of its mechanical stability, good electrical conductivity and low background signal. The inside of the Quorum Q330T ES chamber, specimen stage and holders were cleaned and wiped with acetone. After cleaning, mounts were placed in a chamber (specimen holders) and the lid was closed. The rod shaper was used to prepare two carbon rods for pulsed evaporation. One rod had 1.2 mm diameter by 5 mm long and the other was flattened. Carbon rods were inserted into their respective terminals and clamp screws were tightened up to fix rods positions. It was ensured that the stage is fitted before setting the profile parameters for carbon pulse rod evaporation. The profile's pulse current was set at 75A for coating thickness of 15 nm.

TESCAN VEGA3 SB EasyProbe scanning electron microscope was used to photograph each carbon-coated mount. CL and BSE images were expedient in revelation of internal

structures of zircon grains. Carbon coating and scanning electron microscope (SEM) imaging were conducted at the University of Johannesburg, Analytical Facility.

3.6.9 U-Pb geochronology and data reduction

Sample mounts were prepared for ion microprobe analysis by removing the carbon coating. After cleaning, the mounts were analysed by laser ablation inductively coupled mass spectrometry (LA-ICPMS) at the Earth Lab, University of the Witwatersrand. The analysis of ~50 grains per sample targeted cores and rims, avoiding cracks and inclusions. Data were acquired by single spot analysis (30 μm), using a laser repetition rate of 8 Hz and a fluence of 2.5 Jcm^{-2} . Zircon standard GJ1 ([Jackson et al., 2004](#)) served for calibration, and Temora-2 ([Black et al., 2003, 2004](#)) and Plešovice ([Sláma et al., 2008](#)) zircon certified reference materials (CMRs) were analysed as unknowns to evaluate accuracy and precision.

The LA-ICPMS U-Pb geochronology data were reduced using the Iolite[®] extension ([Hellstrom et al., 2008; Paton et al., 2011](#)) to the software IGOR Pro[®], ISOPLOT-R and Microsoft Excel[®]. The data reduction scheme (DRS) VizualAge ([Petrus and Kamber, 2012](#)) was used to minimise discordance and to enable common lead correction. In Iolite software[®] data was auto selected for $^{207}\text{Pb}^*/^{235}\text{U}$ measures. Graphic presentation and calculation of Concordia and upper intercept ages was carried out using the software ISOPLOT-R ([Vermeesch, 2018](#)). Uncertainties on individual and mean/regressed ages are 2SE (standard error, absolute).

4 LITHOLOGIES OF NORTH-CENTRAL IVORY COAST ASSOCIATED WITH THE FSZ, INCLUDING PETROGRAPHY, GEOCHEMISTRY AND GEOCHRONOLOGY RESULTS

4.1 Introduction

Desktop study, geological and structural mapping of the study area were pivotal methodologies used to understand the geological units making up the north-central Ivory Coast. Specific samples of these rock units were collected for petrographic, geochemical and geochronological analyses. Geochronological studies (U-Pb geochronology) are important regarding the absolute age of geological events. These geological events include structural events presented in [Chapter 5](#). Geochemical data was used to classify rock units presented in [subsection 4.3.2](#). All gathered information was used to produce geological maps, cross sections and stratigraphic column of the study area.

4.2 Lithologies

The geology of the north-central Ivory Coast is characterised by intrusive units, volcano-sedimentary and sedimentary sequences uncomfortably overlying gneissic basement ([Figure 4.1](#) and [4.2](#)). The volcano-sedimentary and sedimentary sequences are intruded by intrusive units of Ferké Batholith. A significant portion of the study area is dominated by Ferké Batholith. Ferké Batholith is constituted by several plutons, namely:

- Pegmatites,
- Tonalite-diorite,
- Granite (two-mica, phenocrystic and microgranite),
- Granodiorite (two-mica and phenocrystic) and
- Granodioritic gneiss.

At the margins of the batholith, the intrusive units are in contact with metamorphosed volcano-sedimentary and sedimentary sequences. Volcano-sedimentary and sedimentary sequences are constituted by:

- Meta-volcaniclastic greywacke and

- Conglomerate-sandstone-siltstone-mudstone succession

The contact between the batholith and the meta-sedimentary units is characterised by mylonite-schist zones, defining the transecting shear zones (FSZ) (Figure 4.1). The composition and texture of intrusive and meta-sedimentary units frequently vary towards or along the contact. Therefore, units in the study are generally deformed, metamorphosed and overlain by a thick subtropical weathering (laterites) profile that obscured much of the surface geology. This section focuses on describing the rock units and their crosscutting relationships across the study area.

4.2.1 Gneiss

Gneiss unit crops out extensively in the western and north-western portion of the study area, especially in the Ouangolodougou region (Figure 4.1). The unit exposure is obscured by heavily weathered material of laterites piles. It is composed of plagioclase (0.5cm), quartz (0.5cm), hornblende (0.3cm) and 1.5-3cm phenocrysts of muscovite, and biotite. It exhibits mineral segregation defining a well-developed banded foliation (1mm- 1cm). Quartz, plagioclase and K feldspar $\pm$ muscovite define leucocratic layers. Melanocratic layers are defined by hornblende and biotite $\pm$ chlorite. In places, the fabric of the gneiss is crosscut by 3-5cm brecciated quartz veins.

4.2.2 Volcano-sedimentary and sedimentary sequences

4.2.2.1 Meta-volcaniclastic greywacke

The meta-volcaniclastic greywacke unit crops out less frequently across the study area. It crops out in one gully where it is non-conformably overlain by a 6-metre thick laterite profile (Figure 4.3a). The unit is dark to greyish brown and consists of clasts that are poorly sorted, coarse to medium-grained (0.2-0.5cm) and silicified. It consists of sub-rounded clasts of quartz, tourmaline, plagioclase, hornblende and volcano-lithic fragments in a very fine matrix. In outcrop scale, it has a well-developed foliation in places; original sedimentary structures such as cross bedding or graded bedding are preserved. The compositional layering is parallel to the foliation. Structurally, quartz veins and fracture cleavage (Figure 4.3b) crosscut the unit. Microscopically, it is composed of clasts of quartz (40%) and plagioclase (40%). Fine matrix constitutes ~20 % of the rock (Figure 4.3c).

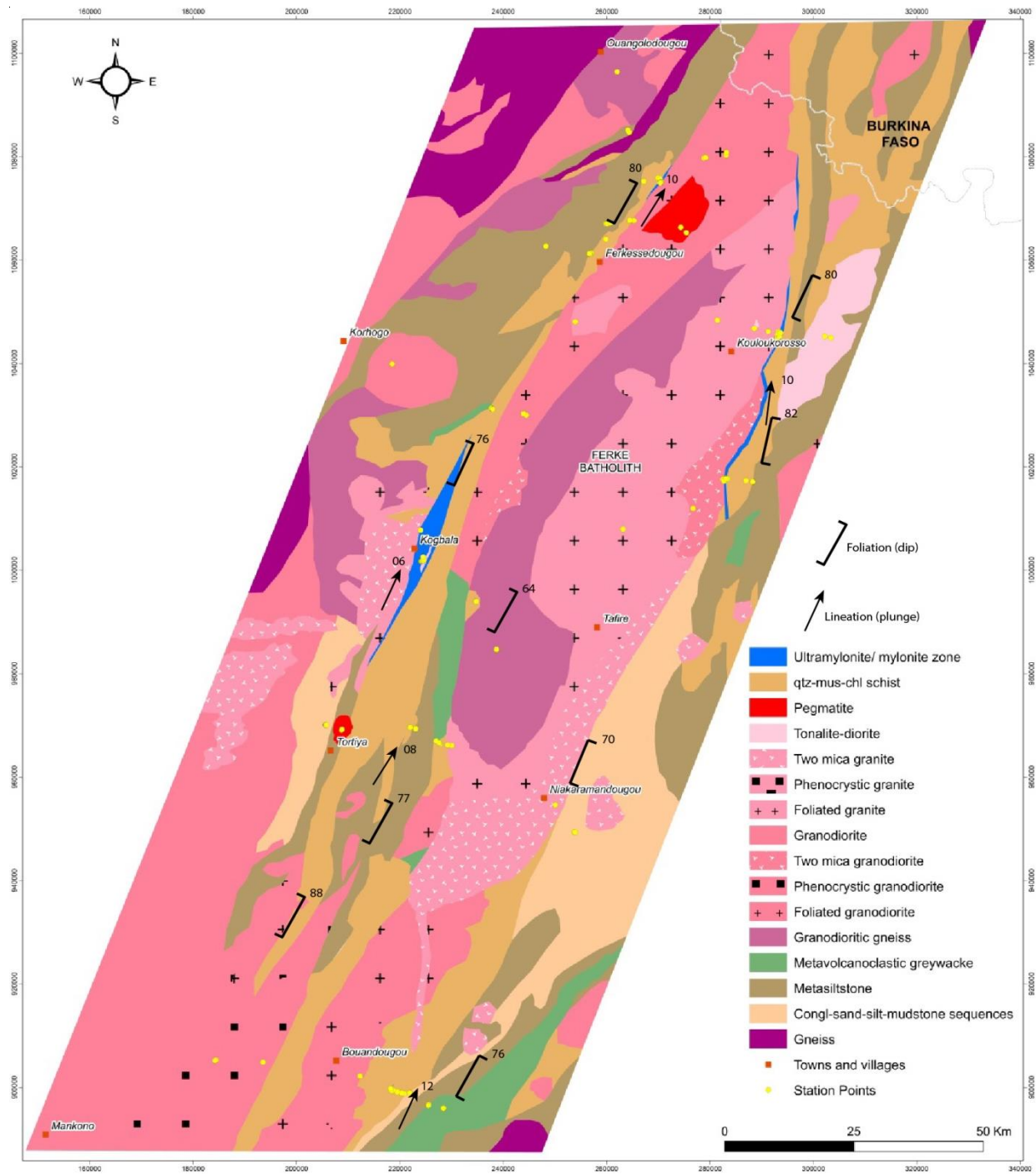


Figure 4.1: The geological map of the study area completed from the field data and extracted from the geophysical and remote sensing data. Sample location and station points are indicated on the map with yellow dots. Projection: Universal Transverse Mercator (UTM) Zone 30 World Geodetic System (WGS) Datum. Qtz- quartz, Mus- muscovite, Chl- chlorite.

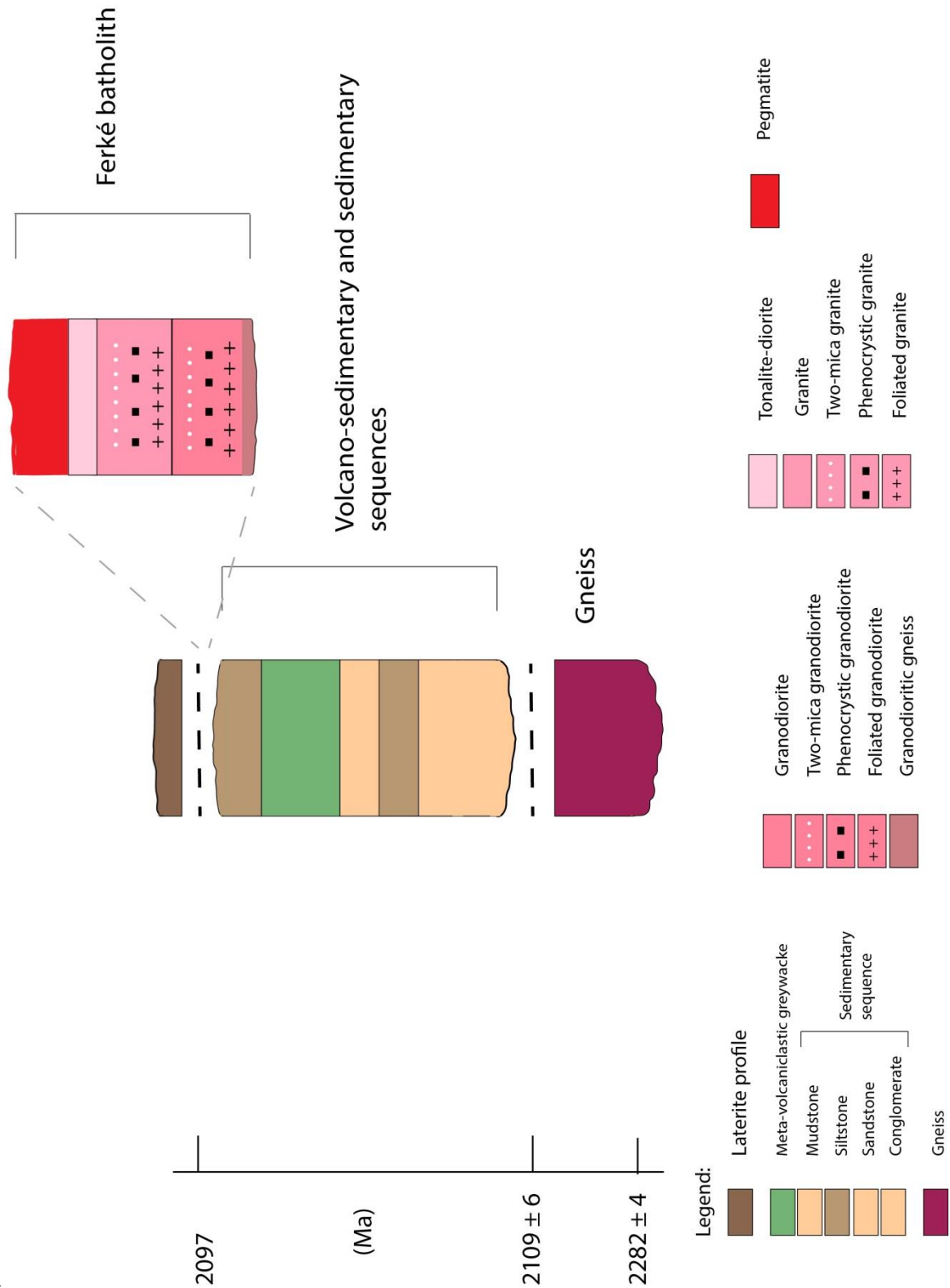


Figure 4.2: The main stratigraphic units and their age correlation for the north-central Ivory Coast. Gneiss is unconformably overlain by metasedimentary units, which are intruded by the Ferké Batholith. The age of 2097 Ma gives maximum age of sedimentation for volcano-sedimentary and sedimentary sequences.

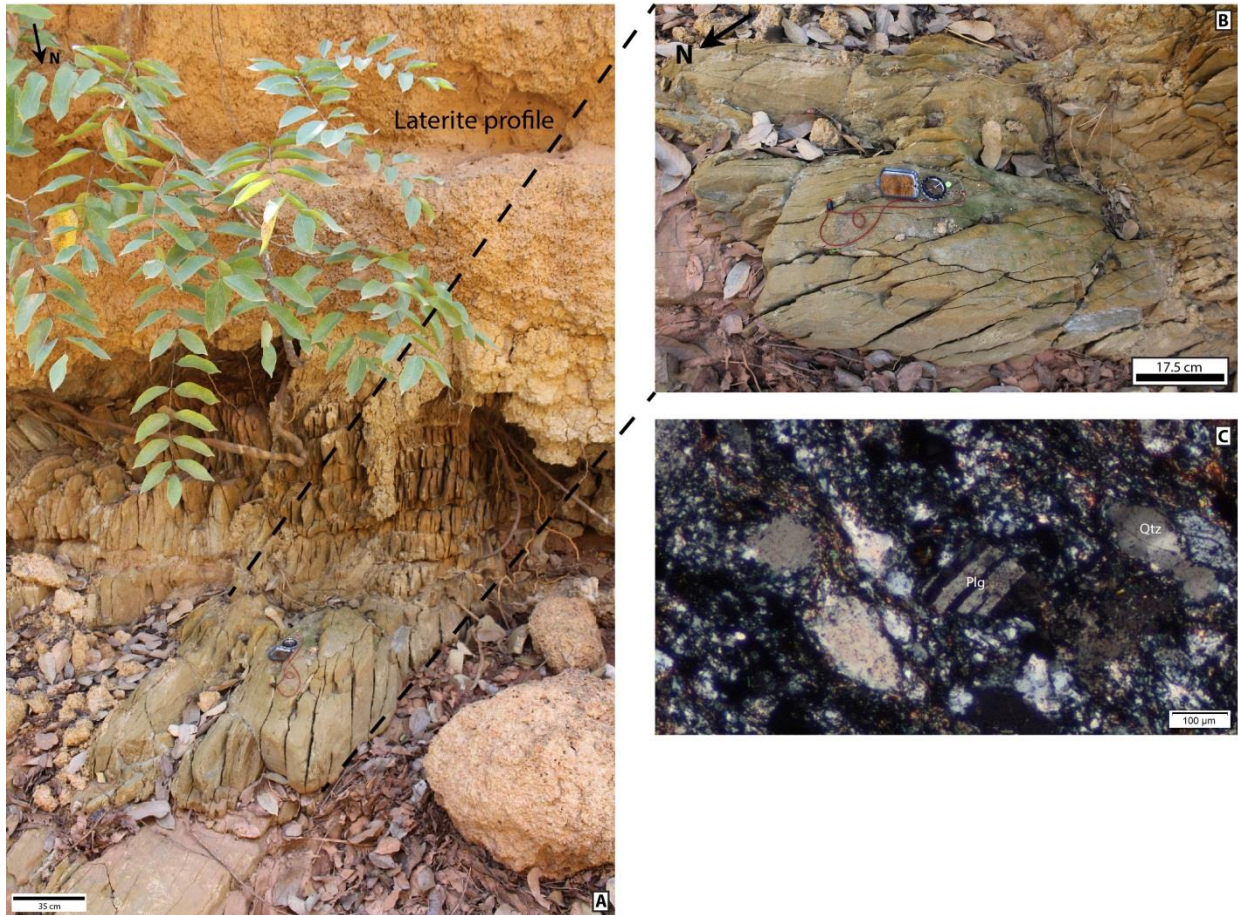


Figure 4.3: Meta-volcaniclastic greywacke. **(a)** Outcrop with laterite profile overlaying the unit in the gully. The laterite profile is ~8-10 m thick. **(b)** The unit crosscut by foliation and fracture cleavage. **(c)** Photomicrograph showing clasts of plagioclase (Plg) and quartz (Qtz) in a fine matrix. Matrix comprises of aggregates of plagioclase, quartz, and chlorite (UTM 30P, 0227014, 966977).

4.2.2.2 Conglomerate-sandstone-siltstone-mudstone succession

The conglomerate-sandstone-siltstone-mudstone succession is intruded by the Ferké Batholith and extensively crops out at the margins of the batholith. It is crosscut by the mylonite-schist zone along the contact (Figure 4.1). The succession forms part of the Bandama sedimentary basin (Doumbia et al., 1998; Pouclet et al 2006).

The most dominant unit of the succession is the meta-siltstone. The unit is composed of silt-sized particles of quartz, biotite ± muscovite ± chlorite and clay material. It is generally schistose but the relict bedding of sedimentary protolith is generally recognisable in outcrop scale. Structurally, the compositional layering is parallel to the foliation. Tight folding is pervasive near the mylonite-schist zone. The unit is commonly crosscut by sheeted quartz veins

in some areas (Figure 4.4) and brecciated quartz-tourmaline-ankerite veins. Twenty metres east of Tortiya, the unit is crosscut by 1-1.5m thick buck quartz veins.



Figure 4.4: Metasilstone with well-developed foliation, moderately to steeply dipping to the east crosscut by sheeted quartz (highlighted in red) veins that are parallel to the foliation (UTM 30P, 0237961, 1031155).

The conglomerate-sandstone-siltstone-mudstone succession is interbedded and crops out extensively in the Tortiya region, west of the study area (Figure 4.1). The conglomerate unit is polymictic and matrix-supported. The matrix is composed of medium- to fine-grained sandstone, siltstone and mudstone particles. The clasts are composed of up to 3 cm pebbles of gneiss, quartz vein clasts and lithic fragments (Figure 4.5a and b). The sandstone unit has a grain size <2 mm and is composed of quartz, plagioclase and lithic fragments. The thickness of the sandstone unit in the succession varies from 1-10m. The siltstone unit is composed of silt-sized quartz and finer material (clay minerals). It has the thickness of up to 15m and commonly crosscut by boudinaged-sheeted veins. The mudstone unit is very fine-grained and composed of clay-rich to kaolinitic material. This thickness of the mudstone unit ranges from 3-5m. The sequence in the Tortiya region is fining towards the east (Figure 4.5a). Structurally, it is folded and crosscut by sheeted quartz veins and fractures.

The succession in the Niakaramandougou region, in east of the study area, exhibits similar characteristics as the sequences in the Tortiya region (Figure 4.6). The sandstone and siltstone units are interbedded with clay-rich material (mudstone). The compositional layering is preserved and it is parallel to the foliation. Structurally, the succession is folded and crosscut by 1-17cm thick quartz veins, fractures and fines towards the east.

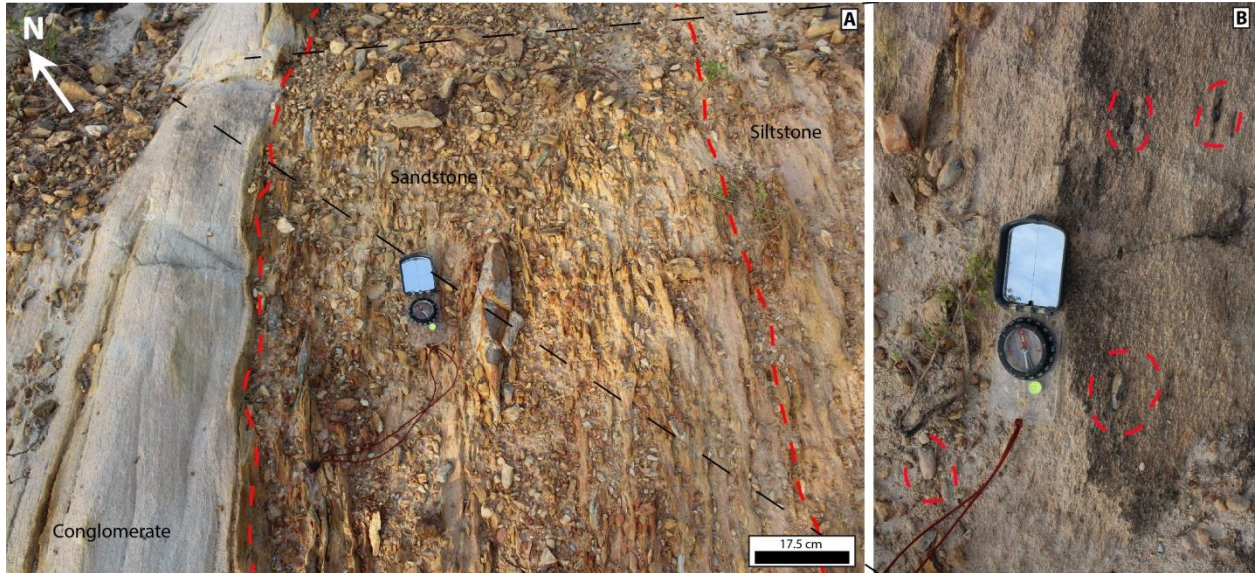


Figure 4.5: Conglomerate-sandstone-siltstone-mudstone succession. (a) Succession showing contacts, foliation and quartz veining. (b) Conglomerate showing polymict pebble-sized clasts of gneiss, quartz vein clasts and lithic fragments. In places, the clasts have been eroded away (UTM 30P, 0205660, 970152).



Figure 4.6: Interbedded succession crosscut by foliation, sheeted veins (highlighted in red) and fractures. Some of the veins are parallel to the foliation (UTM 30P, 0205713, 970074).

4.2.3 Intrusive units

Intrusive rocks comprising the Ferké Batholith crop out extensively in central portion of the study area. The eastern part of the batholith is predominantly granitic, the central part of the batholith is generally granodioritic and towards the western margin of the batholith, the texture is gneissic (Figure 4.1). Some plutons intrude in the external parts of the Ferké Batholith. “External parts” are herein referred to as part of the study area outside of the defining mylonite-schist zones.

4.2.3.1 *Ferké Batholith*

4.2.3.1.1 *Granodioritic gneiss*

Granodioritic gneiss unit frequently crops out in the western portion of the batholith (Figure 4.1). The unit is exposed as 1-2 metre light greyish, medium- to coarse-grained outcrops along the floodplain and along the roadsides. The outcrop ~18km southwest of Tafiré is intruded by granodiorite (Figure 4.7a and c). The unit has equigranular texture with mineral segregation of mafic and felsic minerals defining 0.5-1cm leucocratic and melanocratic bands (Figure 4.7b).

Mineral composition defining leucocratic bands are medium to coarse-sized (0.5-1cm) in hand specimen. Under microscope (Figure 4.7d), it shows equigranular texture with leucocratic bands defined by plagioclase, quartz and orthoclase, accounting for 70% of the rock. Melanocratic bands are defined by biotite and hornblende, these minerals account for 30% of the rock. It is crosscut by fractures and 5-4cm pegmatite veins composed of plagioclase, quartz, tourmaline, biotite, muscovite and K-feldspar. In places the unit is intruded by Pegmatite (subsection 4.4.1.5).

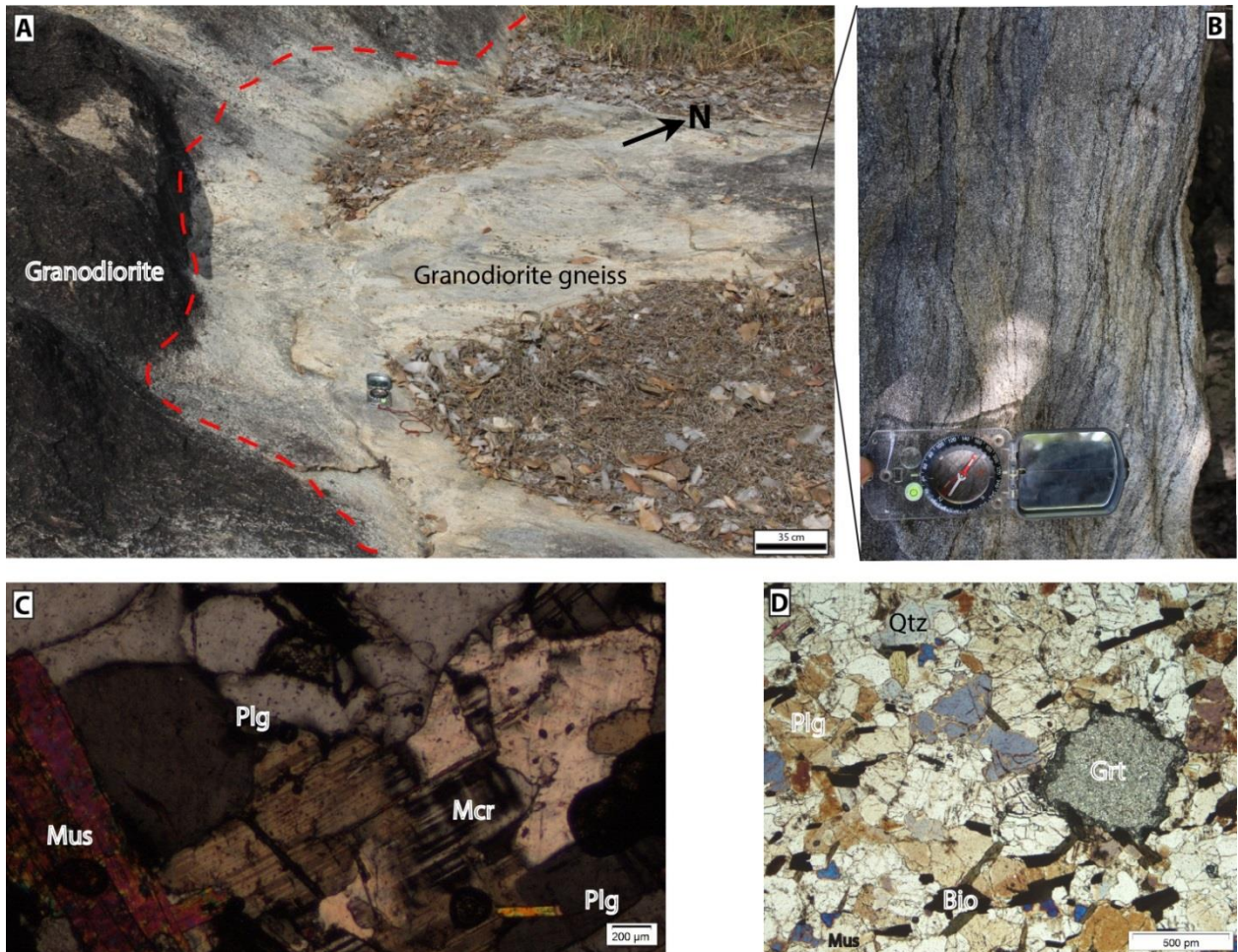


Figure 4.7: (a) Granodiorite gneiss intruded by granodiorite, the contact is marked by the red line. (b) Granodiorite gneiss showing mineral segregation and development of melanocratic and leucocratic bands (UTM 30P, 0238713, 984648). (c) Photomicrograph of granodiorite showing crystals of plagioclase (Plg) and muscovite (Mus). (d) Photomicrograph of granodiorite gneiss showing aligned biotite and a skeletal garnet porphyroblast. Mcr: microcline, Bio: biotite, Qtz: quartz.

4.2.3.1.2 Granodiorite

Granodiorite units predominantly crop out from the western to central parts of the batholith. The unit crops out as an intermediate coloured, medium to coarse-grained intrusive rock. The main constituent minerals of the unit include plagioclase (35%), hornblende (10%), quartz (30%), microcline (10%), muscovite and biotite (15%). The texture and mineral grain-size of the unit varies across the study area.

The outcrops in the western parts of the study area in [Figure 4.1](#) are light greyish in colour and predominantly contain up to 2cm crystals of plagioclase (albite). At outcrop scale, the unit has well-developed and penetrative foliation. The penetrative foliation is clearly defined by mica

and hornblende minerals. The unit is here termed *Foliated granodiorite*. In places, it crosscut by fractures, boudinaged pegmatite and albite veins (Figure 4.8a). The mineral composition under the microscope includes plagioclase (30%), quartz (30%), muscovite (15%) hornblende (15%) and biotite (5%) and ~5% microcline (Figure 4.8b).

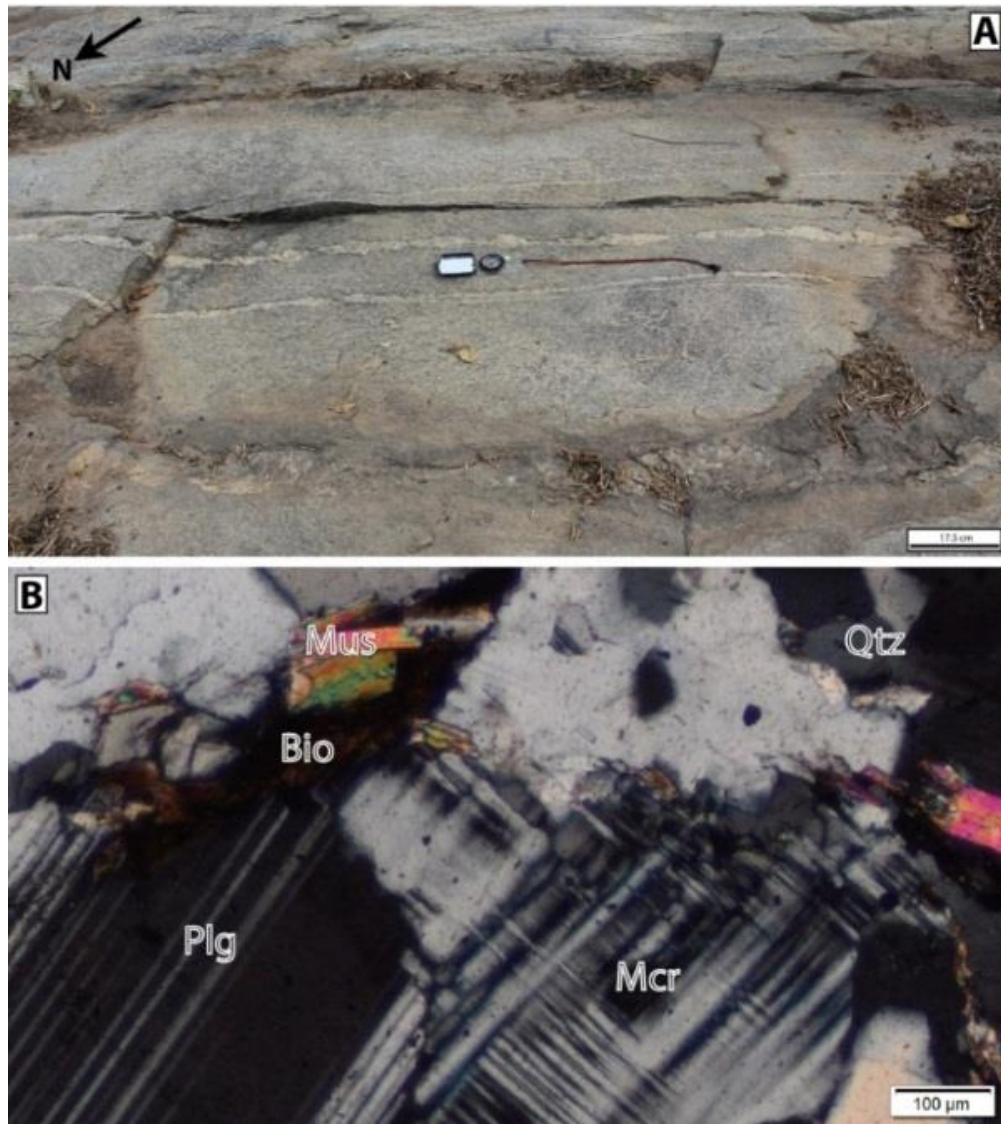


Figure 4.8: (a) Foliated granodiorite crosscut by a set of parallel boudinaged albite-quartz vein (UTM 30P, 0270514, 1075133). (b) Photomicrograph showing plagioclase (Plg) and unhedral microcline (Mcr) phenocrysts. Quartz (Qtz), biotite (Bio) and muscovite (Mus) constitute groundmass.

The outcrops in the southern parts of batholith are dominated by 2-4cm zoned phenocrysts of plagioclase feldspar and contain mafic enclaves (biotite and hornblende) (Figure 4.9a, b and 4.10). Microscopically, the composition mineralogy includes quartz (40%), plagioclase (25%),

muscovite (10%), biotite (10%), chlorite (10%) and ~5% of hornblende (Figure 4.9b). The unit is here termed *Phenocrystic granodiorite* due to its nature and appearance. At outcrop scale, the unit is crosscut by foliation, conjugate shear fractures and 1-5cm thick quartz veins. The foliation is defined by biotite, muscovite and hornblende minerals.

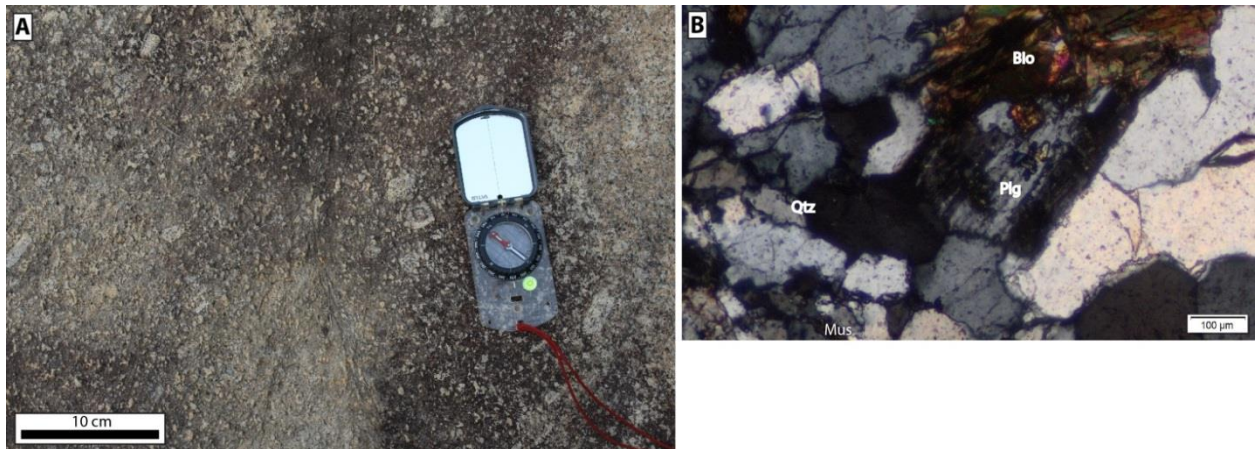


Figure 4.9: (a) Phenocrystic granodiorite with 2-4cm phenocrysts of plagioclase feldspar (UTM 30P, 0184243, 905196). It is crosscut by thin shear bands. (b) Photomicrograph showing phenocrysts of quartz (Qtz) and plagioclase (Plg) with inclusions of biotite and muscovite.



Figure 4.10: Mafic xenolith in granodiorite. Xenolith is composed of biotite and hornblende minerals. Long axis of the xenolith is sub-parallel to foliation (UTM 30P, 0184243, 905196).

The unit cropping out in eastern edge of the batholith is exposed as 10-20 metre light to dark greyish outcrops. In this region, phenocrysts of muscovite and biotite (1-3cm) are predominant and the unit contains 2-5cm mafic xenoliths (Figure 11a and b). Microscopically, constituent minerals include phenocrysts of slightly altered biotite (10%) and muscovite (10%). Other main minerals are the coarse groundmass of plagioclase (35%), quartz (20%), microcline (10%) and 5% of hornblende (Figure 11c). Ten (10) percent is constituted by perthite in plagioclase, sericite and chlorite. The unit is here termed *Two-mica granodiorite*. At outcrop scale, it is crosscut by foliation, fractures, quartz-tourmaline-biotite veins and deformed pegmatite veins.

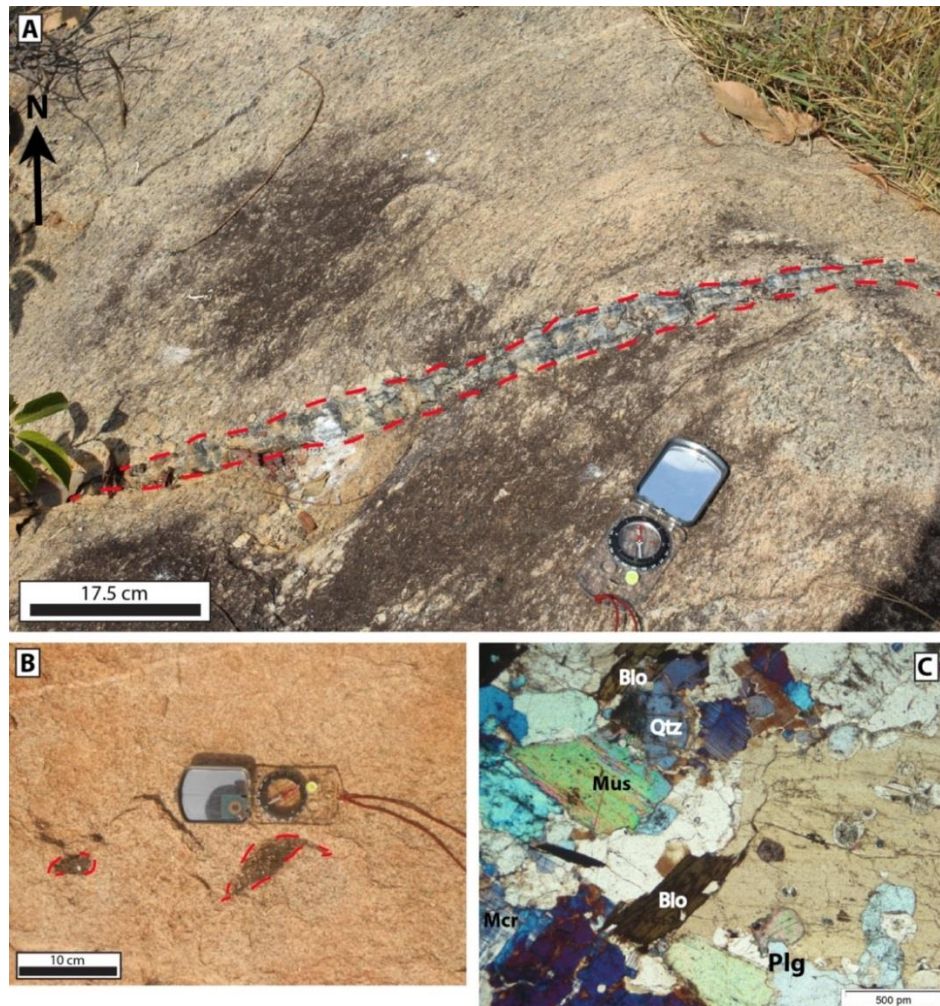


Figure 4.11: (a) An outcrop of two-mica granodiorite with foliation clearly visible and crosscut by quartz-plagioclase-tourmaline-biotite veins. (b) The mafic xenoliths (2-5cm) within the mica dominated granodiorite (UTM 30P, 0276722, 1011939). (c) Photomicrograph abundant phenocrysts of mica minerals (biotite and muscovite).

4.2.3.1.3 Granite

Granite predominantly crops out in the eastern part of the batholith (Figure 4.1). It is exposed as light grey to light pink outcrops, scattered around at 50-100 metre radius, mostly along the road. At outcrop scale, the unit is typically coarse grained, containing phenocrysts of plagioclase, pale-pink K-feldspar and quartz (2-3cm). Coarse-grained groundmass consists of pale-pink orthoclase, chalky plagioclase (albite or andesine), quartz, biotite and muscovite. Granite varies in grain-size and texture along the margin of the batholith.

The unit cropping out in the east-central part of the batholith predominantly contains 2-4 cm phenocrysts of K-feldspar, here termed *Phenocrystic granite* (Figure 4.12a). Towards the margin of the batholith, the unit composition grades into medium crystals of 3 mm and finer composition. The finer composition is here termed *Microgranite* (Figure 4.12a). The mineral composition includes K-feldspar (40%), plagioclase (20%), quartz (20%) and hornblende (15%). Biotite and muscovite constitute ~5% of the unit (Figure 4.12b). Structurally, the unit is intensely strained, crosscut by pervasive foliation and cm-m scale mylonite zones. Microgranite is ~10-15 metre wide and then grades into coarser composition (phenocrystic granite) towards the margin. Phenocrystic granite is crosscut by the mylonite-schist zone, quartz veins and fractures.

The unit cropping out in the south-east margin of the batholith is dominated by 2-3cm phenocrysts of muscovite and biotite (Figure 4.13a and b). In places, the unit contains 3-20cm mafic xenoliths. The unit is here designated as *Two-mica granite*. The groundmass is coarse (0.5-1cm) plagioclase, hornblende, quartz, K-feldspar, muscovite and biotite. Microscopically, it shows seriate texture dominated by plagioclase and mica phenocrysts (Figure 4.13c). Mineral composition includes 25% of K-feldspar, plagioclase (25%), hornblende (5%), quartz (20%), muscovite and biotite (20%). Chlorite, perthite and opaque minerals constitute ~5%. Chlorite is replacing biotite; biotite contains pleochroic halos around inclusions of zircons. K-feldspar is showing strings of perthite. Quartz shows undulatory extinction. At outcrop scale, the unit is crosscut by penetrative foliation defined by mica and hornblende minerals. A set of fractures and 5-10cm pegmatite veins crosscut the unit. Veins are composed of 0.5-1cm plagioclase, tourmaline and quartz.

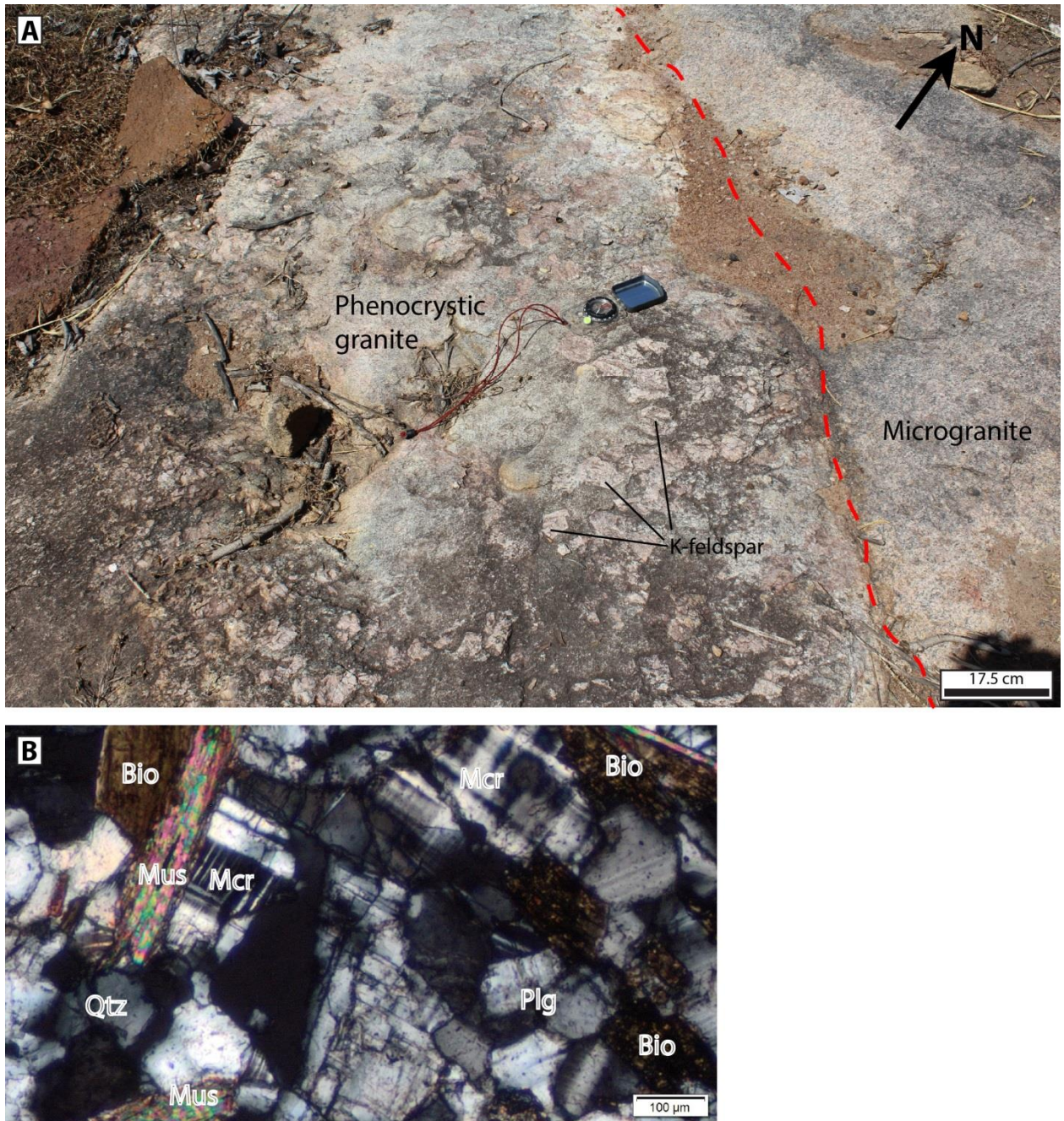


Figure 4.12: (a) Phenocrystic granite representing (2-4cm) K-feldspar phenocrysts. **(b)** Microgranite is characterised by the finer granitic composition. Microcline (Mcr) dominated photomicrograph showing quartz (Qtz) and plagioclase (Plg) constituting a coarse groundmass (UTM 30P 0291266, 1046163).

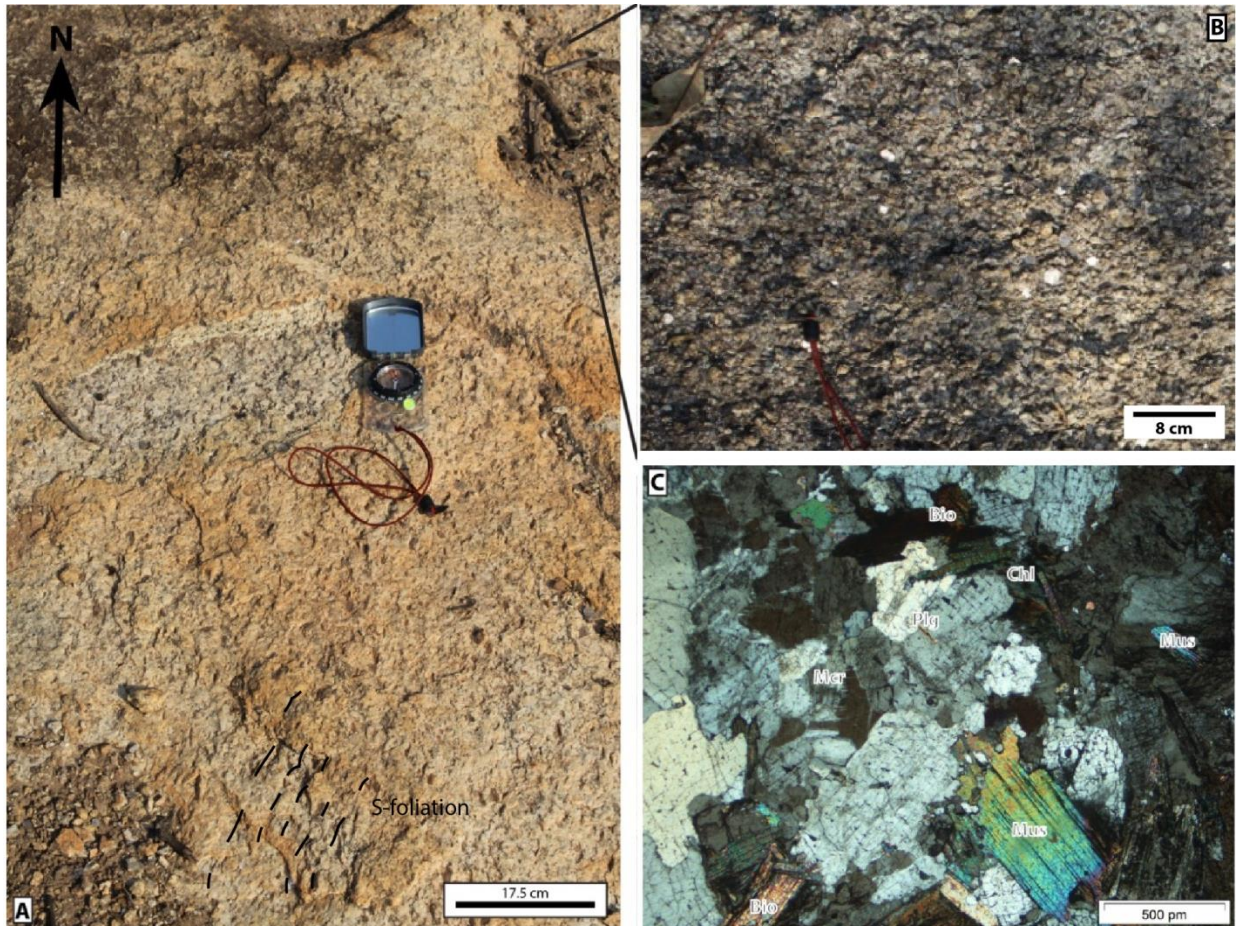


Figure 4.13: (a) An outcrop image of two-mica granite with (b) clearly showing domination of biotite and muscovite phenocrysts and the foliation (UTM 30P, 0230076, 966097). (c) Photomicrograph showing phenocrysts of muscovite (Mus), biotite (Bio) and plagioclase (Plg). Chlorite (Chl) replacing biotite (Bio) is the indication of metamorphism.

4.2.3.1.4 Tonalite

The tonalite unit predominantly crops out in the north eastern margin of the batholith. It is equigranular, medium-grained (1 cm) and crops out in several localities across the study area due to compositional grading to/from granite and granodiorite. At outcrop scale, it is crosscut by penetrative foliation and pegmatite veins (Figure 4.14a). The veins are folded, coarse and composed of up to 3 cm plagioclase, tourmaline, quartz and 2-4 cm biotite. Towards the margin of the batholith, it is crosscut by fractures that contain very fine to glassy material. Tonalite under microscope is composed of plagioclase (40%), quartz (20%), microcline (15%), hornblende (5%) muscovite (10%) and ~ 10% of biotite (Figure 4.14b).

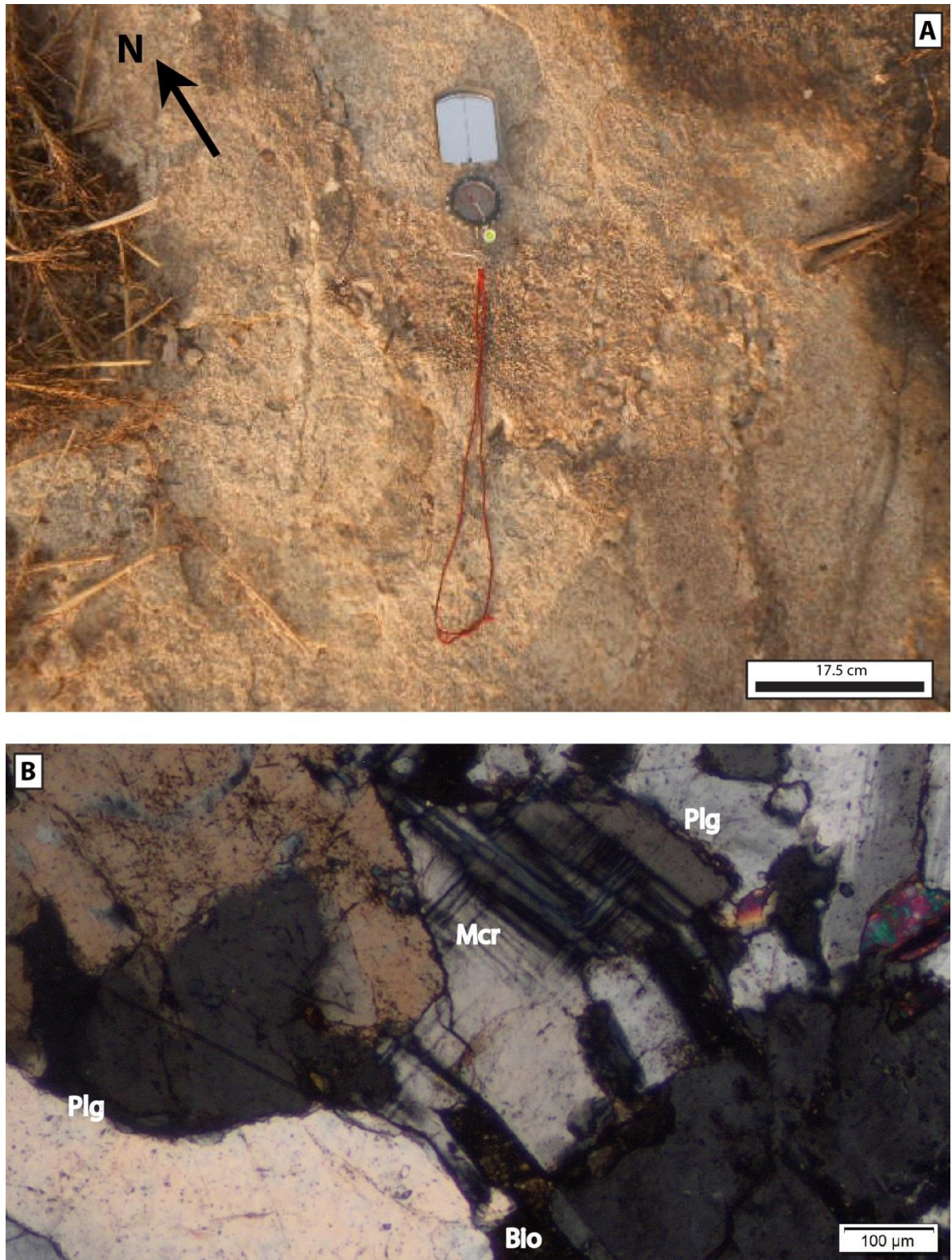


Figure 4.14: (a) Tonalite crosscut by folded quartz-plagioclase-tourmaline-biotite veins with northeast trending fold axes (UTM 30P, 0288563, 1046770). (b) Plagioclase (Plg) dominated photomicrograph showing biotite (Bio) and microcline (Mcr) as coarse groundmass. Fine groundmass comprises of chlorite (Chl), muscovite (Mus), quartz (Qtz) and biotite.

4.2.3.1.5 Pegmatite

The pegmatite unit crops out as light-greyish large (100 - 500m long) coarse-grained (2-4cm) bodies containing granodioritic and gneissic xenoliths. It is composed of 2-4cm plagioclase grains, K-feldspar, quartz and hornblende. Pegmatite cropping out in the north-western portion of the batholith (~ 10km east of the town of Ferkessédougou) is dominated by gneissic granodiorite xenoliths (Figure 4.15a). Pegmatite unit has a composition that is similar to granite with abundant quartz, feldspar, mica and green apatite (Figure 4.15b). Microscopically, plagioclase and quartz constitute ~ 90%. Muscovite and hornblende make up 10% of the unit (Figure 4.15c). At outcrop scale, the grainsize increases towards the east and is crosscut by pegmatite veins, penetrative and gneissic foliation. Veins vary in composition, plagioclase-tourmaline-quartz veins are crosscut by plagioclase (albite)-quartz veins. Penetrative foliation crosscuts all the veins in the region.

The unit cropping out near the Tortiya region, west of the study area (Figure 4.1), is exposed as a 500 m wide pluton. It intrudes the gneiss and contains gneissic xenoliths (Figure 4.16a). Under microscope, it is composed of quartz (30%), plagioclase (~30%), biotite (15%), microcline (15%), hornblende (5%) and 5% of muscovite, (Figure 4.16b). At outcrop scale it is crosscut by foliation, fractures, boudinaged plagioclase-quartz veins as well as en-echelon pattern. The foliation is non-penetrative and it is parallel to gneissic foliation.

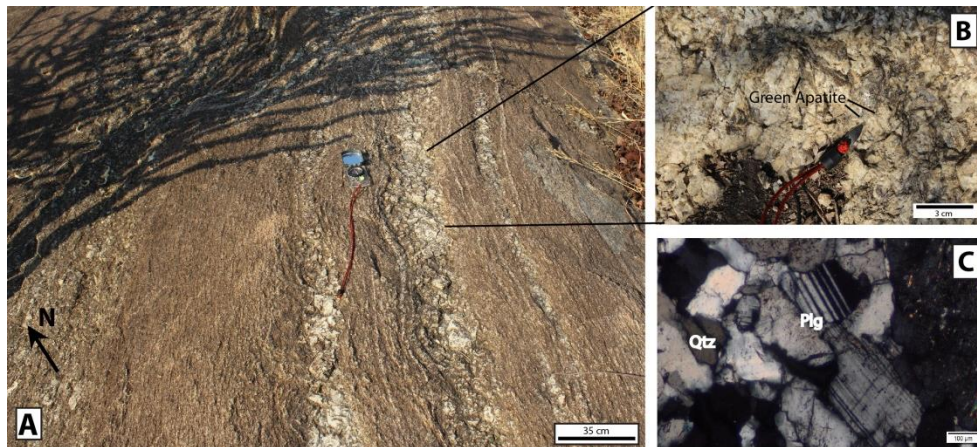


Figure 4.15: (a) Pegmatite (~ 10km east of the town of Ferkessédougou) containing gneissic xenoliths and crosscut by boudinaged veins. Veins are parallel to gneissic foliation (UTM 30P, 0275402, 1065296). (b) Zoomed-in picture of the pegmatite showing green apatite crystals (c) Aggregates of muscovite (Mus) making up groundmass for quartz (Qtz) and plagioclase (Plg) phenocrysts.

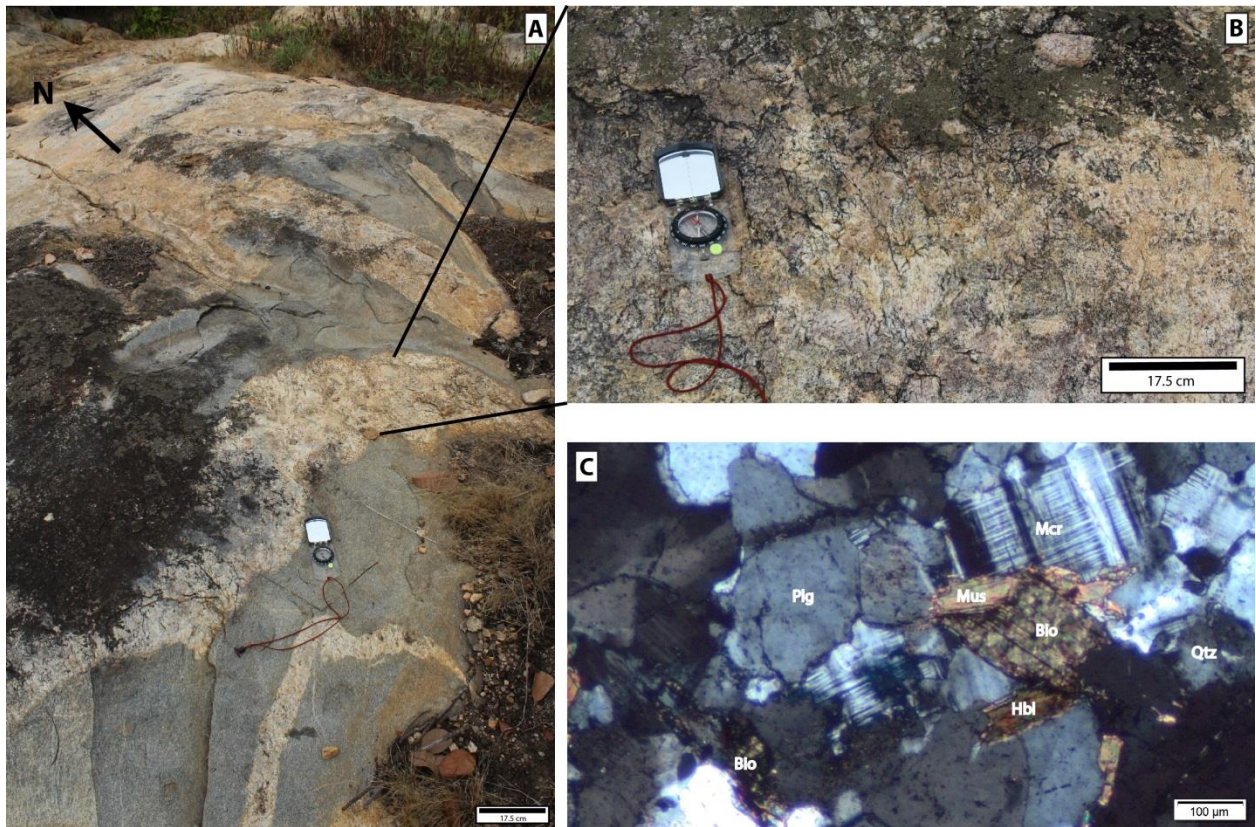


Figure 4.16: (a-b) Pegmatite cropping out near the Tortiya region, crosscutting gneiss. It contains gneissic xenolith and composed of phenocrysts of quartz and plagioclase (UTM 30P, 0208730, 969100). (c) Photomicrograph dominated by phenocrysts of plagioclase (Plg) and microcline (Mcr).

4.2.4 Intrusive units proximal to the Ferké Batholith

4.2.4.1 Granodiorite

The granodiorite crops out extensively in the western portion of the study area, ~10km east-southeast of the town of Korhogo. The unit is exposed in the field by the road-side as a light-to dark greyish unit. It is dominated by 2 cm phenocrysts of hornblende (Figure 4.17a). The coarse groundmass (0.5-1cm) is composed biotite, muscovite, plagioclase and quartz. Microscopically, it has plagioclase (30%), quartz (25%), hornblende (20%), biotite (10%), microcline (5%), muscovite (5%) and 5% of chlorite (Figure 4.17b). At outcrop scale, the unit is crosscut by weak foliation and 1-3cm thick veins. These veins are composed of plagioclase, K-feldspar and hornblende.

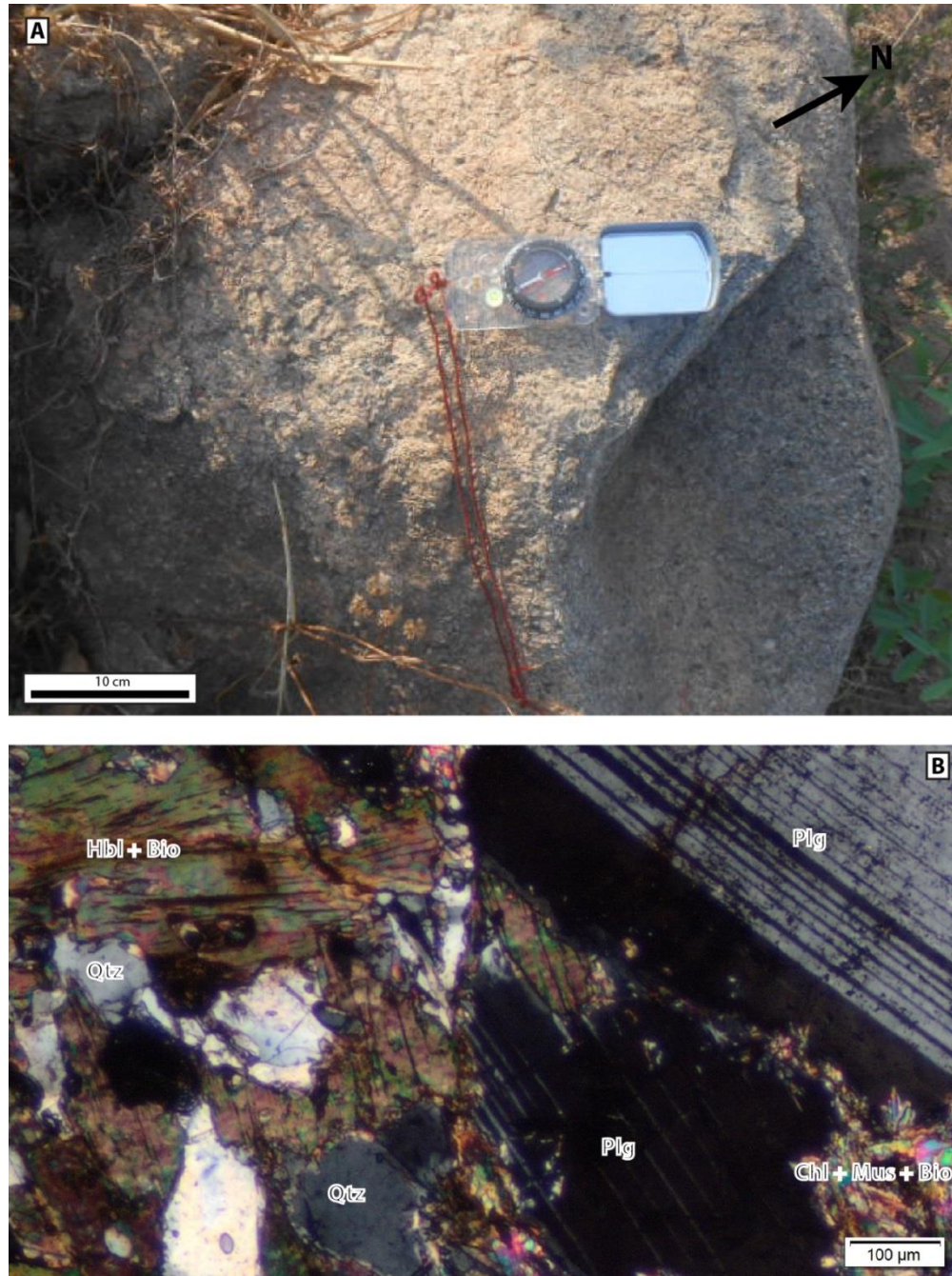


Figure 4.17: (a) Granodiorite (~10 km east-southeast of the town of Korhogo) dominated by 2 cm phenocrysts of hornblende (UTM 30P, 0218508, 1039917). **(b)** Photomicrograph showing phenocrysts of hornblende (Hbl), euhedral plagioclase (Plg) and biotite (Bio). Groundmass comprises of quartz (Qtz), muscovite (Mus), quartz (Qtz) and biotite.

4.2.4.2 Diorite

The unit crops out to the east of the study area, ~5km west of the village of Sekolo. It is exposed as a speckled black and white "salt and pepper" rock in the bushes by the road side (~20m from the A12 road). It is dominated by 2-2.5cm phenocrysts of hornblende and

plagioclase (Figure 4.18a). The groundmass is composed of quartz, plagioclase, hornblende and biotite. Under microscope, the composition consists of hornblende (40%), plagioclase (30%), biotite (20%) and 10% of quartz (Figure 4.18b). At outcrop scale, the unit intrudes the metasedimentary sequences and is crosscut by well-developed foliation, fractures and pegmatite veins (1-3cm). Pegmatite veins are composed of biotite, muscovite, quartz and hornblende.

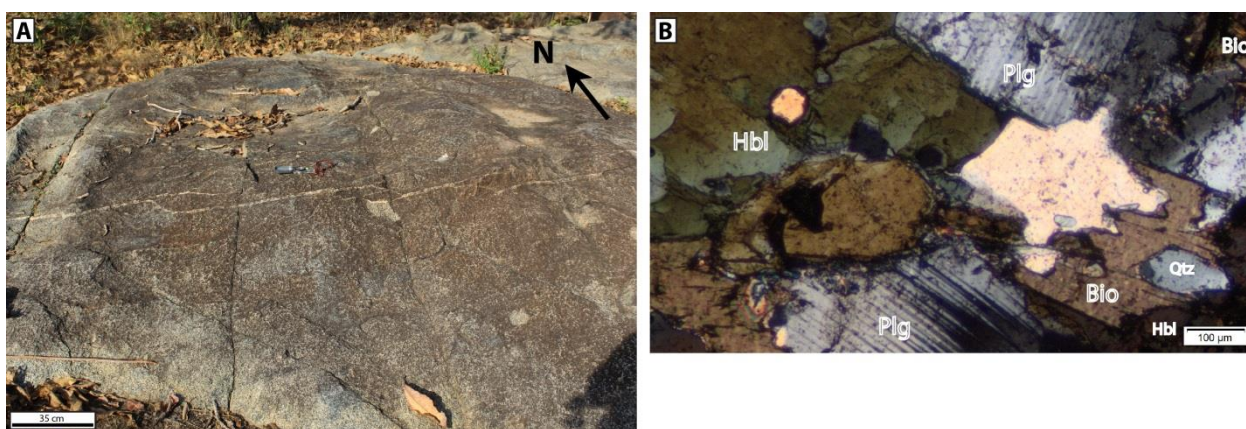


Figure 4.18: (a) Diorite outcrop crosscut by fractures and a set of right-stepping en echelon veins (UTM 30P, 0303380, 1044962). (b) Photomicrograph showing phenocryst of hornblende (Hbl) and subhedral plagioclase (Plg). Hornblende is anhedronal and pleochroic from darker to lighter green.

4.3 Geochemical and Geochronological studies

Geochemical and geochronological studies across the Baoulé-Mossi domain of the WAC have been essential in classification of rock units and timing the absolute age of geological events. These geological events include crystallisation, metamorphism, mineralisation and deformation phases, which can be distinguished by isotopic ages from specific samples, gathered from batholiths, greenstone belts, plutons and individual igneous bodies. Previous geochronological analyses for intrusive rocks from the Baoulé-Mossi domain include mainly zircon U–Pb and Pb–Pb ages (Leube et al., 1990; Hirdes et al., 1992; Davis et al., 1994; Pons et al., 1995; Doumbia, 1997; Doumbia et al., 1998; Egal et al., 2002; Gasquet et al., 2003; Castaing et al., 2003; Naba et al., 2004; Lompo, 2009; De Kock et al., 2011, 2012; Tapsoba et al., 2013a, 2013b and Tshibubudze et al., 2013).

During field work, specific samples were selected for absolute geochronology, principally to constrain the relative chronologies and information gathered in the north-central Ivory Coast

(Figure 4.19). Geochronological studies undertaken from the selected intrusive rocks in the northern region of Ivory Coast include:

- [Gasquet et al. \(2003\)](#) have reported inherited zircon U-Pb ages of 2162 ± 32 and 2154 ± 1 Ma for granitoids (Dabakala region). This study shows that these granitoids are syntectonic and do not correspond to reworked pre-Birimian crust.
- [Lüdtke et al. \(1999, 1998\)](#) and [Hirdes et al. \(1996\)](#) attained zircon U-Pb ages of 2152 ± 3 Ma for granodiorite intrusion (east of Téhini belt) and 2152 ± 2 Ma for the oldest granodiorites (west of the Wango-Fitini belt). This data is interpreted to represent crystallisation ages.
- Granitoids in Marabadiassa-Katiola region yield 2137 ± 9 Ma ([Hirdes et al., 1996](#)) and 2123 ± 3 Ma ([Doumbia et al., 1998](#)) which represent a minimum estimate for crystallisation of the rocks.
- [Doumbia et al. \(1998\)](#) reported a magmatic emplacement age of the Ferké leucogranite at 2094 ± 6 Ma (monazite Pb-Pb).

Previous whole-rock geochemical investigations on the rocks from the northern Ivory Coast have emphatically revealed an evolution of the magma genesis in relationship with the regional geotectonic history ([Doumbia et al., 1998](#); [Pouclet et al., 2006](#); [Vidal et al., 2009](#)).

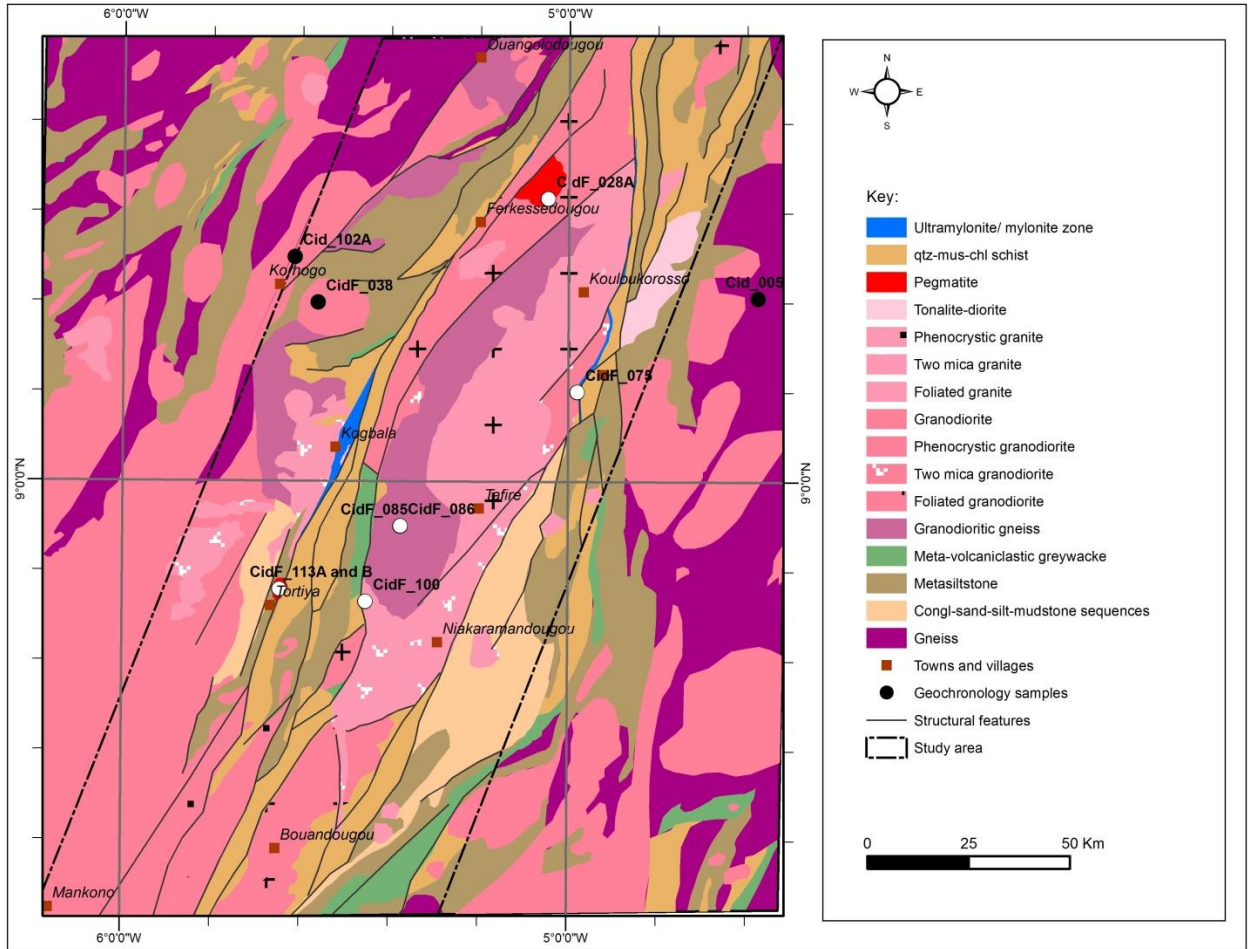


Figure 4.19: Geology map of the study area with sample location for the analysed samples. Black dots were analysed in Australia (UWA) using SHRIMP U-Pb. White dots were analysed at the University of the Witwatersrand or University of Johannesburg using LA-ICPMS U-Pb.

4.3.1 Analytical method and procedure

Zircon is an important accessory mineral in most sedimentary, igneous and metamorphic rocks. Thanks to its durability, zircon is chemically resistant, relatively insoluble and refractory (MacRae et al., 2014). It can withstand weathering, recycling, as well as high-temperature, metamorphism, anataxis and other geological events (El-Bialy and Ali, 2013). It is for these reasons that U–Pb dating of zircon is a key tool in geochronology for unravelling complex successions of magmatic and metamorphic events in terranes. According to Valley (2003), zircon can provide reliable and robust estimates of age, compositions of coexisting minerals, melts and constraints on the petrogenesis of host rocks.

Six samples were selected for geochemical and geochronological studies. Each sample was crushed, milled and portions were separated for LA-ICPMS and XRF analysis. Samples for geochronology were separated using conventional density and magnetic separation techniques, and then handpicked under a binocular microscope. Zircon grains were set in five epoxy mounts, which were then polished to expose the internal structures. Each sample was coated with carbon and the zircons were then studied under optical microscope using both reflected and transmitted light. The samples Cid_F 028A, Cid_F 100, Cid_F 113A and Cid_F 113B plotted in [Figure 4.19](#) were also documented in scanning electron microscope (SEM), using cathodoluminescence (CL) and backscattered-electron (BSE) to reveal their external and internal textures. The SEM instrument used was a TESCAN VEGA3 SB EasyProbe, carried out in the Analytical Facility, Faculty of Science at the University of Johannesburg. [Sub-section 3.6](#) has all the itemised details of the extraction procedure, imaging, zircon analysis and data processing.

Additionally, four samples (Cid_005, Cid_102a, Cid_F 038 and Cid_F 086) were collected for geochronological studies as part of this research. However, these samples were processed and analysed by Nicolas Thebaud, a Research Associate Professor, Hammond and Nisbet Fellow at the Centre for Exploration Targeting, University of Western Australia. Therefore, the analysed data results are incorporated in this section.

A total of six samples, Cid_F 028A, Cid_F 075, Cid_F 085, Cid_F 100, Cid_F 113A and Cid_F 113B were included in a geochemical classification and nomenclature using numerous discrimination diagrams using XRF data presented in [Table 2 and 3](#).

Table 2: Table of major element composition (in wt. %) from XRF analysis data for samples selected for U-Pb geochronological and geochemical studies.

	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	Cr ₂ O ₃	NiO	LOI	Total
CidF_028A	73.77	14.56	0.30	0.01	0.06	0.39	2.68	7.53	0.02	0.27	0.01	0.00	0.60	100.20
CidF_075	72.39	14.65	1.18	0.03	0.29	0.57	3.64	4.79	0.11	0.32	0.01	0.00	0.96	98.94
CidF_085	73.51	14.90	1.01	0.01	0.17	0.46	3.81	4.49	0.05	0.41	0.01	0.00	0.83	99.66
CidF_100	71.82	14.41	1.29	0.01	0.29	0.74	3.64	5.07	0.13	0.28	0.01	0.00	0.66	98.34
CidF_113A	69.45	13.46	0.47	0.02	0.03	0.91	3.69	5.40	0.02	0.01	0.01	0.00	0.28	93.75
CidF_113B	74.39	12.60	1.51	0.03	0.16	1.33	3.98	3.34	0.11	0.03	0.01	0.00	0.19	97.69

Table 3: Table of trace element composition (in ppm) from XRF analysis data for samples selected for U-Pb geochronological and geochemical studies.

	Sc	V	Cr	Ti*	Co	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Mo	Ba	Pb	Th	U
CidF_028A	0.48	d.l.	d.l.	0.1329	0.92	3.57	5.66	4.86	16.77	375.34	90.72	4.08	11.34	3.93	0.11	274.39	32.11	d.l.	1.25
CidF_075	4.33	9.4	1.28	0.183521	1.32	2.79	17.01	31.24	17.68	257.13	90.7	6.56	60.78	8.2	1.4	295.83	19.84	2.57	3.84
CidF_085	1.73	0.49	1.19	0.023785	0.44	2.13	4.28	23.24	16.52	222.15	57.44	2.16	29.48	6.19	0.2	117.49	15.58	d.l.	1.22
CidF_100	4.77	8.5	10.9	0.250903	d.l.	2.86	18.57	37.42	20.95	255.46	134.49	3.46	79.29	5.03	0.29	394.3	21.59	3.89	3.25
CidF_113A	d.l.	2	0.64	0.176547	0.71	d.l.	4.98	4.59	20.25	268.62	67.92	7.43	29.49	6.29	0.65	197.56	45.64	10.19	22.74
CidF_113B	3.35	1.31	d.l.	0.406926	1.3	5.68	6	24.77	16.44	152.91	72	20.06	102.51	9	0.08	230.22	25.97	10.83	1.33
	d.l. - below detection limit																		
	*Ti (in wt %)																		

4.3.2 Sample SEM imaging, U-Pb Geochronology and Geochemistry

This section presents detailed characteristics of zircons in each sample that include the general morphology and internal textures from CL and BSE images. All zircons from selected samples were analysed using CL and BSE images. Black or white (no fill) circles on the CL images represent the location of the U–Pb laser spots and the concordia diagrams represent the $^{206}\text{Pb}/^{238}\text{U}$ vs $^{207}\text{Pb}/^{235}\text{U}$ data. It should be noted that most U-Pb concordia ages returned with an “uncertainty” of ± 1 Ma, the software rounds-off values such as 0.8 and 1.2 to the value of 1 Ma.

4.3.2.1 Sample Cid_F 028A

Sample Cid_F 028A is a biotite-plagioclase-quartz-hornblende-K-feldspar pegmatite with gneissic xenoliths, cropping out northeast of the town of Ferkéssédougou at UTM 30P 0275373 1065317 (Figure 4.20a). Zircon grains are generally euhedral to subhedral, sub-rounded and medium to long prismatic. They range in length from approximately 100 to 150 μm and display prominent core with variable overgrowths deduced to be inherited, because they are structurally discontinuous to the outer growth zones. Cores in CL response are showing various degrees of metamictisation (note radial fractures), ranging from dark to medium-light (Figure 4.20b and c). These cores are inclusion-rich and show distinctly oscillatory zoned rims. Mineral and melt inclusions are common in these zircons grains. Recrystallisation patches in high CL inner rims are inclusion-rich and show truncation of oscillatory-zoned inner parts. In one grain, an inherited core is identified on the basis of its bright and well-rounded appearance (Bolhar et al., 2016), the outer rim is thick with dark CL-bands indicating high growth rate.

The core analysis produced all discordant zircon data points. These define an age of 1985 ± 9 Ma that is herein deduced as crystallisation age (Figure 4.21). Core analyses on zircon no.7 yield age at 2138 ± 1 Ma (Figure 4.20b). Ages in zircon (core) no.14 (Figure 4.20c) and no.12 define younger ages at 1308 ± 1 and 1807 ± 1 Ma, respectively. Rim analyses define a weighted

mean age of 2188 ± 12 Ma (Figure 4.22) and a Pb loss line within error with a calculated upper intercept age of 2109 ± 6 Ma (Figure 4.23a). One most concordant rim data yielded an age of 2183 ± 1 Ma (Figure 4.23b).

Rims yielded older ages (2188 ± 12 , 2183 ± 1 and 2109 ± 6 Ma) than the core (2138 ± 1 , 1985 ± 9 , 1807 ± 1 and 1308 ± 1 Ma). Similar rim-core age variation was reported by Wan et al. (2011) in eastern Shandong, who referred to it as “age resetting” commonly associated with high-grade metamorphism. Metamorphism results in metamictisation of zircons which leads to alteration in zircon structure, composition and age (Bomparola et al., 2007; Geisler et al., 2007). Metamictised zircons have corroded cores with radial cracks that are fluid pathways used to flush out the U (more compatible) and Th (less compatible) to the zircon margins. Therefore, analysed laser spots define “age resetting”.

Spot numbers referring to the grain number and data are represented in Table 4. Sample Cid_F 028A obtained Th/U ratio value below 0.1 for 99% of all analysed zircons, indicating strong metamorphic origin. With regards to all other samples, Cid_F 028A show highest U (ppm) content, the lowest Th (ppm) content, hence plotting in the metamorphic field (Figure 4.35). U-Pb ages 2188 ± 12 , of 2183 ± 1 and 2109 ± 6 Ma are herein deduced to be inherited/xenocrystic zircon ages as these zircons are metamictised (Table 4). All LA-ICPMS U-Pb zircon ages regarding sample Cid_F 028A are summarised and represented in Table 8.

Geochemically, sample Cid_F 028A plots as granite (alkali-rich) in TAS for plutonic rocks diagram of Cox et al. (1979) adapted by Wilson (1989) (Figure 4.36), QAP diagram of Streckeisen (1976) (Figure 4.37a), Ab-An-Or normative triangular plot of Barker (1979) (Figure 4.37b) and in R1-R2 binary diagram of De la Roche et al. (1980) (Figure 4.38). The sample's geochemical character shows calc-alkaline affinity in AFM diagram of Irvine and Baragar (1971) (Figure 4.39a) with a very high-K character as a shoshonitic granitoid in SiO_2 vs. K_2O diagram (after Pearce et al., 1990) (Figure 4.39b), peraluminous composition in A/NK vs. A/CNK diagram of Shand (1943) adopted by Maniar and Piccoli (1989) (Figure 4.40). The sample plots in the syn-collision field on the R1-R2 major element geotectonic discrimination diagram of Batchelor and Bowden (1985) (Figure 4.41). The tectono-magmatic discrimination diagrams in Figure 4.42a and b after Pearce et al. (1984) indicate correspondence with volcanic arc and syn-

collision granites. Discrimination diagram for I- and S-type granites (after Chappell and White, 1974) defines the S-type nature (Figure 4.42c).

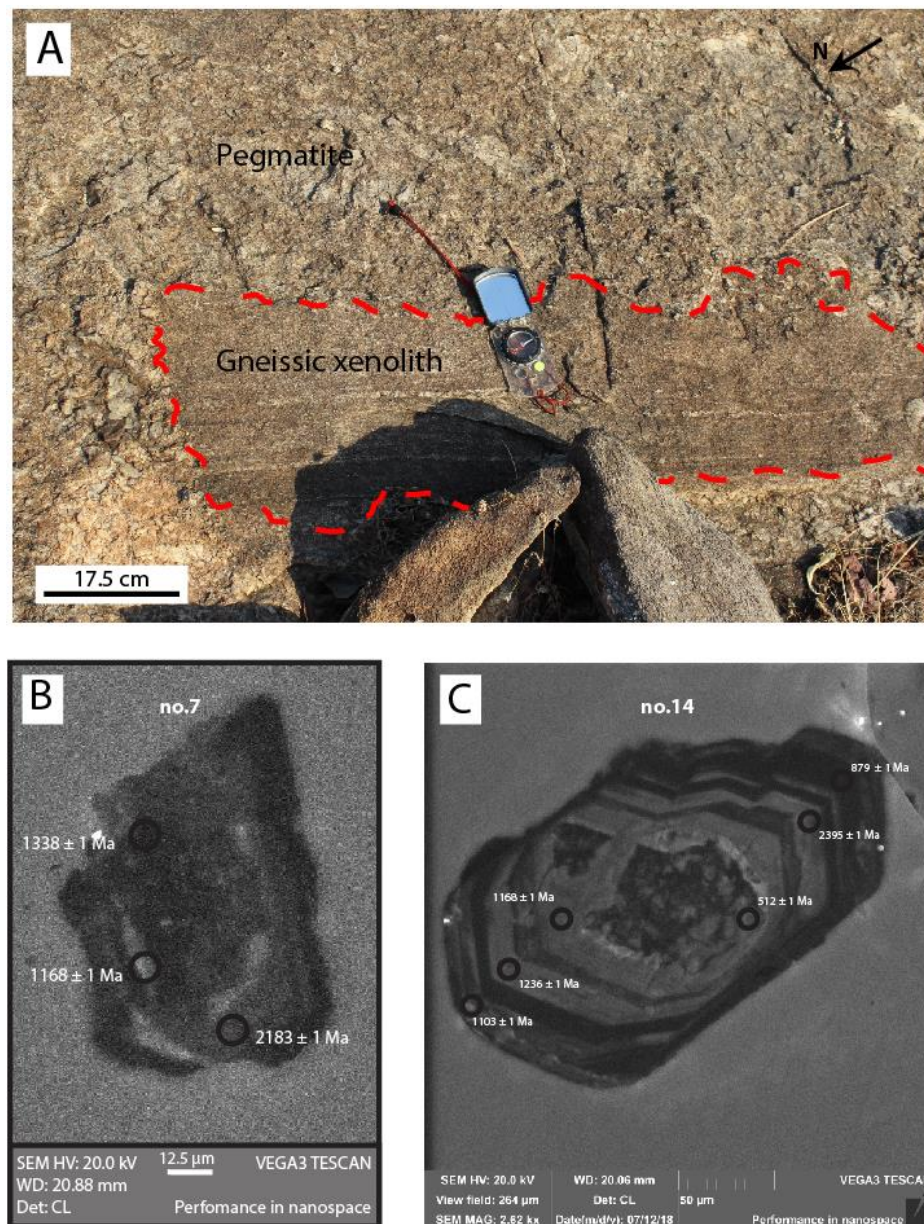


Figure 4.20: (a) Biotite-plagioclase-quartz-hornblende-K-feldspar pegmatite is cropping out in the north-western portion of the batholith (~ 10km east of the town of Ferkessédougou at UTM 30P 0275373 1065317) and contains gneissic xenoliths. (b-c) Cathodoluminescence (CL) images of the zircon grain no.7 and no.14 that were analysed and extracted from the pegmatite. They have well defined cores and oscillatory rims. Notice fractures and pores that probably mark fluid and Pb-loss paths. Circles represent U-Pb data spot that were analysed (U-Pb by LA-ICPMS, 2 standard errors).

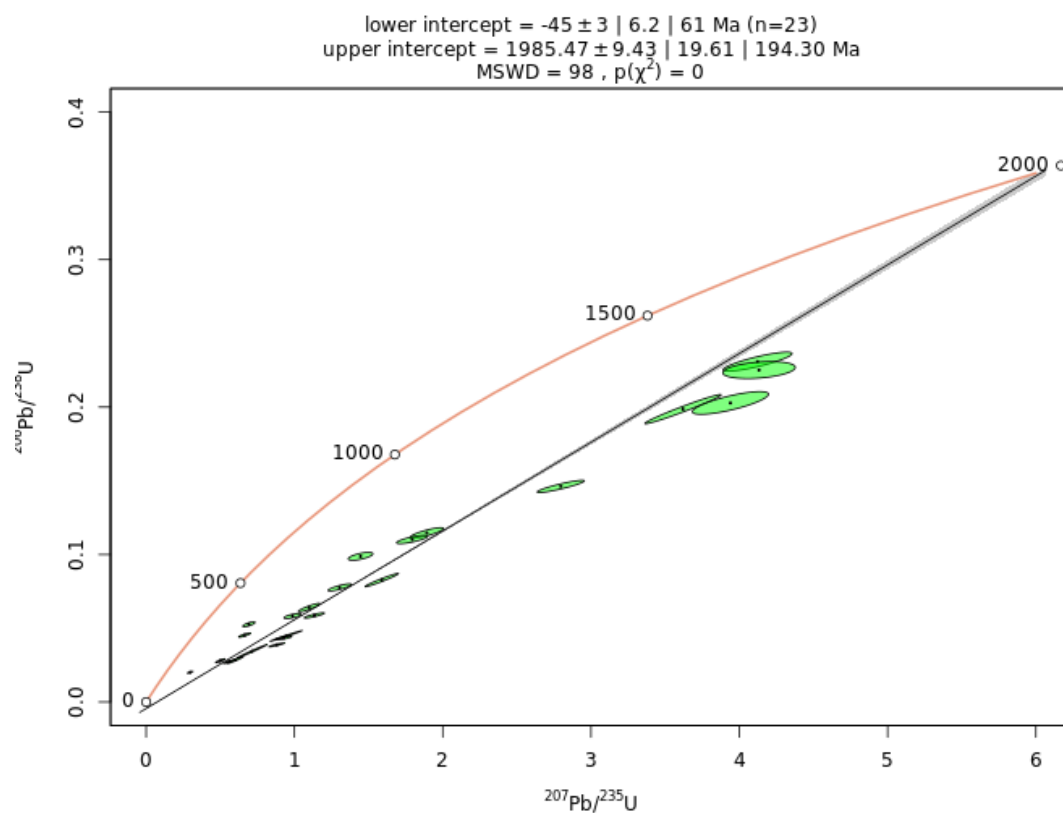


Figure 4.21: The $^{206}\text{Pb}/^{238}\text{U}$ versus $^{207}\text{Pb}/^{235}\text{U}$ Concordia diagram of the pegmatite (zircon cores).

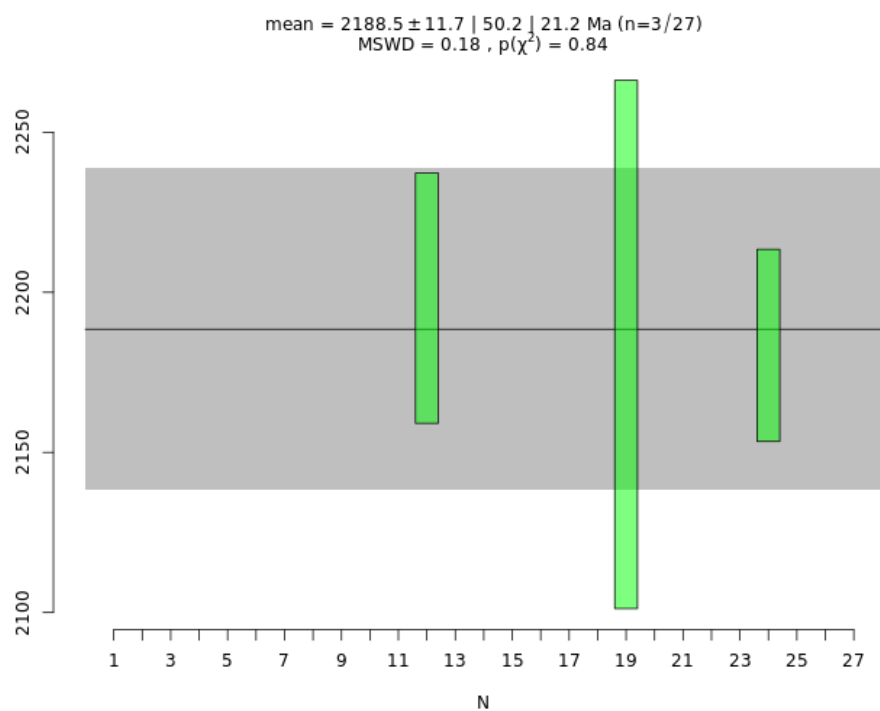


Figure 4.22: Weighted mean diagram for core spots from sample Cid_F 028A.

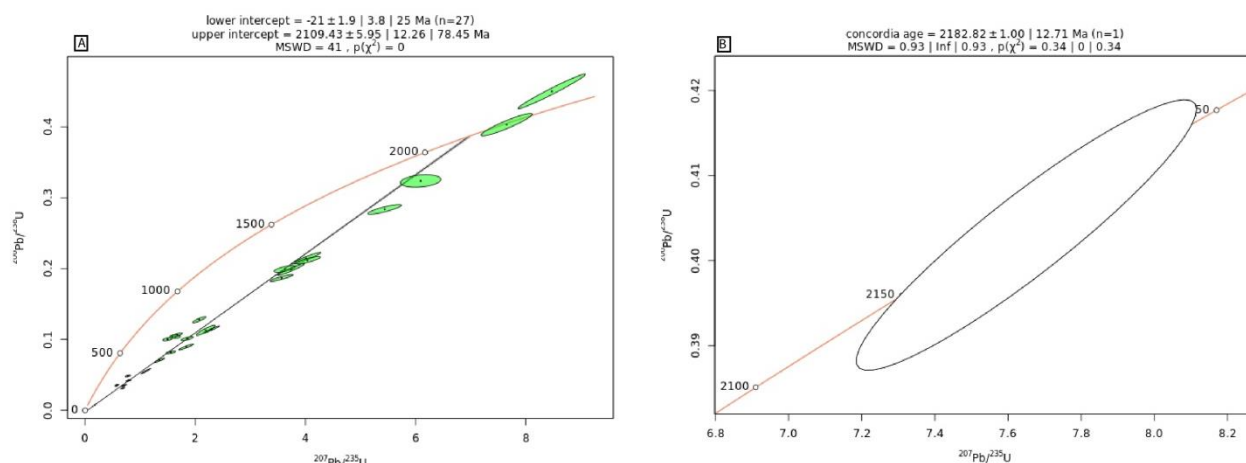


Figure 4.23: (a) The $^{206}\text{Pb}/^{238}\text{U}$ versus $^{207}\text{Pb}/^{235}\text{U}$ Concordia diagram of the pegmatite (zircon rims). **(b)** $^{206}\text{Pb}/^{238}\text{U}$ versus $^{207}\text{Pb}/^{235}\text{U}$ Concordia diagram for only the most concordant data (zircon rims).

Table 4: Summary of LA-ICPMS U-Pb zircon data, sample CidF_028A.

CidF_028	Source	U		Th/U	Pb						Error								
A Zircon	file	(ppm)	(ppm)	Ratio	(ppm)	²⁰⁷ Pb*/ ²⁰⁶ Pb ±%	²⁰⁷ Pb/ ²³⁵ U ±%	²⁰⁶ Pb/ ²³⁸ U ±%			Correlation	²⁰⁶ Pb/ ²³⁸ U	Age (Ma)	Age (Ma)	Age (Ma)	Age (Ma)	Age (Ma)	Age (Ma)	Discordant
1	3_1c1	6740	115.3	56.7	1190	0.1558	0.0063	0.601	0.045	0.0285	0.002	0.96414	181	12	470	29	2404	60	92.36
	3_1c2	5150	197.6	24.8	894	0.1516	0.0059	0.714	0.084	0.0344	0.0038	0.99376	217	23	520	43	2359	54	90.73
	3_1r1	2928	29.71	97.5	653	0.1451	0.0055	1.103	0.073	0.0553	0.003	0.98229	346	19	744	34	2287	42	84.77
	3_1r2	8300	157.1	52.4	725	0.1695	0.0067	0.1794	0.0087	0.00765	0.00017	0.67588	49.11	1.1	167.4	7.5	2548	46	98.071
2	3_2c1	4320	58.3	78.2	956	0.1492	0.0057	0.559	0.031	0.0274	0.0011	0.95407	174	7	449	20	2332	46	92.54
	3_2r1	1220	8.66	149.7	898	0.148	0.0057	1.834	0.11	0.0894	0.0035	0.93905	551	21	1048	39	2319	46	76.27
	3_3c1	5470	468	11.92	1977	0.1646	0.0063	0.881	0.044	0.03875	0.0011	0.92713	245	6.9	640	24	2502	40	90.23
3	3_3r1	1178	7.42	162.3	1585	0.13902	0.0052	5.436	0.25	0.2835	0.0056	0.85412	1608	28	1889	40	2211.2	43	27.28
	3_3r2	2950	111.3	25.66	2040	0.146	0.0055	2.293	0.12	0.1141	0.0041	0.9707	695	24	1203	38	2296.6	39	69.66
4	3_4c1	1500	25.9	57.8	323	0.1228	0.0048	0.987	0.047	0.0583	0.0014	0.69418	365.4	8.8	695.6	24	1994	40	81.61
	3_4c2	2660	83.4	29.9	365	0.1065	0.0041	0.664	0.033	0.04538	0.0012	0.87014	286	7.6	517.2	20	1738	46	83.5
	3_4r1	1346	19.5	72.4	223	0.1153	0.0045	0.776	0.038	0.04864	0.0011	0.69717	306.1	7	581.7	22	1881	43	83.68
	3_4r2	1212	115.3	10.43	319	0.1463	0.0059	0.71	0.038	0.03509	0.0011	0.84341	222.2	6.8	542	23	2304	46	90.34
5	3_5c1	1632	36.8	44	660	0.1404	0.0055	1.134	0.056	0.0587	0.0015	0.8695	367.4	9.2	769	28	2229	40	83.42
	3_5c2	1089	2.04	666	513	0.1202	0.0046	1.893	0.092	0.1147	0.0029	0.83272	699	17	1078	33	1964	52	64.3
	3_5r1	1260	2.76	584	574	0.1147	0.005	1.637	0.079	0.104	0.0021	0.055766	637.8	12	982	31	1860	69	65.19
6	3_5r2	1117	1.95	780	432	0.1082	0.0043	1.498	0.072	0.1004	0.002	0.59619	616.9	12	927	29	1765	53	64.93
	3_6c1	1629	37.1	44.1	458	0.1221	0.0047	1.305	0.064	0.0777	0.002	0.83063	482.2	12	847	29	1989	43	75.72
	3_6r1	871	4.46	220	226	0.1139	0.0044	1.671	0.08	0.1065	0.0024	0.77366	652.2	14	997	30	1863	35	64.88
7	3_6r2	2560	48.9	52.7	728	0.1353	0.0053	0.787	0.038	0.04206	0.00088	0.7352	265.6	5.4	589.6	22	2168	51	87.72
	3_7c1	1360	43.7	46.4	298	0.1291	0.0049	4.123	0.19	0.2308	0.0053	0.8495	1340	27	1656	38	2086.4	42	35.8
	3_7c2	2610	612	4.69	742	0.13239	0.0049	3.62	0.21	0.1986	0.0081	0.98044	1164	43	1542	45	2129.5	39	45.3
8	3_7r1	1790	124	20.8	651	0.1382	0.0052	7.65	0.38	0.403	0.013	0.93014	2175	59	2184	47	2208	48	1.7
	3_8c1	5680	170.6	32.28	647	0.106	0.0043	0.2967	0.016	0.02017	0.00055	0.89273	128.7	3.5	263	13	1725	62	92.53
	3_8c2	3980	105	39.6	761	0.131	0.0053	0.5	0.026	0.028	0.0011	0.89671	177.8	7.2	409.9	18	2104	57	91.42
9	3_8r1	1938	12.24	159.4	602	0.1581	0.0061	0.682	0.033	0.03124	0.00078	0.82829	198.3	4.9	527.1	20	2435	37	91.85
	3_8r2	834	1.49	750	484	0.1318	0.0052	1.855	0.091	0.1013	0.0023	0.74174	621.7	13	1062	32	2118	41	70.46
	3_9c1	3010	157	18.34	1660	0.1538	0.006	0.927	0.045	0.04348	0.001	0.7625	274.3	6.2	664.7	24	2386	46	88.52
10	3_9r1	918	7.16	128.4	500	0.1383	0.0054	1.353	0.074	0.0707	0.0025	0.92823	440	15	863	33	2206	33	80
	3_10c1	965	6.55	171	201	0.1063	0.0042	1.446	0.068	0.0988	0.0022	0.64024	607	13	908.1	29	1736	47	64.9
	3_10r1	2379	14.97	157.4	525	0.1178	0.0046	0.5806	0.028	0.03568	0.00081	0.71334	226	5.1	464.2	18	1921	40	88.2
11	3_10r2	2910	19.7	148.5	702	0.1187	0.0046	0.5747	0.027	0.03526	0.00083	0.75368	223.3	5.2	460.4	18	1938	40	88.48
	3_10c2	1483	11.38	135.8	249	0.0952	0.0038	0.693	0.034	0.0527	0.0014	0.76765	331	8.8	533.3	20	1531	47	78.34
	3_11c1	1376	6.79	201.6	605	0.1174	0.0045	1.794	0.086	0.1102	0.0023	0.77756	674	14	1041	31	1917	42	64.83
12	3_11r1	1480	4.28	540	635	0.1173	0.0045	2.073	0.1	0.1279	0.0036	0.88999	775	20	1137	34	1913	44	59.4
	3_12c1	93.9	58.1	1.591	390	0.133	0.0057	4.133	0.2	0.2251	0.0047	0.31939	1310	25	1657	40	2134	38	38.42
	3_12c2	124	77.4	1.644	602	0.1407	0.0059	3.94	0.21	0.2028	0.0063	0.77192	1188	34	1614	44	2233	43	46.6
12	3_12r1	59.3	6.93	18.6	79.5	0.1356	0.0058	6.09	0.3	0.3235	0.0072	0.26539	1809	36	1986	42	2176	41	66.8
	3_12r2	325	9.5	36	122	0.142	0.0059	2.19	0.14	0.1129	0.0059	0.92096	687	35	1161	48	2246	51	16.9

13	3_13c1	2970	115.1	25.8	1142	0.1482	0.0059	0.944	0.089	0.0448	0.003	0.99328	281	18	659	42	2320	54	87.94
	3_13c2	1410	2.66	660	487	0.1249	0.0049	1.999	0.06	0.064	0.0024	0.90687	399	15	751	29	2024	48	80.14
	3_13r1	1148	3.76	349	1094	0.1348	0.0051	4.01	0.22	0.2144	0.007	0.9579	1250	38	1626	46	2162.3	43	42.2
	3_13r2	1522	1.7	1170	626	0.13133	0.0049	3.626	0.16	0.1996	0.0038	0.70123	1173.2	20	1554.4	36	2115.2	34	44.42
	3_13r3	2250	2.18	1430	969	0.1377	0.0052	1.555	0.072	0.08186	0.0017	0.66389	507.2	9.9	952.4	29	2197	43	76.85
14	3_14c1	3920	230	18.93	1059	0.1399	0.0053	1.589	0.092	0.0827	0.0037	0.97393	511	22	958	37	2224	46	76.9
	3_14r1	1250	7.7	201	669	0.13623	0.0051	8.47	0.5	0.45	0.02	0.98137	2389	89	2260	60	2178.9	39	-9.6
	3_14c2	2360	18.7	135.4	886	0.1365	0.0051	3.74	0.2	0.1987	0.0068	0.96379	1166	37	1573	42	2184.7	41	46.5
	3_14c3	3210	105.2	31.2	811	0.1383	0.0052	2.796	0.13	0.1462	0.0034	0.90642	879	19	1352	36	2203.3	37	59.98
	3_14r3	2170	15.8	140	872	0.13821	0.0052	4.037	0.19	0.2115	0.0044	0.85097	1236	23	1640.1	37	2204.3	36	43.88
2 standard errors		2180	11.55	189.7	836	0.13814	0.0051	3.566	0.17	0.1867	0.004	0.90683	1103	22	1540	38	2205.6	36	49.96

4.3.2.2 Samples Cid_F 075 and Cid_F 085

No viable zircon grains were extracted from these samples, probably because of the method used for separation. In the early stages of mineral separation, it is possible to “over-crush” or “over-mill” the samples. This error may lead to reduction of grain size into powder or very minute fractions. Therefore, samples Cid_F075 and Cid_F085 will only be geochemically analysed. Sample Cid_075 was collected from a two-mica granodiorite, located along Yédandiekaha-Niakaramandougou branch, southwest of the town of Yédandiekaha at UTM 30P 0282476 1017589. Sample Cid_F085 was collected from a granodiorite intruding gneiss, located southeast of the village of Kogbala at UTM 30P 0238713 984648. Samples plot as granite in TAS for plutonic rocks diagram of Cox et al. (1979) adapted by Wilson (1989) (Figure 4.36), QAP diagram of Streckeisen (1976) (Figure 4.37a), Ab-An-Or normative triangular plot of Barker (1979) (Figure 4.37b) and in R1-R2 binary diagram of De la Roche et al. (1980) (Figure 4.38). They correspond to (high K) calc-alkaline granites with peraluminous composition in the AFM diagram, SiO₂ vs. K₂O diagram and A/NK vs. A/CNK diagram (after Shand, 1943; Irvine and Baragar, 1971; Maniar and Piccoli, 1989; Pearce et al., 1990) (Figure 4.39a and b; Figure 4.40). The R1-R2 major element geotectonic discrimination diagram of Batchelor and Bowden (1985) (Figure 4.41) confined samples in the syn-collision field. Tectonic discrimination diagrams show that these samples are confined to volcanic arc granite types and show syn-collisional characteristics (Rb vs. Y+Nb and Nb vs. Y binary variation diagrams after Pearce et al., 1984) (Figure 4.42a and b) with an I-type source (after Chappell and White, 1974) (Figure 4.42c). These diagrams indicate that the evolution of these granitoids might be associated with subduction–accretion tectonics.

4.3.2.3 Sample Cid_F 100

The two-mica granite crops out east of town of Tortiya and intrudes metasedimentary units at UTM 30P 0230076 966097 (Figure 4.24a). Internal structures of zircon crystals from the sample show features characteristic for changing chemical conditions. The grains are sub-

rounded, subhedral and short prismatic, with variable length of approximately 100 to 120 μ m. In most zircons, present core-rim relationship is disturbed, diffused and almost completely obliterated by metamictisation (with radial cracks). Where discernible, the oscillatory zoning is truncated by white to light grey inner rim crystallisation patches. One grain displays a bright response and “less” metamictised core with grey to dark outer rims, indicating rapid growth rate (Figure 4.24b). Apart from zircons, the sample contains very bright white fluorapatite grains with irregular to semi-elongated shape and multiple inclusion-rich cracks. These fluorapatite grains can be easily identified as “comet-like” structures.

Cores and rims were specifically targeted to obtain crystallisation and metamorphic ages. Figure 4.25 shows a U-Pb Concordia diagram with core data points defining a concordia age at 2174 ± 1 Ma. Core analysis on zircon no.1 produced an age of 2175 ± 1 and 2150 ± 1 Ma (Figure 4.21b). Ages of 2174 ± 1 and 2175 ± 1 Ma is herein deduced as an inherited age for sample Cid_F 100. Figure 4.26a shows a diagram from core data points defining a weighted mean age of 2132 ± 12 Ma. Rim analyses define a Pb loss line within error with a calculated upper intercept age of 2037 ± 33 Ma (Figure 4.26b). The age of 2037 ± 33 Ma is herein deduced as the metamorphic or recrystallisation age for sample Cid_F 100. Other rims returned fairly young ages of 771 and 438 ± 1 Ma. Numbers referring to the grain number and data are represented in Table 5. All LA-ICPMS U-Pb zircon ages about sample Cid_F 100 are summarised and represented in Table 8. The sample obtained Th/U ratio greater than 0.1, which points to crystallisation from magmatic zircons (Figure 4.35).

Geochemically, the sample plots in the granite field in TAS for plutonic rocks diagram of Cox et al. (1979) adapted by Wilson (1989) (Figure 4.36), QAP diagram (after Streckeisen, 1976) (Figure 4.37a) Ab-An-Or normative triangular plot (after Barker, 1979) (Figure 4.37b) and in R1-R2 binary diagram (after De la Roche et al., 1980) (Figure 4.38). This granite plots in the high-K calc-alkaline granite field in AFM diagram (after Irvine and Baragar, 1971, Figure 4.39a) and SiO₂ vs. K₂O diagram (after Pearce et al., 1990, Figure 4.39b). In the A/NK vs. A/CNK diagram (after Shand, 1943 adopted by Maniar and Piccoli, 1989) sample Cid_F100 indicates peraluminous character (Figure 4.40). The R1-R2 major element geotectonic discrimination diagram of Batchelor and Bowden (1985) confined sample in the syn-collision field (Figure 4.41). Tectonically, this granite is confined to volcanic arc granite types and show syn-collisional

characteristics in Rb vs. Y+Nb and Nb vs. Y binary variation diagrams of [Pearce et al. \(1984\)](#) (Figure 4.42a). In Figure 4.42b K₂O versus Na₂O diagram (after [Chappell and White, 1974](#)) supports the I-type character of this granite (Figure 4.42c), since, Na₂O (wt %) is >3.2.

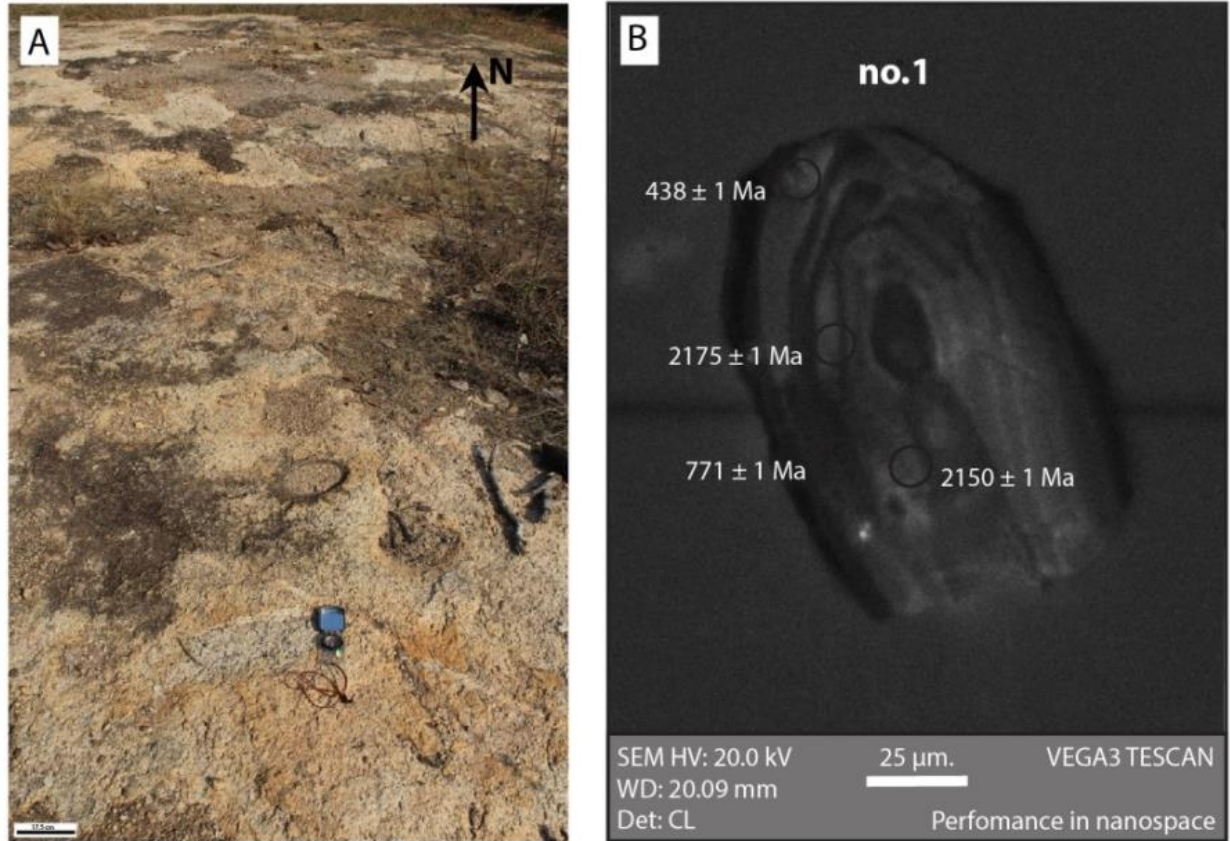


Figure 4.24: (a) Two-mica granite cropping out east of town of Tortiya and intruding metasedimentary units at UTM 30P 0230076 966097. (b) CL image, the black circles correspond to the location of the U–Pb analyses (U–Pb by LA-ICPMS, 2 se) and the number (no.1) is assigned to grain correspond to the original numbering used during the imaging of the mounts.

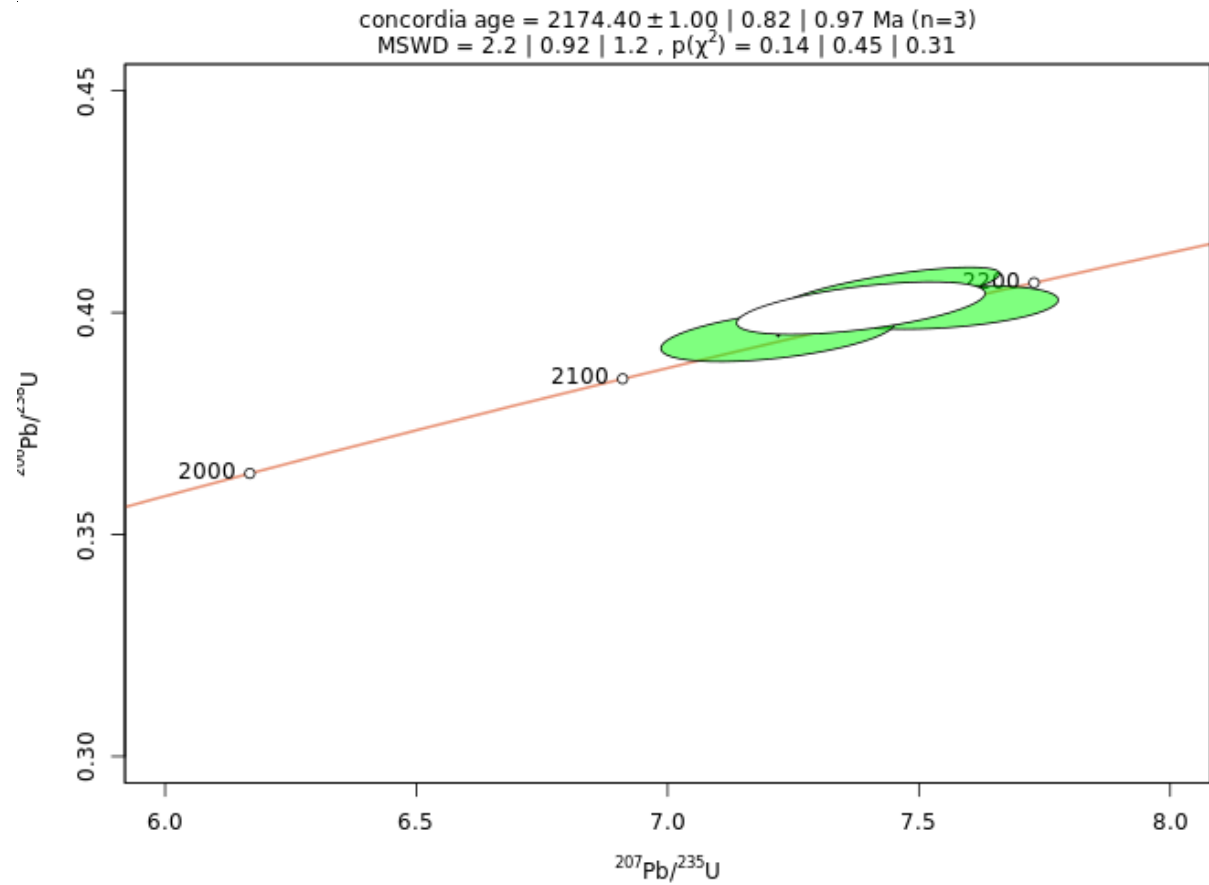


Figure 4.25: The $^{206}\text{Pb}/^{238}\text{U}$ versus $^{207}\text{Pb}/^{235}\text{U}$ Concordia diagram summarising strongly concordant U–Pb geochronological data from the zircon cores.

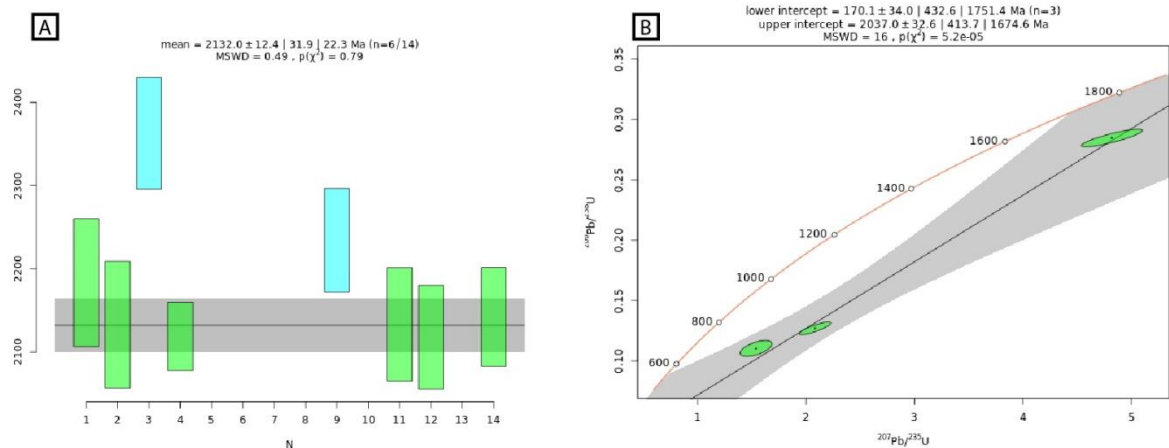


Figure 4.26: (a) Weighted mean diagram for core spots from sample Cid_F 100. (b) The $^{206}\text{Pb}/^{238}\text{U}$ versus $^{207}\text{Pb}/^{235}\text{U}$ Concordia diagram data points from zircon rims of the two-mica granite. The regression to the zircon data points is also shown.

Table 5: Summary of LA-ICPMS U-Pb zircon data, sample CidF_100

Cid F_100	U	Th	Th/U	Pb							Error								
Zircon number	Source file	(ppm)	(ppm)	Ratio	(ppm)	²⁰⁷ Pb* ²⁰⁶ Pb ±%	²⁰⁷ Pb ²³⁵ U ±%	²⁰⁶ Pb ²³⁸ U ±%			Correlation	²⁰⁶ Pb ²³⁸ U = (Ma)	²⁰⁷ Pb ²³⁵ U Age (Ma)	± (Ma)	²⁰⁷ Pb ²⁰⁶ Pb Age (Ma)	± (Ma)	Discordant (%)		
1	1_1c1	85.9	56.6	1.486	528	0.135	0.0055	7.55	0.36	0.4012	0.0078	0.34071	2174	36	2174	44	2160	41	-1
	1_1c2	66.4	66.3	0.98	558	0.1325	0.0057	7.22	0.37	0.3949	0.0094	0.49743	2143	44	2132	45	2126	45	-1.3
	1_1r1	733	173	4.57	1534	0.1993	0.0079	1.94	0.094	0.0703	0.0019	0.76449	437.9	12	1092	32	2821	49	84.47
	1_1r2	1011	46.8	20.5	815	0.1181	0.0049	2.083	0.12	0.1271	0.0043	0.84531	770	25	1134	39	1919	62	59.6
2	1_2c1	146.7	58.85	2.443	610	0.1507	0.0059	6.85	0.32	0.328	0.0066	0.52248	1828	32	2089	41	2352	40	22.22
	1_2c2	310	236	1.341	1445	0.1313	0.0051	5.35	0.33	0.295	0.013	0.95226	1656	64	1858	51	2114	40	21.6
3	1_2r1	459.6	69.3	7.59	1327	0.1789	0.0074	2.949	0.15	0.1213	0.0047	0.86208	737	27	1390	38	2639	57	71.8
	1_3c1	382	76.6	5.47	580	0.1185	0.0048	2.932	0.16	0.1788	0.0045	0.84243	1060	25	1383	41	1931	50	44.99
4	1_3r1	70.5	3.99	22.6	20.4	0.101	0.0065	1.539	0.12	0.1104	0.0054	0.58196	673	31	926	49	1635	80	57.1
	1_4c1	2260	805	2.822	10640	0.3143	0.012	3.351	0.17	0.0778	0.0027	0.95799	482	16	1486	40	3541	46	86.35
	1_4c2	523	234.2	2.3	3406	0.2001	0.0077	5.166	0.24	0.1886	0.0053	0.84246	1113	28	1844	40	2825	49	60.5
	1_4r1	80.8	14.6	6.06	292	0.1449	0.0058	7.57	0.36	0.3797	0.008	0.50438	2073	37	2177	43	2292	40	9.1
5	1_4r2	368	34.1	10.31	729	0.1391	0.0053	5.19	0.29	0.2699	0.0096	0.97145	1536	48	1844	46	2214	46	30.4
	1_5c1	385	147.3	2.555	1657	0.1491	0.0058	5.78	0.3	0.2843	0.011	0.92159	1608	53	1934	46	2333	52	30.6
	1_5r1	379	139.2	2.667	1706	0.1639	0.0065	4.94	0.24	0.2216	0.006	0.8147	1289	32	1807	41	2493	48	48.2
	1_6c1	661	1069	0.615	7020	0.1415	0.0059	6.19	0.3	0.3194	0.0086	0.65927	1789	43	2003	46	2234	65	18.9
6	1_6c2	1350	2270	0.5651	6730	0.1702	0.0084	2.574	0.15	0.1096	0.004	0.64418	670	23	1281	43	2530	79	72.8
	1_6r1	421	37.7	10.73	1146	0.2124	0.0086	2.428	0.12	0.083	0.0019	0.68854	514.9	12	1253	38	2924	44	82.36
	1_6r2	463	347	1.578	2840	0.1947	0.0075	6.17	0.3	0.2295	0.0058	0.80742	1331	31	1995	44	2781	44	52.27
	1_7c1	418	34.9	11.72	481	0.1329	0.0051	6.746	0.31	0.3689	0.0074	0.50815	2023	35	2077	41	2131	42	4.9
7	1_7c2	370	113	8.4	920	0.1308	0.005	7.382	0.34	0.4073	0.0079	0.65737	2202	36	2157	41	2111.1	38	-4.4
	1_7r1	490	9.65	49	1136	0.1484	0.0058	5.5	0.26	0.2675	0.0055	0.69149	1528	28	1896	41	2325	52	34.37
8	1_8c1	892	390	2.225	2490	0.1287	0.0049	4.692	0.23	0.2636	0.0065	0.87977	1507	33	1762	40	2078	48	27.4
	1_8c2	427	630	0.6575	5120	0.133	0.0051	7.44	0.35	0.4048	0.0086	0.73048	2190	39	2164	43	2136	42	-2.4
	1_8r1	1492	177	8.95	1290	0.12217	0.0046	4.819	0.23	0.2846	0.006	0.85915	1614	30	1786	39	1989.2	42	18.7
	1_8r2	1191	1339	1.03	3090	0.1955	0.0081	2.13	0.1	0.0793	0.0023	0.60356	492	14	1156	34	2781	61	82.18
2 standard errors																			

4.3.2.4 Sample Cid_F 113A

Plagioclase-hornblende-quartz-K-feldspar-mica pegmatite crops out north of the town of Tortiya intruding metasedimentary units located at UTM 30P 0208817 969238 (Figure 4.27a). Zircon grains from this sample vary in shape; sub- to anhedral and short prismatic with length from approximately 70 to 100µm. The grains are entirely characterised by large, dark and extensively metamictised zones (Figure 4.27b), also evident from crosscutting cracks. They are also characterised by relatively brightly luminescent inclusions. Oscillatory zones are slightly observable in some grains, as medium grey inner rims, followed by darker outer rims.

The sample core analysis produced all discordant zircon data points. These define an age of 1842 ± 20 Ma that is herein inferred as younger core age (Figure 4.28). Core extensively consist of metamictised zones, however, analysis on zircon no.17 yield age at 2211 ± 1 Ma (Figure 4.27b). One spot on zircon no.18 produced age at 2015 ± 1 Ma. Figure 4.29a shows core data points defining a weighted mean age of 2387 ± 19 Ma. Rim analyses define a Pb loss line within error with a calculated upper intercept age of 2190 ± 13 Ma (Figure 4.29b). Ages on rim analyses returned age range of $1158-1901 \pm$ Ma. Numbers referring to the grain number and data are represented in Table 6. Sample CidF_113A has the highest Th (ppm) content when compared to other samples. U and Th contents of the zircons are plotted in Figure 4.35. Over 99% of all

analysed zircons point to igneous origin of the zircons, indicated by Th/U ratios greater than 0.1. All LA-ICPMS U-Pb zircon ages about sample Cid_F 113A are summarised and represented in Table 8.

Geochemically, sample Cid_F113A plots in the granite field in classification diagrams such as TAS for plutonic rocks diagram of Cox et al. (1979) adapted by Wilson (1989) (Figure 4.36), QAP diagram by Streckeisen (1976) (Figure 4.37a), Ab-An-Or normative triangular plot by Barker (1979) (Figure 4.37b) and R1-R2 binary diagram by De la Roche et al. (1980) (Figure 4.38). This granite plots in the high-K calc-alkaline granite field in AFM diagram (after Irvine and Baragar, 1971, Figure 4.39a) and SiO₂ vs. K₂O diagram (after Pearce et al., 1990, Figure 4.39b). In binary A/NK against A/CNK plot (after Shand, 1943 adopted by Maniar and Piccoli, 1989) the sample suggests peraluminous character along with other samples from Ferké batholith, suggesting that all the granites derived from a source of narrow chemical composition (Figure 4.40). The R1-R2 major element geotectonic discrimination diagram of Batchelor and Bowden (1985) confined sample in the syn-collision field (Figure 4.41). Tectonic discrimination diagrams of this granite confines to volcanic arc granite types and show syn-collisional characteristics (after Pearce et al., 1984) (Figure 4.42a and b). K₂O versus Na₂O diagram (after Chappell and White, 1974) supports the I-type character of this granite (Figure 4.42c).

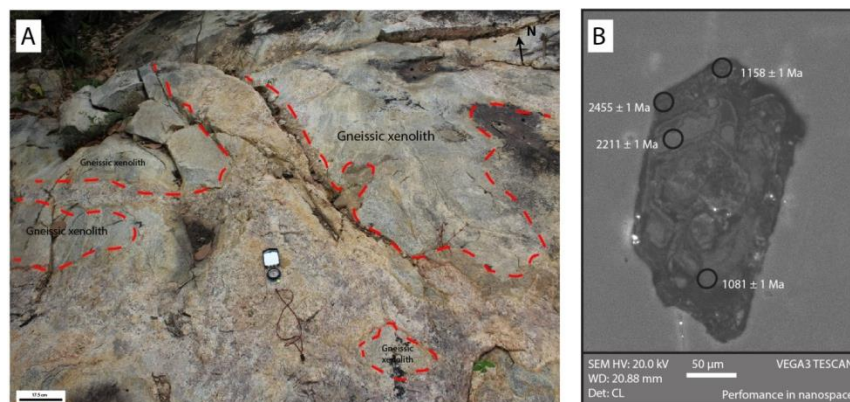


Figure 4.27: (a) Plagioclase-hornblende-quartz-K-feldspar-mica pegmatite is cropping out north of the town of Tortiya intruding metasedimentary units and containing gneissic xenoliths. It is located at UTM 30P 0208817 969238. (b) CL image, the black circles correspond to the location of the U-Pb analyses (²⁰⁷Pb/²³⁵U by LA-ICPMS, 2 se) and the number (no.17) is assigned to grain correspond to the original numbering used during the imaging of the mounts.

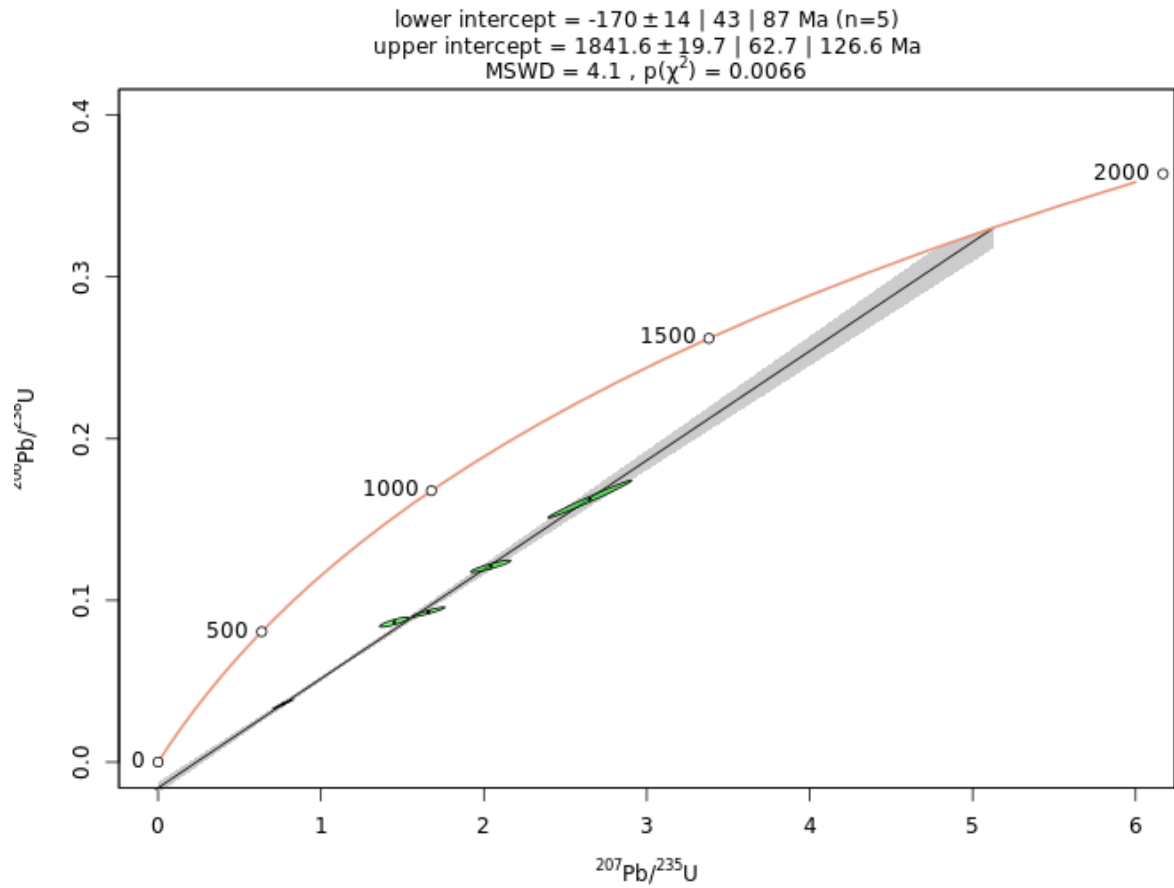


Figure 4.28: The $^{206}\text{Pb}/^{238}\text{U}$ versus $^{207}\text{Pb}/^{235}\text{U}$ Concordia diagram summarising strongly concordant U–Pb geochronological data from zircon core points of the pegmatite.

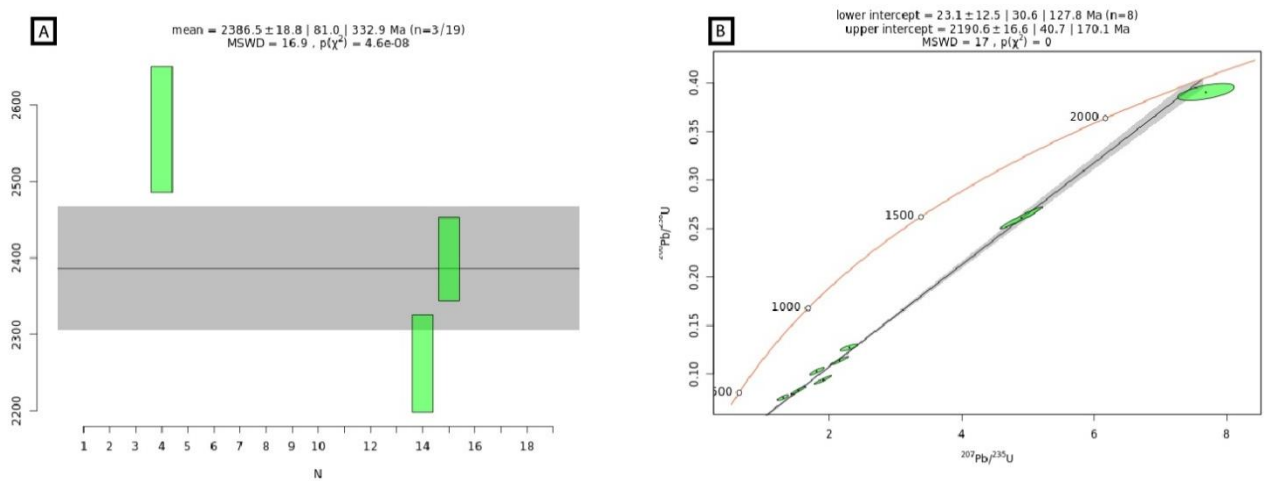


Figure 4.29: (a) Weighted mean diagram for core spots from sample Cid_F 113A. **(b)** The $^{206}\text{Pb}/^{238}\text{U}$ versus $^{207}\text{Pb}/^{235}\text{U}$ Concordia diagram data points from zircon rims of the pegmatite. The regression to the zircon data points is also shown.

Table 6: Summary of LA-ICPMS U-Pb zircon data, sample CidF_113A.

Cid F_113	Source file	U (ppm)	Th (ppm)	Th/U Ratio	Pb (ppm)	$^{207}\text{Pb}/^{206}\text{Pb}$	$\pm\%$	$^{207}\text{Pb}/^{235}\text{U}$	$\pm\%$	$^{206}\text{Pb}/^{238}\text{U}$	$\pm\%$	Error Correlation	$^{206}\text{Pb}/^{238}\text{U}$ Age (Ma)	$\pm$ (Ma)	$^{207}\text{Pb}/^{235}\text{U}$ Age (Ma)	$\pm$ (Ma)	$^{207}\text{Pb}/^{206}\text{Pb}$ Age (Ma)	$\pm$ (Ma)	Discordant (%)
1	2_1c1	1690	5.50E+03	0.521	4350	0.1537	0.0062	3.015	0.14	0.1428	0.0036	0.5579	860	20	1411	37	2385	61	63.7
	2_1r1	1339	850	2.37	2240	0.1308	0.005	2.298	0.11	0.1273	0.003	0.81005	774	18	1211	35	2108	42	63.3
	2_1r2	1963	2980	1.01	3170	0.1478	0.0056	1.905	0.11	0.094	0.0036	0.95906	578	21	1079	37	2317	42	75
2	2_2c1	1870	1160	4.89	2590	0.1218	0.0046	2.042	0.1	0.1211	0.0031	0.90826	736	18	1126	34	1980	46	62.93
3	2_3c1	1153	87.6	13.78	823	0.121	0.0047	1.451	0.074	0.0866	0.0025	0.85793	535	15	907	31	1972	45	72.8
	2_3r1	795	92.8	8.91	665	0.1241	0.005	1.301	0.07	0.0758	0.0024	0.80406	471	14	841	31	2015	47	76.63
	2_4r1	1900	2190	1.59	4.78E+04	0.238	0.039	10.33	0.5	0.438	0.034	0.77982	2280	160	2460	45	2680	140	-1
4	2_4c1	1810	870	2.29	4.69E+04	0.438	0.098	11.71	0.57	0.401	0.04	0.18333	2090	190	2576	47	2730	160	-4.5
5	2_5c1	11980	1.85E+05	0.06485	10460	0.1571	0.006	0.768	0.051	0.0359	0.0023	0.99194	227	14	572	26	2420	63	90.6
	2_5r1	1653	16050	0.1025	1.75E+04	0.13561	0.0051	4.9	0.26	0.261	0.0091	0.97421	1491	46	1792	44	2172.5	40	31.3
	2_6c1	2350	24720	0.0924	2.14E+04	1.05	0.26	10.29	0.5	0.301	0.038	0.017408	1610	200	2456	46	2640	160	4
6	2_6c2	1437	92.8	15.46	3.21E+04	3.03	0.41	26.45	1.2	0.236	0.053	-0.25381	1200	250	3362	44	3530	220	3
	2_6r1	5090	1579	3.28	3.19E+04	2.61	0.43	7.24	0.43	0.069	0.013	0.12542	417	77	2121	56	4060	160	77.3
	2_6r2	1549	302	5.35	15460	0.1498	0.0068	11.42	0.58	0.554	0.024	0.75932	2822	98	2550	47	2351	73	-22.3
7	2_7r1	1161	371	5.11	1092	0.1334	0.0052	1.532	0.089	0.083	0.0033	0.92552	513	20	935	35	2145	42	76
8	2_8c1	1473	380	4.99	4080	0.1616	0.0061	2.509	0.13	0.1123	0.0031	0.92514	685	18	1270	36	2473.3	41	72.26
	2_8r1	1165	105	11.67	3630	0.1722	0.0068	3.258	0.16	0.1377	0.0043	0.85718	831	24	1469	39	2575	55	67.59
	2_9c1	2130	670	3.43	3940	0.1403	0.0052	2.541	0.12	0.131	0.0032	0.91869	793	19	1280	36	2231.3	43	64.44
9	2_9c2	2350	16370	0.1403	3620	0.1417	0.0054	2.094	0.11	0.107	0.0036	0.95235	655	21	1139	38	2244	51	70.71
	2_9r1	2070	710	4.54	2940	0.1281	0.005	1.812	0.091	0.1029	0.0034	0.89706	630	20	1046	34	2067	56	69.3
	2_9r2	2110	5640	0.43	3480	0.137	0.0052	2.152	0.11	0.1137	0.0036	0.94958	694	21	1160	37	2189	44	68.31
10	2_10c1	1430	73.1	19.58	2050	0.1494	0.0057	2.28	0.11	0.1104	0.0026	0.81791	675	15	1203	34	2341	43	71.13
	2_10r1	1075	51.3	21.03	1830	0.1816	0.0071	2.026	0.098	0.0808	0.0018	0.69886	500.9	11	1121	33	2664	47	81.18
11	2_11c1	1389	74	18.71	748	0.1155	0.0047	2.65	0.21	0.1626	0.0095	0.98974	965	53	1274	63	1880	67	49.5
12	2_12c1	1533	297	8.05	8510	0.1683	0.0064	5.52	0.27	0.2381	0.0059	0.89507	1379	31	1899	41	2540	50	45.75
	2_12c2	3156	307.3	10.45	9480	0.1929	0.0074	2.896	0.16	0.1097	0.0045	0.96944	669	26	1373	40	2766	51	75.65
	2_12r1	887	30.49	28.53	7360	0.1684	0.0063	7.99	0.38	0.3433	0.008	0.8874	1901	38	2229	43	2541	36	25.2
13	2_13r1	941	37	24.94	3450	0.1425	0.0053	7.689	0.35	0.3905	0.0072	0.5942	2125	34	2194.3	41	2257.8	43	5.83
14	2_14c1	3330	7680	0.469	5230	0.129	0.0048	1.659	0.083	0.0928	0.0025	0.93644	572	15	990	32	2081	49	72.56
15	2_15c1	1570	2470	0.691	4410	0.2493	0.0097	2.438	0.11	0.0706	0.0016	0.67748	439.8	9.5	1252	34	3178	49	86.15
	2_16c1	2573	1.46E+04	0.26	2.27E+04	0.182	0.02	6.04	0.4	0.257	0.014	0.090069	1470	72	1955	53	2640	150	38.7
	2_17c1	1660	129	12.41	8660	0.1555	0.0061	8.77	0.4	0.4091	0.0094	0.59596	2209	43	2313.1	41	2402	50	8
16	2_17c2	3720	433	9.06	10930	0.1721	0.0067	4.3	0.26	0.1825	0.0096	0.9764	1074	52	1676	48	2576	56	57.8
	2_17r1	1176	61.2	18.8	5650	0.15372	0.0057	9.885	0.45	0.4625	0.009	0.78514	2454	40	2423.1	42	2387.3	36	-2.85
	2_17r2	3020	1.392	1.392	12010	0.1787	0.0067	4.88	0.24	0.1969	0.0052	0.95257	1158	28	1795	43	2640.1	44	56.02
18	2_18c1	1460	17.2	17.2	3410	0.1374	0.0052	6.97	0.37	0.367	0.014	0.96639	2008	66	2100	48	2192	52	7.9
	2_18c2	1170	13.9	13.9	3050	0.1327	0.005	9.16	0.46	0.499	0.015	0.93502	2601	68	2347	47	2134	52	-22.5
	2_19c1	887	20.82	20.82	12890	0.1422	0.0054	16.41	0.79	0.833	0.024	0.88114	3895	85	2896	46	2255	55	-72.8
19	2_19r1	2690	3.26	3.26	2.30E+04	0.233	0.031	8.208	0.37	0.318	0.023	0.53958	1750	120	2252.7	42	2830	140	28.4
	2_19c2	3500	6.8	6.8	1.97E+04	0.227	0.039	5.374	0.25	0.225	0.017	0.54022	1290	92	1879.2	39	2590	130	41.2
	2_20c1	9640	1.74	1.74	4.48E+04	3.05	0.4	4.5	0.38	0.0172	0.0025	-0.4739	109	15	1676	69	4340	180	93.5
20	2_20r1	2570	6.97	6.97	3.95E+04	2.77	0.46	14.63	0.71	0.159	0.03	-0.63239	890	160	2787	46	3580	190	44.8
	2_20c2	1720	1.595	1.595	3.29E+04	1.73	0.33	19.54	0.93	0.313	0.054	-0.03811	1590	250	3064	46	3210	150	2
21	2_21c1	1892	2.56	2.56	9340	0.325	0.012	4.043	0.19	0.0894	0.002	0.86709	551.7	12	1639	38	3592	47	84.64
2 standard errors																			

4.3.2.5 Sample Cid_F 113B

Sample Cid_F 113B is a gneiss, collected from the same location as sample Cid_113A (Figure 4.30a). Zircon grains are euhedral, sub-rounded and long prismatic. They vary in length from approximately 150 to 210 μm (Figure 4.30b and c). All grains display a distinct core-rim microstructure. The bright structures reveal cores; are structurally discontinuous to the outer growth zones, show truncated zoning as well as recrystallisation patches and convoluted zoning. The cores commonly contain large inclusions that appear as “comet-like” structures (Figure 4.30c). The outer rims are medium to thin dark bands, indicating rapid growth rate.

In Figure 4.31, $^{206}\text{Pb}/^{238}\text{U}$ versus $^{207}\text{Pb}/^{235}\text{U}$ Concordia diagram with data points define a Pb loss line within error with a calculated upper intercept age of 2279 ± 5 Ma. Core analysis on

zircon no.4 and no.10 produced ages at 2044 ± 1 and 2150 ± 1 Ma. Other cores from zircon no.4, no.10 and no.40 yield age of 2338 ± 1 Ma, this is inferred as inherited cores. Zircon no.21, no.22, no.23 and no.24 returned ages 2044 ± 1 Ma, 2053 ± 1 Ma, 1789 ± 1 Ma and 1988 ± 1 Ma (Figure 4.30b). The most concordant core data yielded a concordia age of 2271 ± 1 Ma (Figure 4.32a). Figure 4.32b shows core data points defining a weighted mean age of 2270 ± 5 Ma. Rim analyses define a Pb loss line within error with a calculated upper intercept age of 2261 ± 6 Ma (Figure 4.33a). The most concordant rim data returned a concordia age of 2266 ± 1 Ma (Figure 4.33b). Rim data points define a weighted mean age of 2289 ± 8 Ma (Figure 4.34). Other rim data returned younger ages ranging at 2044 - 512 ± 1 Ma. Numbers referring to the grain number and data are represented in Table 7. The Th/U ratio is greater than 0.1 indicating that these are magmatic zircons (Figure 4.35). All LA-ICPMS U-Pb zircon ages about sample Cid_F 113B are summarised and represented in Table 8.

Geochemically, modal compositional plot of QAP diagram by Streckeisen (1976) classifies the rock as granodiorite, due to >65% plagioclase content (Figure 4.37a). In the normative An–Ab–Or plot (Barker, 1979), this sample is confined of granite field (Figure 4.37b). The R1-R2 relation (De la Roche et al. 1980) also suggests that the sample is granite in composition (Figure 4.38). The R1-R2 major element geotectonic discrimination diagram of Batchelor and Bowden (1985) confined sample in the syn-collision to post-collision field (Figure 4.41), and its evolution might be associated with extensional tectonics after post-collision. Tectonic discrimination diagrams of this sample confines to volcanic arc granite (after Pearce et al., 1984, Figure 4.42a and b). K₂O versus Na₂O diagram (after Chappell and White, 1974) supports the I-type character of this granite (Figure 4.42c).

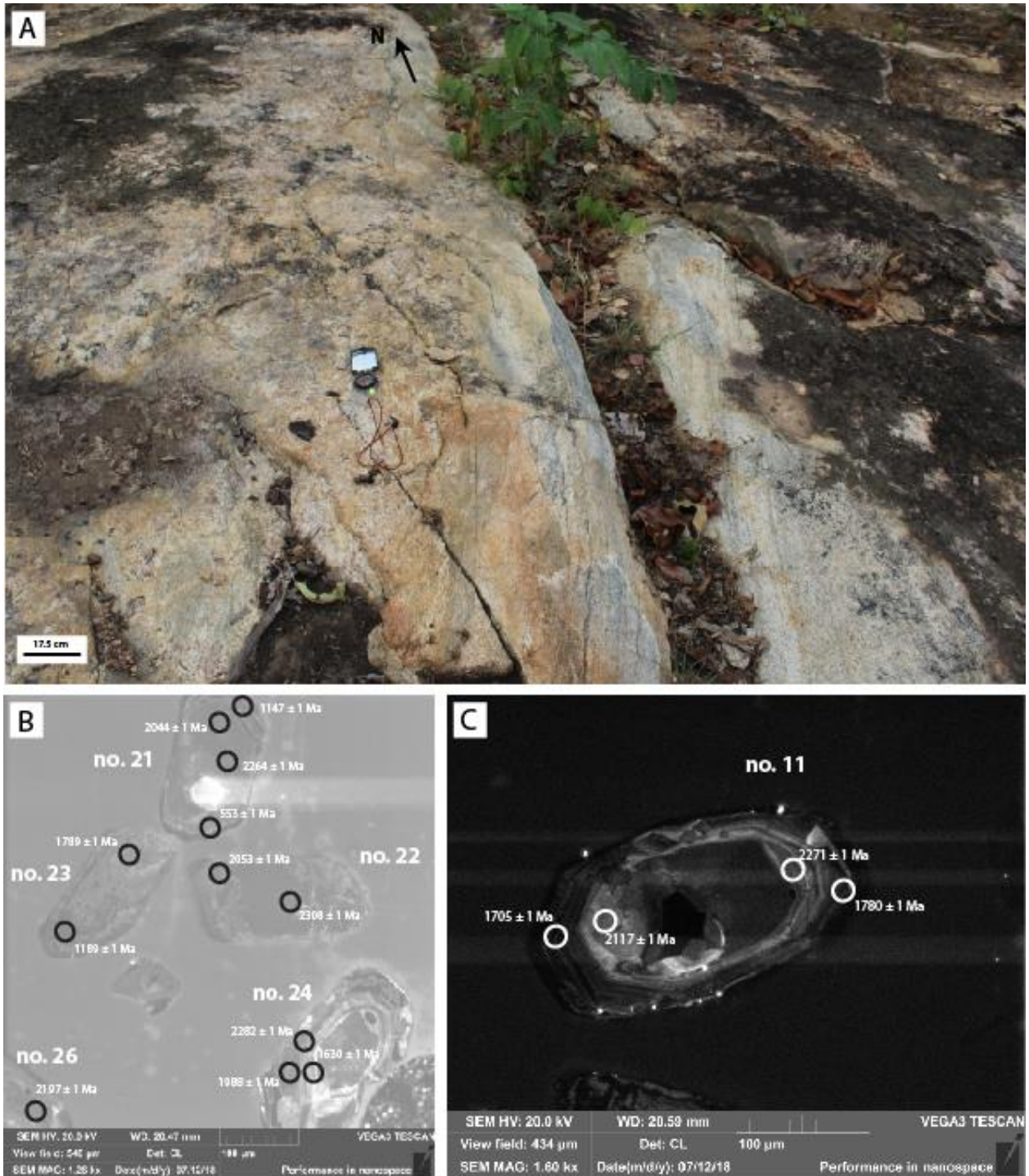


Figure 4.30: (a) A gneiss cropping out east of the town of Tortiya at UTM 30P 0208817 969238. (b-c) Cathodoluminescence (CL) images of the zircon grain no.21, no.22, no.23, no.24, no.26 and no.11 that were analysed and extracted from the pegmatite. They have well defined cores and oscillatory rims. Notice fractures and pores that probably mark fluid and Pb-loss paths. Circles represent U-Pb dates ($^{207}\text{Pb}/^{235}\text{U}$ by LA-ICPMS, 2 se).

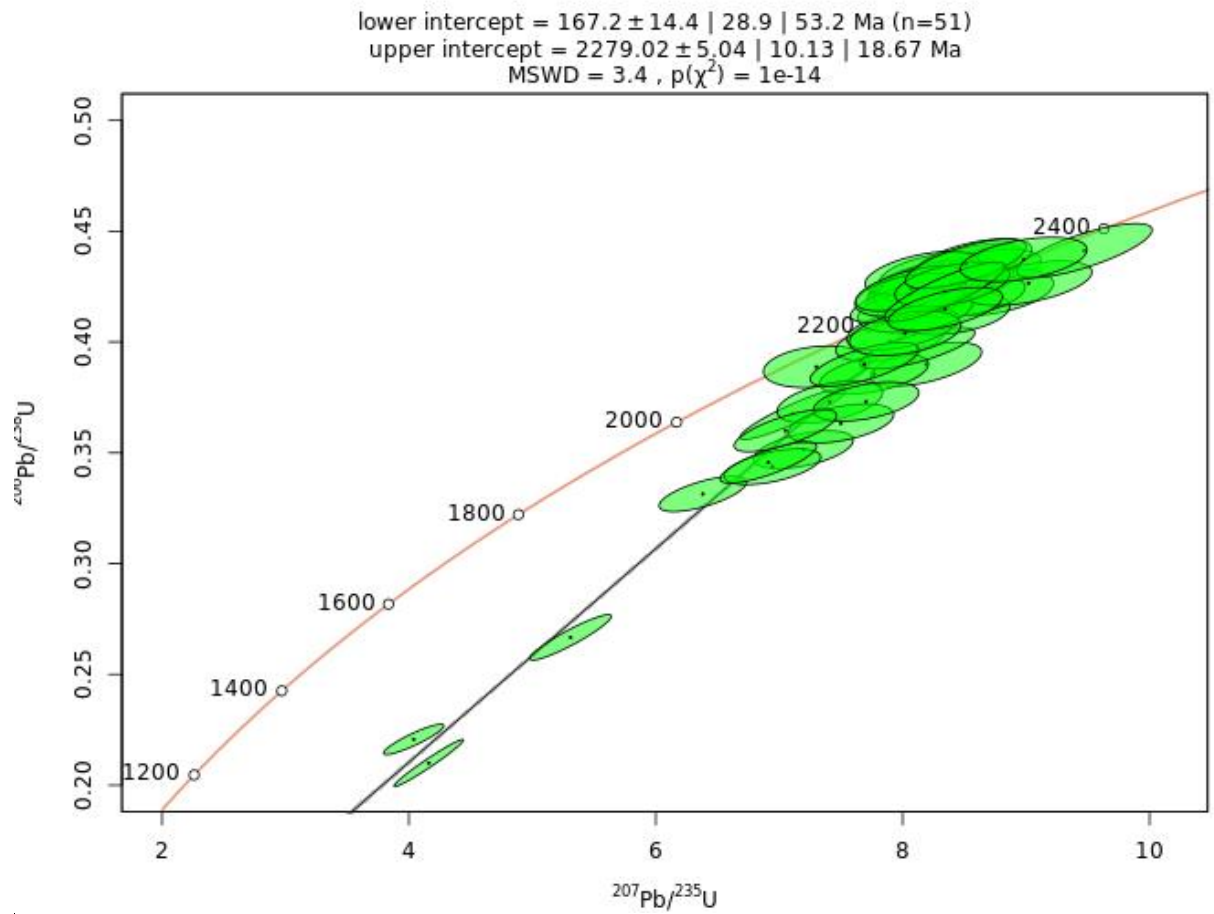


Figure 4.31: The $^{206}\text{Pb}/^{238}\text{U}$ versus $^{207}\text{Pb}/^{235}\text{U}$ Concordia diagram summarising strongly concordant U–Pb geochronological data for zircon cores from points of the gneiss.

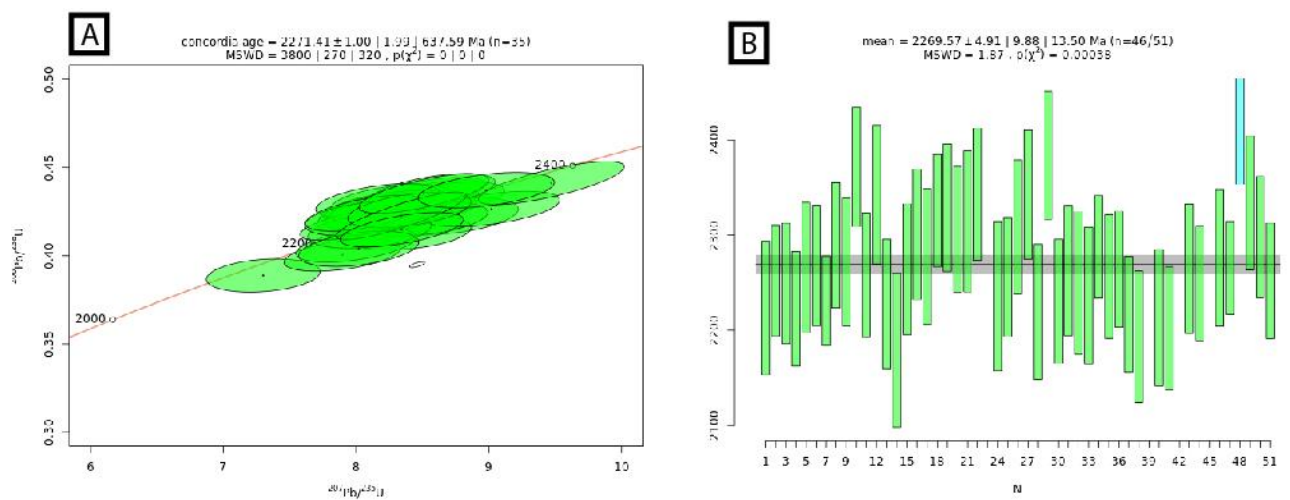


Figure 4.32: (a) Concordia diagram for only the most concordant data (zircon cores). (b) Weighted mean diagram for core spots from sample Cid_F 113B.

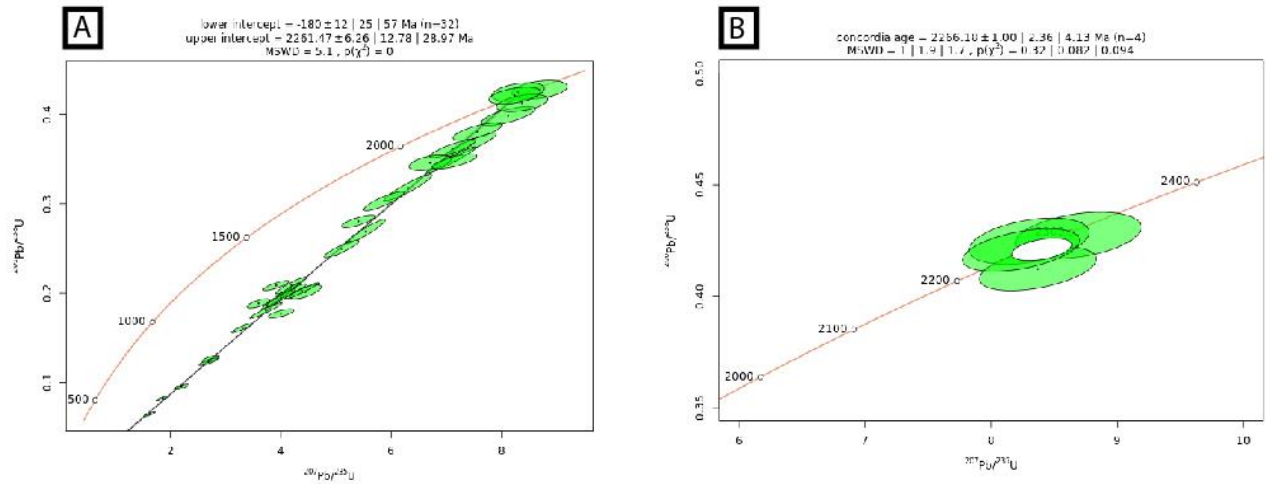


Figure 4.33: (a) The $^{206}\text{Pb}/^{238}\text{U}$ versus $^{207}\text{Pb}/^{235}\text{U}$ Concordia diagram summarising strongly concordant U-Pb geochronological data for zircon rims from points of the gneiss. (b) Concordia diagram for only the most concordant data (zircon rims).

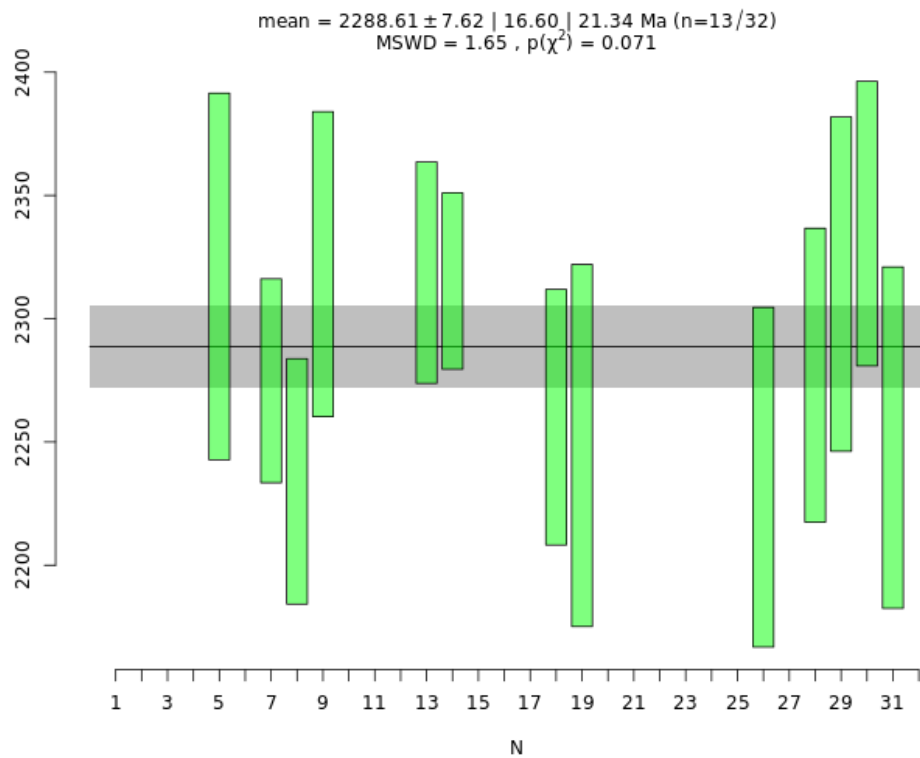


Figure 4.34: Weighted mean diagram for rim spots from sample Cid_F 113B.

Table 7: Summary of LA-ICPMS U-Pb zircon data, sample CidF_113B.

CidF_113		U	Th	Th/U	Pb			²⁰⁷ Pb/ ²³⁵ U				Error								
B Zircon Number	Source file	(ppm)	(ppm)	Ratio	(ppm)	²⁰⁷ Pb* ²⁰⁶ Pb ±%	U	±%	²⁰⁶ Pb/ ²³⁸ U	±%	Correlation	²⁰⁶ Pb/ ²³⁸ U	± (Ma)	²⁰⁷ Pb/ ²³⁵ U Age (Ma)	± (Ma)	²⁰⁷ Pb/ ²⁰⁶ Pb Age (Ma)	± (Ma)	Discordant (%)		
1	4_1c1	564	546	1.0206	4510	0.1401	0.0052	8.173	0.37	0.4243	0.0076	0.4055	2280	34	2250.6	39	2226.1	36	-2.41	
	4_1r	353	93.6	3.61	640	0.1345	0.0051	7.216	0.33	0.3894	0.0076	0.62242	2119	35	2137	41	2156	40	1.6	
	4_1cx	432	397	1.098	3340	0.1423	0.0054	8.47	0.39	0.4325	0.0086	0.72267	2316	39	2280	41	2254	42	-2.8	
	4_2c1	462	304	1.526	4140	0.1725	0.0065	10.86	0.51	0.457	0.0094	0.7814	2425	42	2508	43	2582	46	6	
2	4_2c2	1302	126.8	10.14	5050	0.1688	0.0065	5.56	0.29	0.2406	0.0078	0.96544	1387	40	1906	44	2544	46	45.2	
	4_2r1	1740	294	8.06	8430	0.198	0.018	7.315	0.33	0.2964	0.007	0.44227	1672	36	2149.4	41	2650	22	36.6	
3	4_2cr2	792	86.2	8.89	4430	0.1724	0.0064	8.925	0.41	0.3756	0.0072	0.73465	2055	34	2328.9	42	2580.6	38	20.34	
	4_3c1	498	249	1.984	2353	0.1416	0.0053	8.495	0.39	0.4345	0.0081	0.61449	2325	36	2284.1	41	2248.3	41	-3.6	
	4_3r1	555	363	1.518	3100	0.1548	0.0058	7.319	0.33	0.3423	0.0065	0.64372	1897	31	2151.1	40	2399	45	20.86	
	4_3cx1	814	374	2.175	2910	0.1396	0.0053	6.381	0.29	0.3314	0.0065	0.67098	1845	31	2029	41	2222.5	38	16.91	
4	4_4c1	149.9	69.1	2.144	976	0.1557	0.006	9.38	0.43	0.4349	0.0084	0.52128	2327	38	2374	43	2409	46	3.3	
	4_4c2	452	286.4	1.517	2880	0.1437	0.0054	9.36	0.43	0.4719	0.01	0.79561	2490	44	2374	41	2270.8	33	-9.7	
	4_4r1	1092	66.6	16.84	1831	0.13355	0.005	6.894	0.31	0.3731	0.007	0.67959	2043	33	2096.9	40	2144.5	38	4.55	
	4_5c1	296.9	158.1	1.826	1354	0.143	0.0054	8.432	0.38	0.4271	0.0078	0.42895	2292	35	2278.6	42	2263.5	34	-1.32	
5	4_5c2	670	573.4	1.138	4673	0.14309	0.0053	8.245	0.37	0.4172	0.0076	0.57752	2247	34	2257.5	41	2262.5	34	0.64	
	4_5r1	587	612	0.95	6420	0.1504	0.0057	4.19	0.22	0.2021	0.0068	0.9313	1184	36	1665	42	2349	47	49.5	
	4_5r2	278	104.3	2.647	2670	0.164	0.0067	8.15	0.4	0.3618	0.0076	0.56492	1990	36	2245	44	2495	61	20	
	4_6c1	610	300.6	1.987	2620	0.1396	0.0052	7.11	0.35	0.3675	0.0094	0.91488	2015	44	2120	43	2223.8	46	9.6	
6	4_6r1	922	253	3.601	1770	0.1463	0.0057	2.174	0.12	0.1065	0.0031	0.9759	652	18	1166	35	2301	45	71.65	
	4_6c2	262.2	109.7	2.375	1093	0.145	0.0055	8.643	0.39	0.4319	0.0081	0.50279	2314	36	2300	41	2287.8	37	-1.25	
7	4_7c1	735	960	1.011	7040	0.1531	0.0058	4.31	0.22	0.2031	0.0053	0.90966	1191	29	1690	42	2382	42	50	
	4_7r1	1196	778	1.494	9690	0.1566	0.0062	2.723	0.13	0.1265	0.0034	0.73005	767	19	1332	35	2414	57	68.04	
	4_8c1	338.9	218	1.531	1838	0.1434	0.0054	8.435	0.38	0.4258	0.0078	0.46404	2286	35	2277.9	41	2266.1	36	-0.9	
	4_8c2	227	136.8	1.648	1273	0.1525	0.0059	8.188	0.37	0.3899	0.0081	0.56581	2121	38	2251.9	42	2374	40	10.5	
8	4_8r1	466	56.2	8.21	6380	0.1851	0.008	8.52	1.1	0.315	0.03	0.99458	1720	140	2144	100	2686	66	37.4	
	4_9c1	240.9	92.3	2.579	1876	0.1741	0.0067	10.3	0.49	0.428	0.008	0.64773	2296	36	2459	44	2595	52	11.56	
	4_9c2	436	317.9	1.349	2701	0.1426	0.0053	8.339	0.38	0.4244	0.0078	0.55452	2280	35	2268.7	42	2256.5	40	-1.11	
	4_9r1	719	98.8	7.07	1747	0.1386	0.0053	3.596	0.17	0.1885	0.0043	0.70663	1113	23	1546	37	2209	45	49.55	
9	4_9r2	667	350	1.97	1633	0.1462	0.0056	4.19	0.23	0.2087	0.0079	0.93666	1219	42	1660	48	2299	49	46.8	
	4_10c1	78.7	33	2.388	396	0.1591	0.0066	8.19	0.4	0.377	0.012	0.67911	2055	56	2247	44	2443	57	15.1	
	4_10c2	98.5	41.2	2.346	458	0.1505	0.0061	8.72	0.41	0.4224	0.0086	0.38785	2270	39	2308	45	2350	38	3.2	
	4_10r1	72.7	32.9	2.171	372	0.1479	0.006	8.69	0.41	0.4273	0.0085	0.35291	2292	38	2303	43	2324	36	1.2	
10	4_10r2	497	1000	0.732	1544	0.148	0.0057	4	0.28	0.197	0.012	0.98088	1152	64	1602	58	2321	44	50.1	
	4_10r3	582	400	1.403	3550	0.1583	0.0061	5.67	0.27	0.2601	0.0057	0.82109	1489	29	1923	41	2435	45	38.82	
	4_11c1	276.9	141.5	1.934	1268	0.1401	0.0053	8.155	0.37	0.4224	0.0077	0.47053	2271	35	2247.1	41	2232	37	-1.79	
	4_11c2	100.7	3.79	28.5	61.1	0.137	0.0057	7.3	0.35	0.3888	0.0077	0.23095	2116	36	2149	43	2185	45	2.6	
11	4_11r1	280	123	2.207	1138	0.1442	0.0056	6.31	0.35	0.318	0.012	0.9318	1780	57	2015	49	2281	35	22.2	
	4_11r2	279	165	1.722	1149	0.141	0.0054	5.87	0.3	0.3029	0.0088	0.87362	1703	44	1951	44	2238	40	23.8	
	4_12c1	126	51.9	2.438	711	0.1585	0.0062	7.56	0.36	0.3473	0.009	0.69606	1919	43	2177	43	2441	46	21.1	
	4_12r1	183.4	91.3	1.961	1044	0.1479	0.0058	8.12	0.4	0.3981	0.0087	0.71946	2159	40	2239	44	2318	50	6.8	
12	4_12r2	330	58.6	5.48	581	0.135	0.0055	3.21	0.23	0.1754	0.0094	0.98931	1037	48	1440	44	2159	51	52.3	
	4_13c1	224	87.8	2.487	818	0.1428	0.0055	7.897	0.36	0.4004	0.0075	0.45011	2170	35	2219	43	2260	36	3.8	
	4_13r1	362	71.1	4.85	990	0.1605	0.0065	4.45	0.23	0.2014	0.0064	0.72366	1181	35	1717	44	2453	53	51.8	
	4_14c1	218.1	131.8	1.613	1440	0.146	0.0056	7.768	0.36	0.3856	0.0075	0.47974	2101	35	2203	41	2299	37	8.5	
13	4_14r1	827	995	0.806	3159	0.1478	0.0056	3.306	0.16	0.1613	0.0044	0.93068	963	24	1478	37	2322	45	58.41	
	4_15c1	103.5	52.6	1.908	399.4	0.1438	0.0057	7.41	0.35	0.3729	0.0078	0.44817	2042	36	2159	42	2269	43	9.8	
	4_15c2	142.1	113.4	1.213	835	0.1473	0.0057	8.12	0.38	0.3972	0.0077	0.73545	2155	35	2242	42	2317	37	6.98	
	4_15c3	182	156.7	1.128	922	0.1483	0.0058	7.196	0.33	0.3514	0.007	0.50093	1940	34	2135	43	2324	38	16.59	
14	4_15c4	254.2	128.2	1.92	891	0.1459	0.0055	6.945	0.32	0.3437	0.0066	0.53381	1904	31	2103	41	2301	40	17.2	
	4_15r1	662	59.7	11.31	1327	0.1668	0.0065	2.2	0.11	0.0955	0.0026	0.7768	588	15	1178	34	2522	45	76.61	
	4_16c1	134.2	60.7	2.144	596	0.1465	0.0058	8.39	0.39	0.4131	0.008	0.31299	2228	37	2272	42	2304	38	2.9	
	4_16r1	257	70.5	3.47	934	0.147	0.0056	7.44	0.38	0.3655	0.011	0.91065	2004	50	2158	48	2309	41	13.1	
15	4_17c1	639	519	1.195	8450	0.1526	0.0057	9.64	0.46	0.4551	0.011	0.87985	2415	47	2397	44	2376.2	46	-1.6	
	4_17r1	918	377.7	2.306	8780	0.1473	0.0055	7.09	0.37	0.349	0.012	0.96224	1923	57	2113	48	2314.1	40	16.7	
16	4_18c1	158.6	41.9	3.79	516	0.1496	0.0058	7.5	0.35	0.3632	0.0072	0.46363	1996	34	2173	42	2343	38	14.69	
	4_18r1	594	263.7	2.163	2430	0.1564	0.006	5.94	0.29	0.2763	0.0085	0.90692	1570	43	1961	44	2415	47	34.7	
	4_19c1	533	51.5	10.23	1826	0.1526	0.00													

25	4_25c1	288	127.3	2.191	1556	0.1525	0.0058	9.02	0.42	0.4265	0.0082	0.50464	2289	37	2338	42	2380	47	3.69
	4_25c2	294.5	125.2	2.281	1068	0.1402	0.0054	8.215	0.37	0.4248	0.0086	0.52478	2281	39	2253.6	41	2229	43	-2.4
	4_25r1	505	65.9	7.51	924	0.1518	0.0064	3.73	0.24	0.1805	0.0071	0.95808	1067	38	1577	55	2355	60	55
	4_25r2	761	195	4.63	1700	0.1516	0.0062	5.54	0.29	0.269	0.011	0.94459	1531	59	1898	46	2355	65	33.9
26	4_26c1	252.6	164	1.495	1274	0.1422	0.0055	8	0.37	0.406	0.0079	0.49261	2196	36	2229	42	2246	39	2.3
	4_26c2	267.8	154.2	1.71	1812	0.1542	0.006	9.74	0.45	0.4572	0.011	0.62713	2425	47	2409	42	2390	49	-1.8
	4_26r1	397.6	56.3	7.04	1162	0.157	0.0062	2.689	0.14	0.1236	0.0035	0.84206	751	20	1319	38	2421	47	68.96
	4_26r2	496	532	0.999	2610	0.1486	0.0057	5.1	0.26	0.2495	0.008	0.90161	1433	41	1833	42	2328	42	38.3
27	4_27c1	91.39	32.93	2.74	257.4	0.1408	0.0056	8.1	0.38	0.4141	0.0081	0.33245	2233	37	2239	42	2233	49	-0.2
	4_27c2	130.9	50.4	2.553	421	0.1405	0.0055	8.29	0.39	0.4272	0.0081	0.43266	2293	37	2262	44	2231	42	-2.9
	4_27r1	565	82.7	6.75	545	0.1304	0.0049	5.865	0.27	0.3244	0.0068	0.69879	1810	33	1954	41	2106	41	13.9
	4_27r2	373	88	4.09	1612	0.1627	0.0064	5.86	0.3	0.2603	0.0075	0.84275	1489	39	1947	47	2481	48	39.9
28	4_28r1	693	632	1.071	3413	0.1395	0.0052	5.407	0.25	0.2803	0.0058	0.78381	1592	29	1884	39	2220.7	35	28.26
	4_28c1	467.4	295.5	1.562	2639	0.1448	0.0055	6.911	0.32	0.3456	0.0076	0.7896	1912	37	2098	41	2284.7	38	16.2
29	4_29c1	287.7	267.4	1.052	2446	0.142	0.0054	8.57	0.39	0.4364	0.0083	0.54092	2334	37	2291	42	2253	41	-3.7
	4_29c2	230.9	149.6	1.518	1295	0.1427	0.0055	7.69	0.36	0.3899	0.0081	0.67675	2124	39	2193	42	2259.5	34	5.9
	4_29r1	761	419	1.86	2080	0.1359	0.0052	3.916	0.19	0.2085	0.0045	0.83162	1221	24	1614	38	2174	44	43.86
30	4_30c1	537	606	0.8637	4734	0.1389	0.0052	8.03	0.37	0.4185	0.0079	0.68077	2253	36	2233	42	2211.9	37	-1.94
	4_30c2	283.8	181.3	1.53	1538	0.1375	0.0053	8.16	0.38	0.4311	0.008	0.4912	2310	36	2249	43	2195	37	-5.44
	4_30r1	318	75.5	4.261	417	0.1385	0.0056	1.883	0.089	0.0989	0.002	0.58937	608	12	1073	31	2206	41	72.34
	4_30r2	509	66.6	8.61	618	0.1347	0.0053	2.812	0.14	0.1522	0.0039	0.82323	913	22	1355	37	2162	47	57.65
31	4_31c1	982	294	3.259	2870	0.1445	0.0055	4.16	0.23	0.21	0.0087	0.97647	1224	47	1653	47	2281	45	46.1
	4_31r1	224	206.3	1.068	1044	0.1405	0.0055	6.704	0.31	0.3456	0.0069	0.47945	1913	33	2071	41	2234	41	14.1
32	4_32c1	215.1	90.8	2.315	785	0.1392	0.0054	8.065	0.37	0.4211	0.008	0.39864	2265	36	2237	42	2216	34	-2.32
	4_32c2	229.2	97.5	2.27	865	0.1385	0.0053	8.07	0.37	0.4241	0.0083	0.57798	2278	38	2237	41	2207	42	-3.3
	4_32r1	387	40.7	9.02	634	0.1378	0.0054	4.01	0.28	0.213	0.013	0.97428	1237	69	1608	54	2199	53	43.1
	4_33c1	1070	155.1	6.87	1697	0.125	0.0048	2.181	0.12	0.1269	0.0044	0.93157	769	25	1169	36	2028	39	62
33	4_33c2	201.2	96.9	2.035	875	0.1431	0.0055	8.401	0.38	0.4259	0.0082	0.46434	2286	37	2274	41	2266	38	-1
	4_33r1	506	367	1.619	1450	0.1641	0.0064	4.004	0.19	0.1773	0.004	0.71893	1051	22	1633	37	2496	44	57.66
	4_33r2	631	95.4	6.36	1111	0.1339	0.0053	2.138	0.1	0.1157	0.0026	0.70192	705.7	15	1158	34	2145	43	67.11
	4_34c1	244.7	137.6	1.76	1233	0.1414	0.0054	8.51	0.4	0.4353	0.0091	0.69424	2328	41	2286	44	2251.2	38	-3.6
34	4_34c2	99.2	112.9	0.844	1954	0.2263	0.011	14.4	1	0.452	0.013	0.88346	2400	56	2741	62	3001	71	19.91
	4_34r1	264	89.8	3.81	2032	0.205	0.0081	4.9	0.24	0.1736	0.004	0.7434	1031	22	1798	41	2863	51	63.86
35	4_35c1	942	60.8	19.3	6140	0.1327	0.005	4.039	0.2	0.2207	0.0056	0.90281	1284	30	1638	40	2133.1	45	39.7
	4_35c2	172	86.1	1.97	713	0.1444	0.0056	8.02	0.37	0.4039	0.0082	0.39036	2186	38	2231	42	2275	46	3.7
	4_35r1	148	172	0.887	1330	0.1554	0.0062	6.72	0.32	0.3133	0.0077	0.62624	1755	38	2071	42	2403	45	26.8
	4_35r2	169.1	83.3	1.98	913	0.1443	0.0056	7.56	0.36	0.3805	0.0081	0.72654	2077	38	2177	42	2275	41	8.5
36	4_36c1	481	229	2.092	1941	0.143	0.0054	8.34	0.4	0.4226	0.011	0.85479	2269	48	2264	44	2264	42	-0.4
	4_36r1	717	178.4	5.02	1625	0.1365	0.0053	6.6	0.45	0.346	0.017	0.98287	1900	85	2018	73	2182	57	13.5
37	4_37c1	233.6	96.5	2.378	1208	0.1605	0.0065	6.31	0.3	0.2852	0.0068	0.6767	1616	34	2016	42	2458	38	34.1
	4_37r1	262	157	1.673	1500	0.1473	0.0057	8.37	0.38	0.4123	0.008	0.45974	2224	37	2270	42	2313	38	3.6
	4_37r2	811	39.5	20.32	2720	0.1491	0.0056	7.148	0.33	0.3471	0.0067	0.74017	1920	32	2128.6	41	2336.4	36	17.74
	4_38c1	179.5	180	1.113	1830	0.1833	0.0094	9.53	0.46	0.3872	0.011	-0.19907	2106	51	2391	47	2652	77	19
38	4_38r1	227	183.7	1.22	1428	0.1418	0.0054	8.237	0.38	0.4207	0.0078	0.46644	2263	35	2256	42	2248	40	-0.76
	4_38r2	284.8	238.3	1.171	1833	0.1424	0.0054	8.584	0.39	0.4366	0.008	0.5273	2335	36	2295	43	2256	38	-3.69
39	4_39c1	301	238	1.247	2330	0.1555	0.006	9.47	0.45	0.4412	0.01	0.76408	2354	47	2381	43	2408	46	2.1
	4_39r1	174.3	131.1	1.279	1111	0.188	0.0074	8.4	0.41	0.3215	0.0069	0.60472	1796	34	2270	44	2729	41	34.2
40	4_40c1	192.4	129.8	1.471	1106	0.1487	0.0057	8.98	0.42	0.4372	0.0082	0.44268	2337	37	2336	41	2330	42	-0.7
	4_40c2	386	447	0.843	3106	0.1458	0.0055	8.344	0.38	0.4148	0.008	0.5804	2236	36	2267.7	41	2295.7	41	2.5
41	4_40r1	2006	1327	1.524	2.20E+04	0.1643	0.0066	1.864	0.1	0.0827	0.0023	0.91219	512	14	1066	36	2495	60	79.37
	4_41c1	229.5	116.5	1.968	849	0.142	0.0055	7.05	0.34	0.36	0.0078	0.72129	1981	37	2114	42	2247	40	11.8
	4_41r1	542	36.1	15.36	381	0.135	0.0051	5.301	0.25	0.2844	0.0065	0.84648	1612	33	1866	41	2163.3	39	25.4
2 standard errors																			

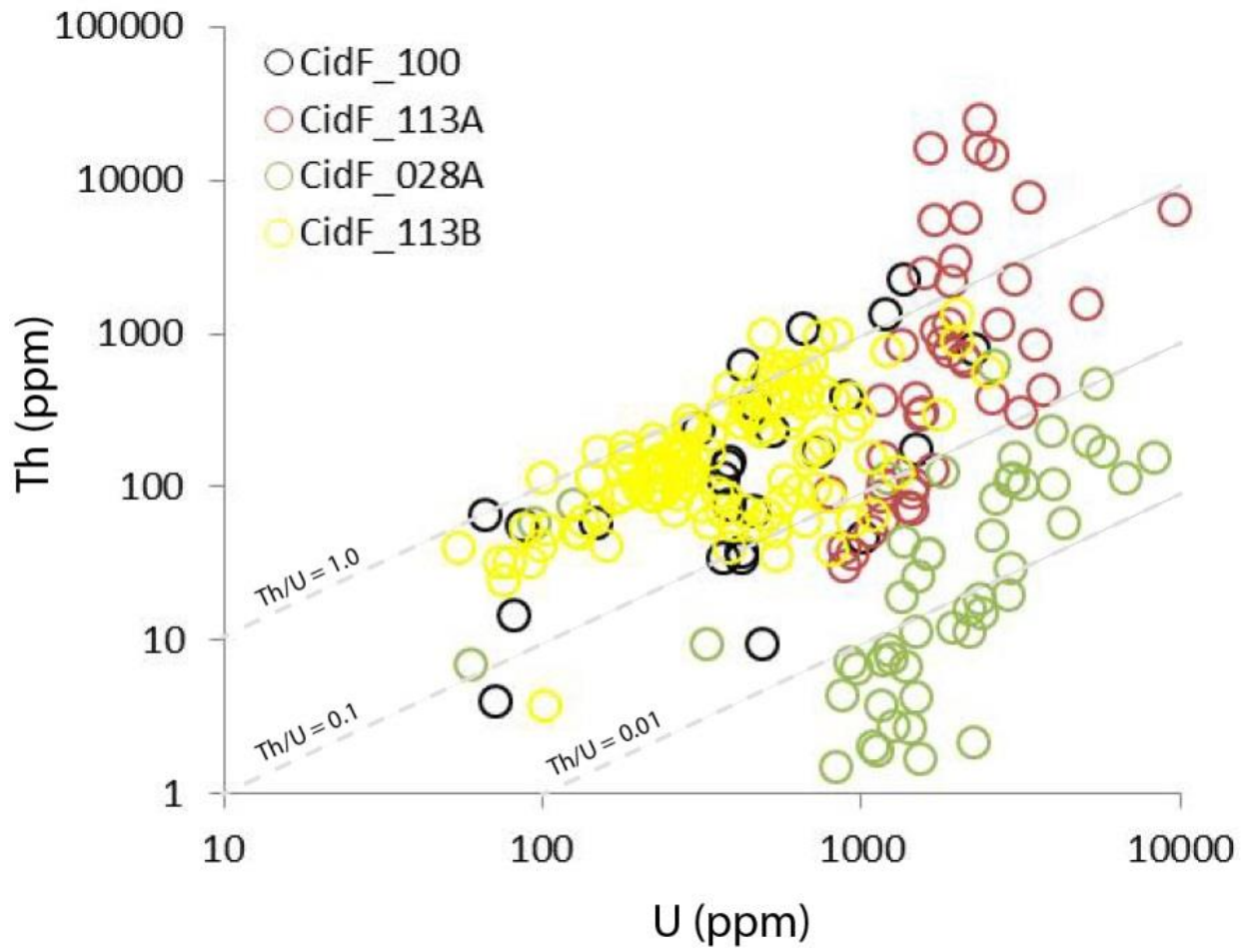


Figure 4.35: Th (ppm) vs. U (ppm) variation diagram for the studied samples. Sample CidF_028A (bold green) has a Th/U ratio less than 0.1 indicating that it is dominated by metamorphic zircons. Samples Cid_F 100, 113A and 113B comprise of magmatic zircon, hence, Th/U ratio is greater than 0.1.

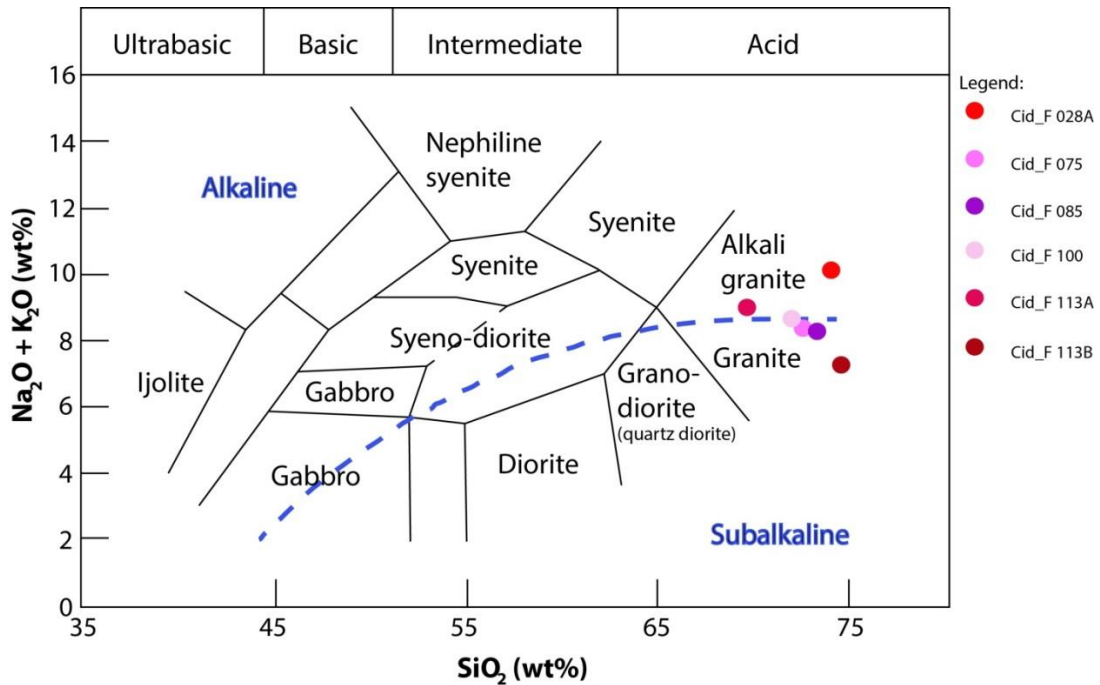


Figure 4.36: TAS (SiO_2 vs. $\text{Na}_2\text{O} + \text{K}_2\text{O}$ variation diagram) for plutonic rocks diagram of Cox et al. (1979) adapted by Wilson (1989). Sample Cid_F 028A plots in the alkali granite field because of high K-feldspar content. Inversely, sample Cid_F 113B is characterized by lower $\text{Na}_2\text{O} + \text{K}_2\text{O}$ (wt%) content.

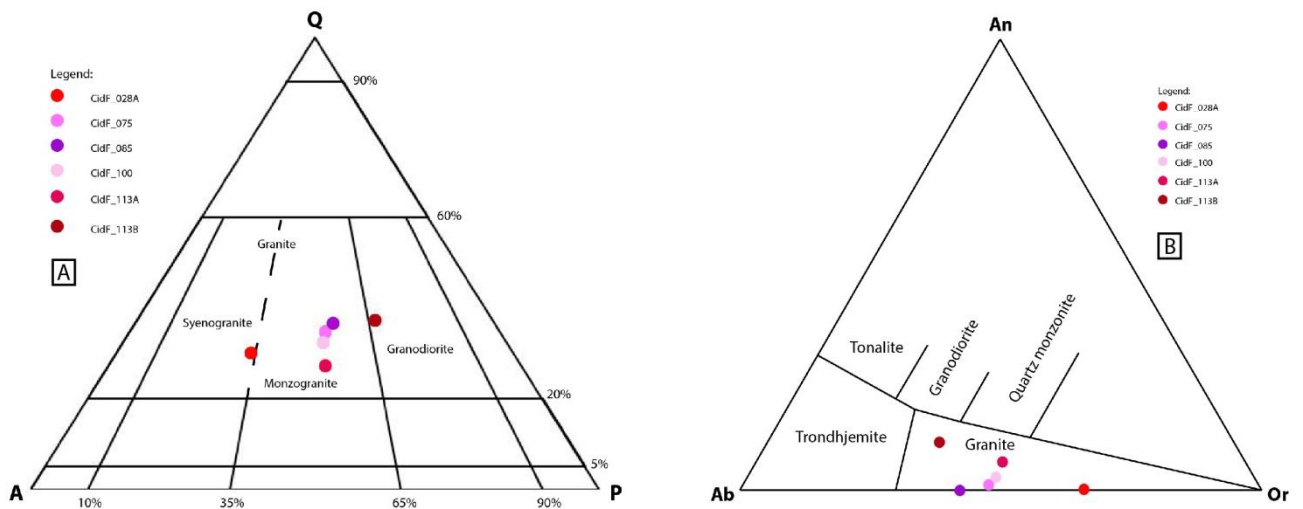


Figure 4.37: (a) QAP diagram of Streckeisen (1976). (b) Normative Anorthite (An) Albite (Ab) Orthoclase (Or) diagram [(O'Connor (1965). modified after Barker (1979))] showing the compositions the granitoids. Sample Cid_F 113B contains the highest amount of plagioclase content i.e. orthoclase.

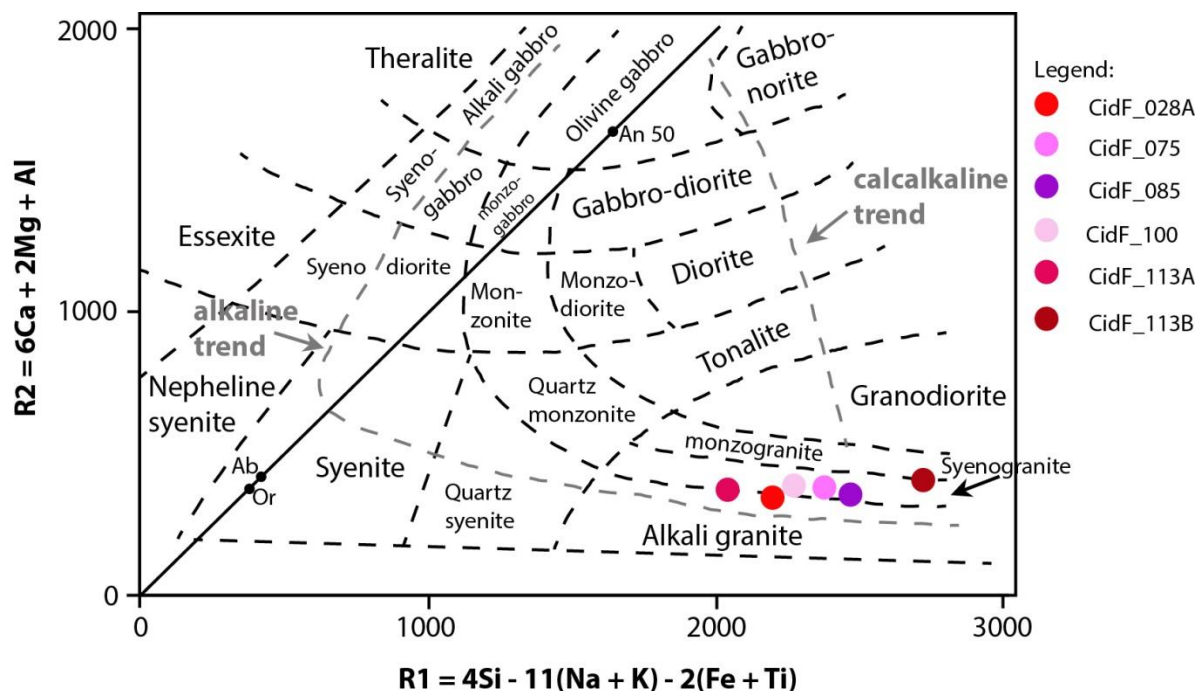


Figure 4.38: R1-R2 multication discrimination diagram (De La Roche et al. 1980) for Ferké Batholith granitoids. Samples plot in the granite (synogranite) field. Sample Cid_F 113B plots in the margin of both synogranite and monzogranite due to higher plagioclase content.

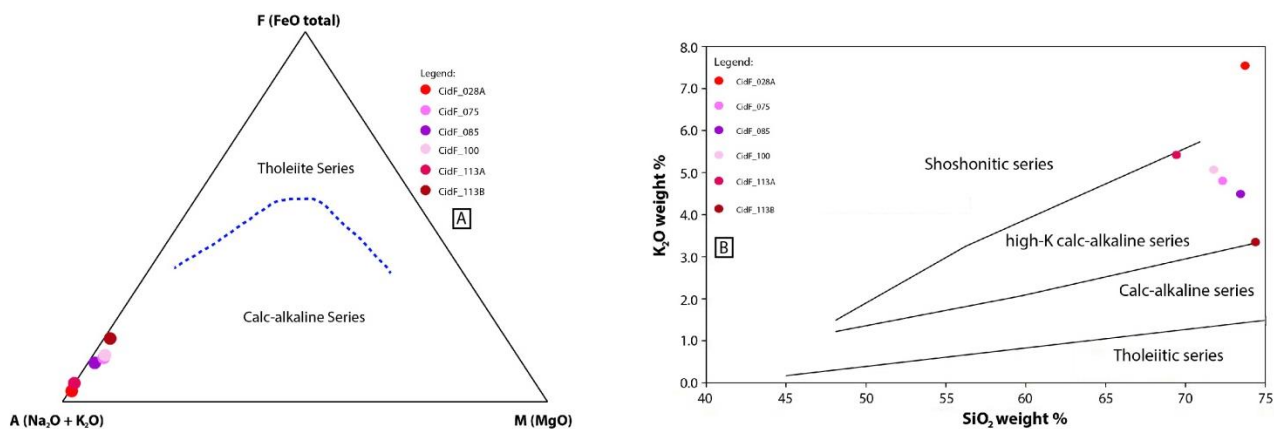


Figure 4.39: (a) AFM diagram for granitoids of the Ferké Batholith, after Irvine & Baragar (1971). (b) SiO_2 (wt. %) vs. K_2O (wt. %) plot (after Pearce et al., 1990) of the batholith. Note sample Cid_F 028A is the only sample displaying shoshonitic character.

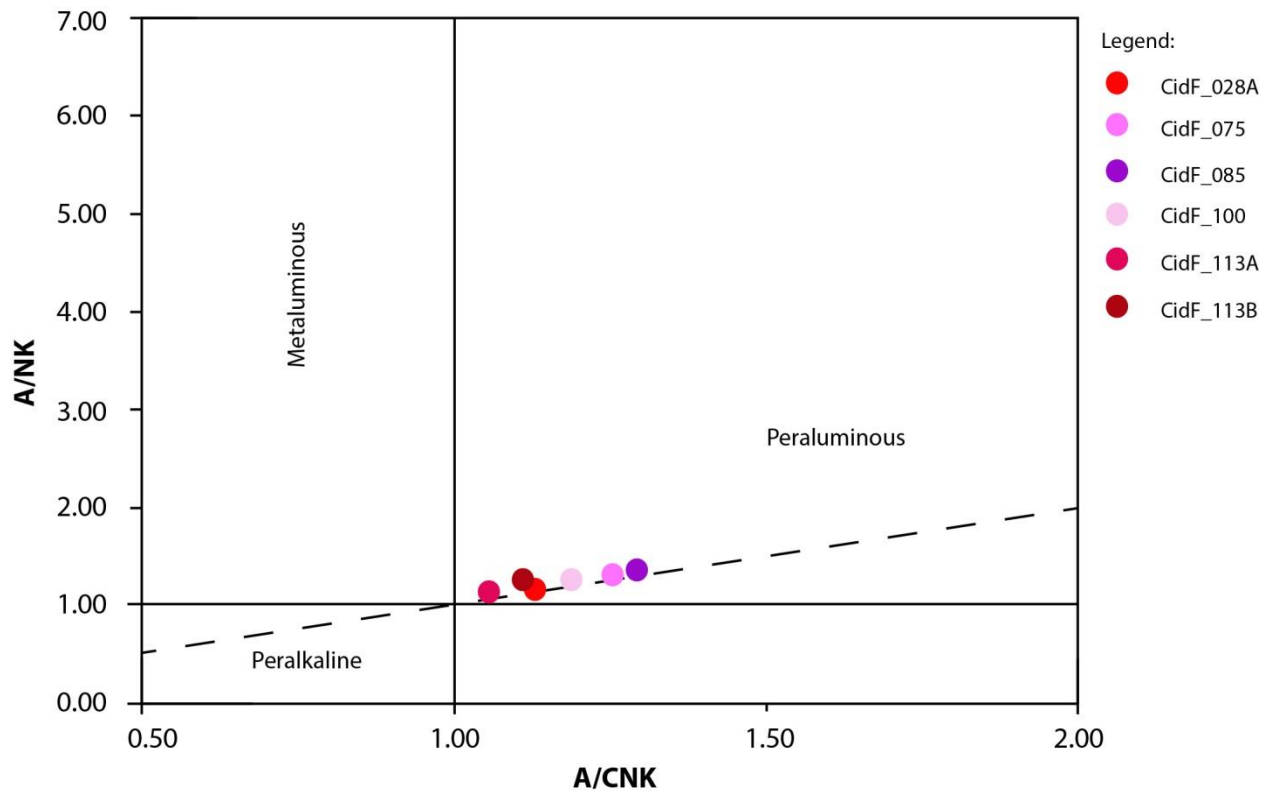


Figure 4.40: CNK [molar Al_2O_3 / $(\text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O})$] vs A/NK (molar Al_2O_3 / $(\text{Na}_2\text{O} + \text{K}_2\text{O})$) diagram of [Shand \(1943\)](#) adopted by [Maniar and Piccoli \(1989\)](#) showing chemical composition of the batholith. All samples commonly plot in the syn-collision field, amplifying the nature of the batholith.

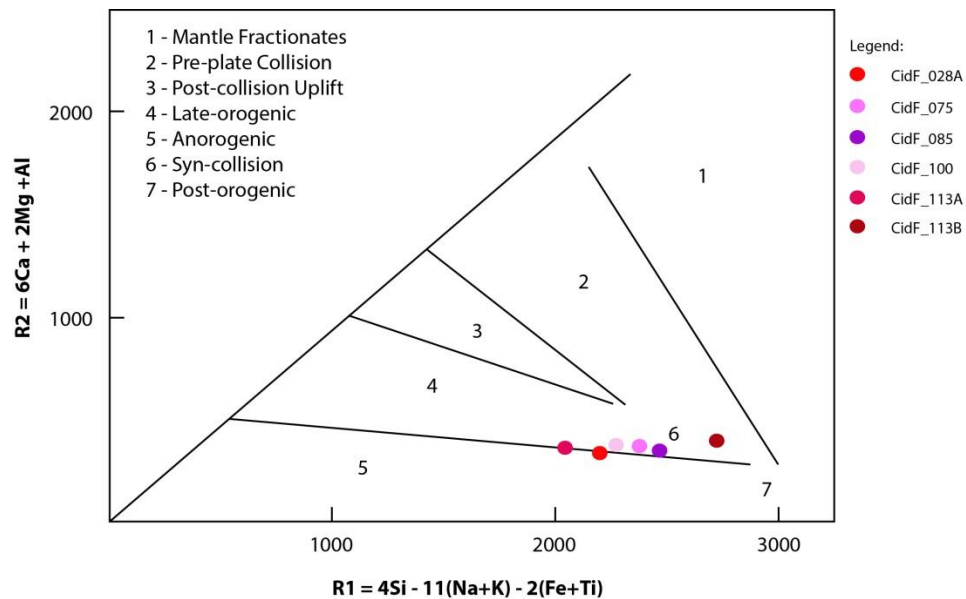


Figure 4.41: The R1-R2 major element geotectonic discrimination diagram of [Batchelor and Bowden \(1985\)](#) and samples. All samples commonly plot in the syn-collision field, amplifying the nature of the batholith.

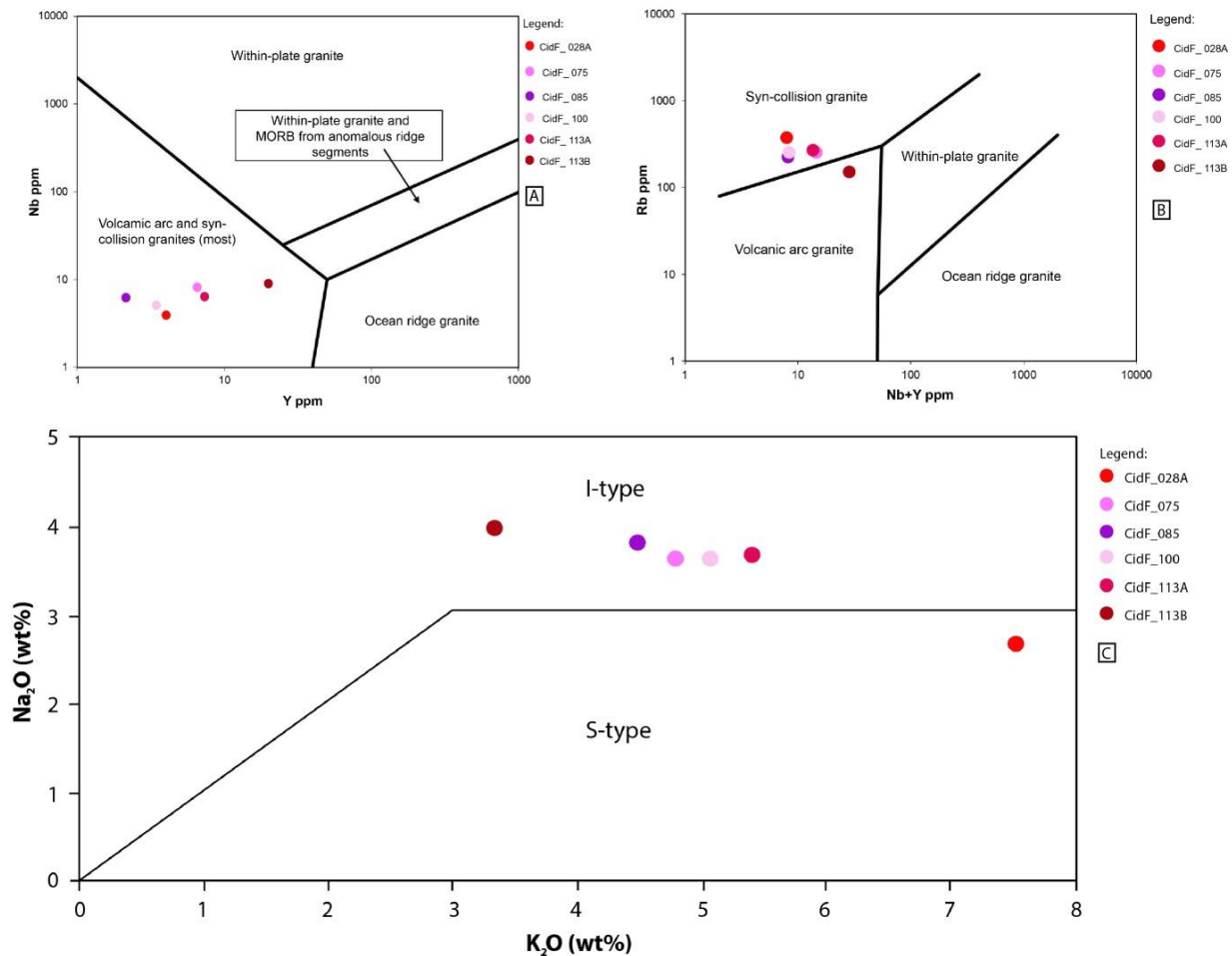


Figure 4.42: (a) and (b) Chemical composition of rocks after [Pearce et al. \(1984\)](#). (C) K₂O versus Na₂O diagram (after [Chappell and White, 1974](#)). Note samples Cid_F 075, Cid_F 085, Cid_F 100, Cid_F 113A and Cid_F113B plot as I-type granites, whereas sample Cid_F 028A is the only sample plotting in the S-type field.

4.3.2.6 Sample Cid_005

Orthogneiss of granodioritic composition crops out to the east of the Ferké Batholith, outside of the study area ~45km east of the village of Kouloukorosso at UTM 30P 0327198 1040578. This sample analysis gave a single magmatic population presenting a concordia age at 2172 ± 4 Ma ([Figure 4.43a](#) and [b](#)) and a weighted mean age at 2173 ± 8 Ma (MSWD=0.69, n=19). The age of 2172 ± 4 Ma is deduced as the magmatic age ([Table 8](#)).

4.3.2.7 Sample Cid_102a

Sample Cid_102a was collected from an orthogneiss unit of granodioritic composition, cropping out ~8km north of the town of Korhogo at UTM 30P 0212851 1051172. U-Pb magmatic age of 2282 ± 4 Ma (MSWD 1.12, n=19) was obtained ([Figure 4.44a](#) and [b](#)). Two

zircons returned younger age at 2120 and 2097 Ma from rims (Table 8). These zircons also returned Th/U less than 0.2 compatible with a metamorphic origin but also associated with high uranium concentration greater than 1000 ppm, which could possibly be an artefact.

4.3.2.8 Sample Cid_F 038

Granodiorite intrudes metasedimentary units ~10km south east of the town of Korhogo at UTM 30P 0218508 1039917. Two distinctive zircon populations returned from this sample. The first population returned a weighted mean age at 2091 ± 6 Ma (MSWD=1, n=17). The second population returned a weighted mean age at 2054 ± 11 Ma (MSWD=1.9, n=4). The age of 2054 ± 11 Ma is tentatively taken as the magmatic age for sample Cid_F 038 (Figure 4.45). An alternative analysis would be that the second population is associated with ancient lead loss and that the age of 2091 ± 6 Ma is the magmatic age (Table 8).

4.3.2.9 Sample Cid_F 086

Orthogneiss of granodioritic composition is intruded by granodiorite ~23km east of the town of Tortiya at UTM 30P 0238706 984714. Sample CidF_086 returned a magmatic population presenting a weighted mean age at 2066 ± 10 Ma (MSWD=0.84, n=12) (Figure 4.46). One inherited zircon returned an age of 2153 ± 16 Ma (Table 8).

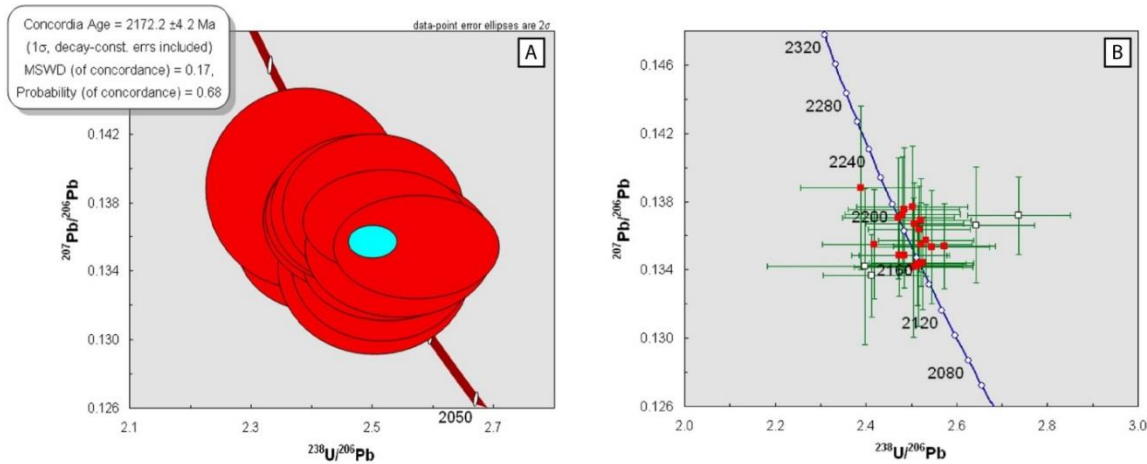


Figure 4.43: (a) Concordia age calculated for concordant analyses of the orthogneiss. (b) Shows concordia data plots associated with the sample Cid_005. Red squares = magmatic population, white squares = discordant analyses.

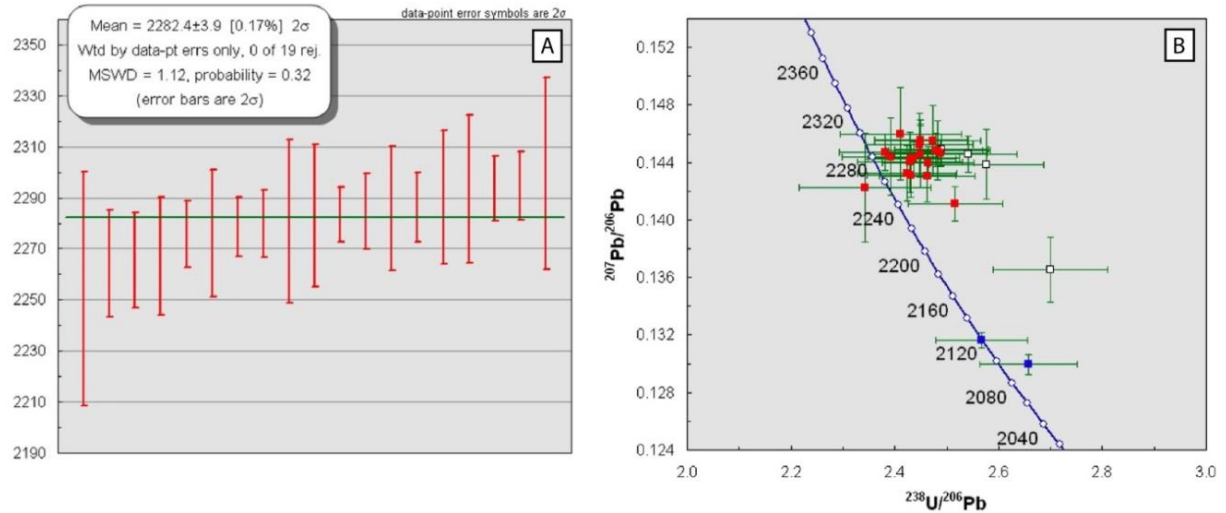


Figure 4.44: (a) Weighted average for magmatic population from sample Cdi_102A. (b) Shows concordia data plots associated with orthogneiss. Red squares = magmatic population, blue squares = possible metamorphic zircons or artefact, white squares = discordant analyses.

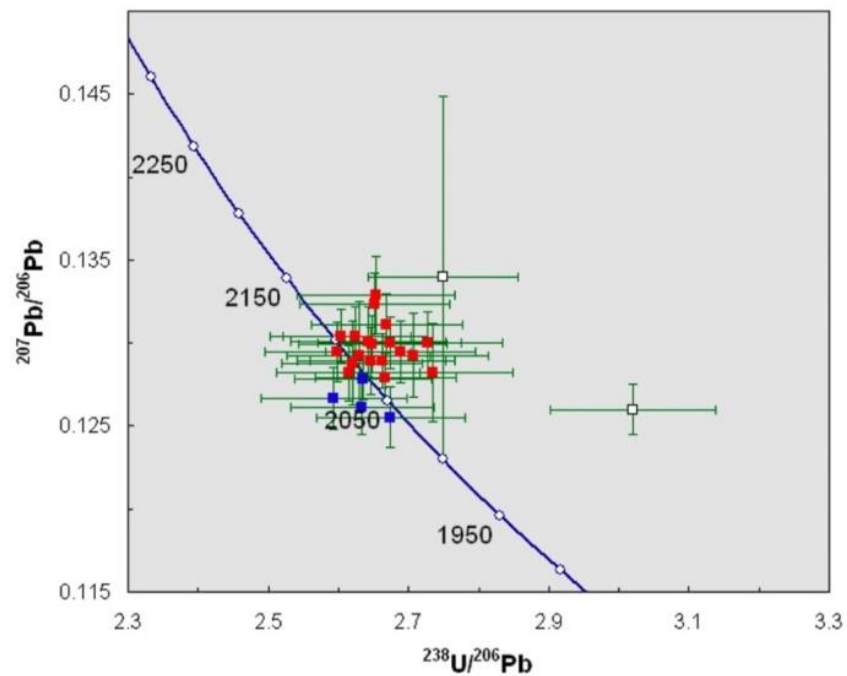


Figure 4.45: Shows concordia data plots associated with Sample Cid_F 038. Red squares = Inherited population, blue squares = magmatic population, white squares = discordant analyses.

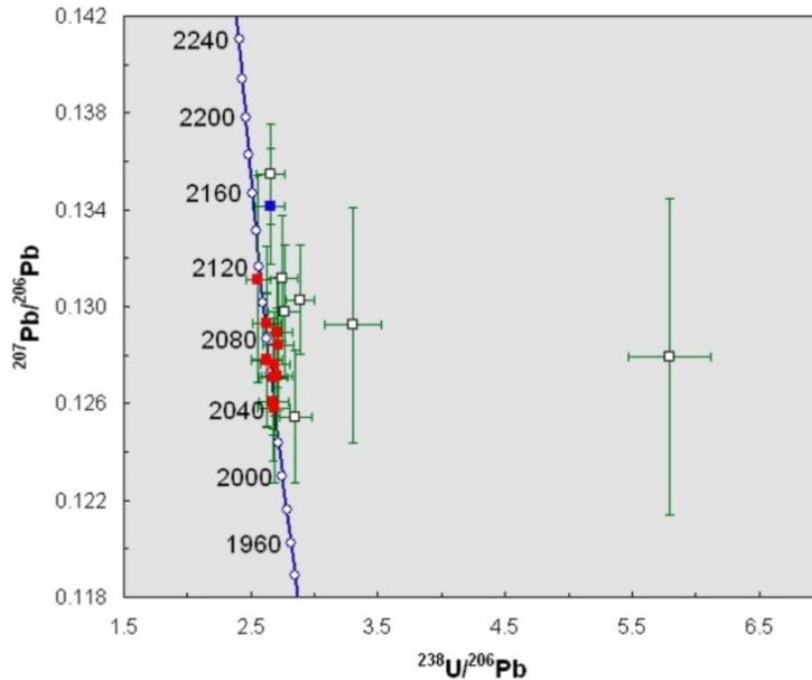


Figure 4.46: Shows concordia plots associated with Sample Cid_F 086. Blue squares = Inherited population, red squares = magmatic population, white squares = discordant analyses.

Table 8 : Summary table of LA-ICPMS U-Pb zircon and U-Pb SHRIMP ages from the analysed samples.

Sample Number	Sample Name	Crystallisation Age	Inherited/ xenocrystic zircon ages	New growth/ recrystallisation age	Core and rim ages	
					Core	Rim
CidF_028A	Pegmatite	1985 ± 9 Ma	2183 ± 1 Ma		1807 ± 1 Ma	1190 ± 1 Ma
			2188 ± 12 Ma		1308 ± 1 Ma	690 ± 1 Ma
					1338 ± 1 Ma	1168 ± 1 Ma
					2109 ± 6 Ma	
CidF_100	Two-mica granite	2132 ± 12 Ma	2175 ± 1 Ma	2037 ± 33 Ma	2150 ± 1 Ma	771 ± 1 Ma
			2174 ± 1 Ma		2146 ± 1 Ma	438 ± 1 Ma
CidF_113A	Pegmatite	2015 ± 1 Ma	2211 ± 1 Ma		1842 ± 20 Ma	1158 ± 1 Ma
			2387 ± 19 Ma			1901 ± 1 Ma
			2190 ± 13 Ma			
CidF_113B	Orthogneiss	2271 ± 1 Ma	2338 ± 1 Ma	2062 ± 1 Ma	2237 ± 1 Ma	512 ± 1 Ma
		2270 ± 5 Ma	2328 ± 1 Ma	2053 ± 1 Ma	2279 ± 5 Ma	1159 ± 1 Ma
			2493 ± 1 Ma	2044 ± 1 Ma	2271 ± 1 Ma	1489 ± 1 Ma
					2261 ± 6 Ma	1988 ± 1 Ma
					2266 ± 1 Ma	
					2289 ± 8 Ma	
Cid_005	Orthogneiss	2172 ± 4 Ma				
		2173 ± 8 Ma				
Cid_102a	Orthogneiss	2282 ± 4 Ma	2120 Ma	2079 Ma		
CidF_038	Granodiorite	2091 ± 6 Ma				
		2054 ± 11 Ma				
CidF_086	Orthogneiss	2066 ± 10 Ma	2153 ± 16 Ma			

5 STRUCTURAL AND TECTONIC OVERVIEW OF THE FERKÉ SHEAR ZONE (FSZ)

5.1 Introduction

The Ferké Shear Zone (FSZ) is a first-order crustal-scale structure and the main structural feature in the study area. Previously, FSZ has been recognised by [Lemoine \(1988\)](#), [Doumbia et al., \(1998\)](#), [Ouattara \(1998\)](#), [Feybesse et al. \(2006\)](#), [Pouclet et al. \(2006\)](#), [Coulibaly et al. \(2008\)](#), [Vidal et al. \(2009\)](#) and [Baratoux et al. \(2011\)](#) as a lineament crosscutting Ivory Coast. Structures defining the FSZ include zones of proto-mylonite, mylonite- to ultra-mylonite and various schists. The FSZ consists of two branches, the eastern and western branches ([Figure 5.1](#)).

The region between the branches consists of the Ferké Batholith; the elongate forms of leucogranites, enveloped by the meta-sedimentary and volcano-sedimentary units. At the eastern edge of the batholith, the eastern branch (herein termed the Yédandiekaha-Niakaramandougou branch) crosscuts the granites, granodiorites, tonalite, diorite and the volcano-sedimentary units including metasiltstone, sandstone and meta-volcaniclastic greywacke. The Yédandiekaha-Niakaramandougou branch in the northeast of the study area merges with the north-south trending Brobo-N'Zi Shear Zone (BNSZ). The western branch (herein termed the Ferké-Bandama branch) crosscuts granodiorites, granites and pegmatites of the Ferké Batholith and the metasedimentary and volcano-sedimentary rocks including metasiltstone and meta-volcaniclastic greywacke.

The study area is divided into 2 domains that is; Domain A: Yédandiekaha-Niakaramandougou branch and Domain B: Ferké-Bandama branch, east and west of the Ferké Batholith ([Figure 5.1](#)) to specifically display the relationship between the rock units and structural features in more prominent detail.

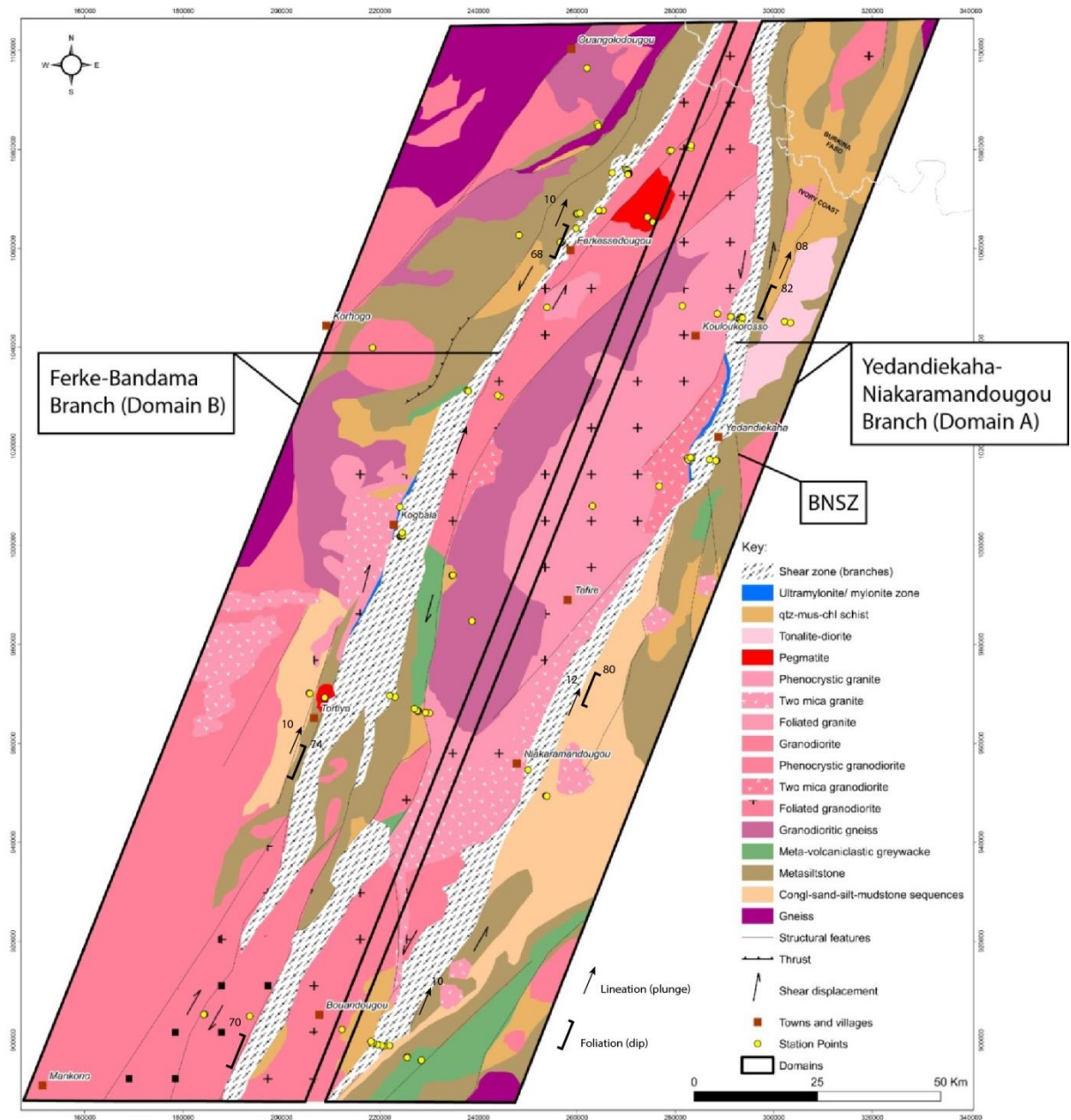


Figure 5.1: Geological map of the north-central Ivory Coast with details of the Ferké Batholith and the surrounding rock units. The boundaries of the batholith are defined by the north-northeast trending FSZ branches (Ferké-Bandama branch and Yédandiekaha-Niakaramandougou branches). BNSZ (Brobo-N'Zi Shear Zone) merges with the YN branch in the eastern portion of the study area. The sense of displacement of the shear zones and the locations of the towns and villages are indicated. Domains A and B are represented as black bold rectangles. Qtz- quartz, mus- muscovite, chl- chlorite.

5.2 The Ferké Shear Zone (FSZ)

5.2.1 The Yédandiekaha-Niakaramandougou branch

The Yédandiekaha-Niakaramandougou branch (YNB) extends hundreds of kilometres along the eastern boundary of Ferké Batholith (Domain A in [Figure 5.2a-c](#)), occurring along the towns of Niakaramandougou, Yédandiekaha and southern parts of Bandama River. This branch has a width of approximately 500m-2km. The shear zone branch forms boundary between the intrusive units and volcano-sedimentary sequences. The degree of metamorphism and intensity of deformation decreases from east to west within the intrusive units and west to east on volcano-sedimentary sequences.

In the Domain A along the YNB, numerous structural features were identified. These structures are characterised by (a) north-northeast to northeast foliation (S_1 and S_{1-C}), lineation (L_1), shears, folds (F_1), veins (V_1), en echelon, conjugate fracture, dilational jogs and the elongation of the Ferké Batholith and other surrounding lithologies ([Figure 5.3a-b](#) and [Figure 5.4a-b](#)). (b) North-northwest to northwest and northwest to west trends are defined by thin shears, foliation (S_2), lineation (L_2), folds (F_2), faults and S_3 fractures.

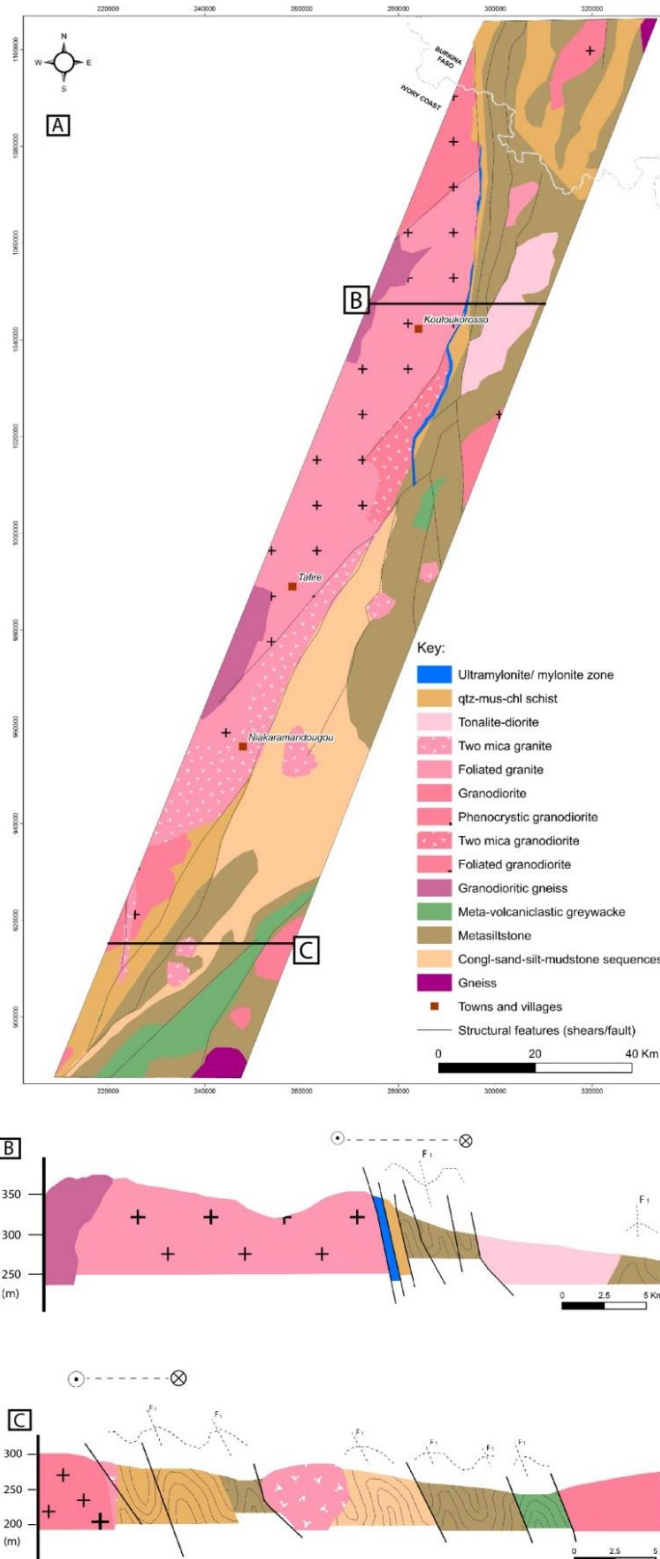


Figure 5.2: (a) The geology map of Domain A, outlining Yédandiekaha-Niakaramandougou branch and the adjacent lithologies. The bold black east-west lines are cross-section lines. (b-c) Cross-sections of the northern and southern parts of the Yédandiekaha-Niakaramandougou branch and adjacent area. The colours correspond to legend in Fig. 5.2a.

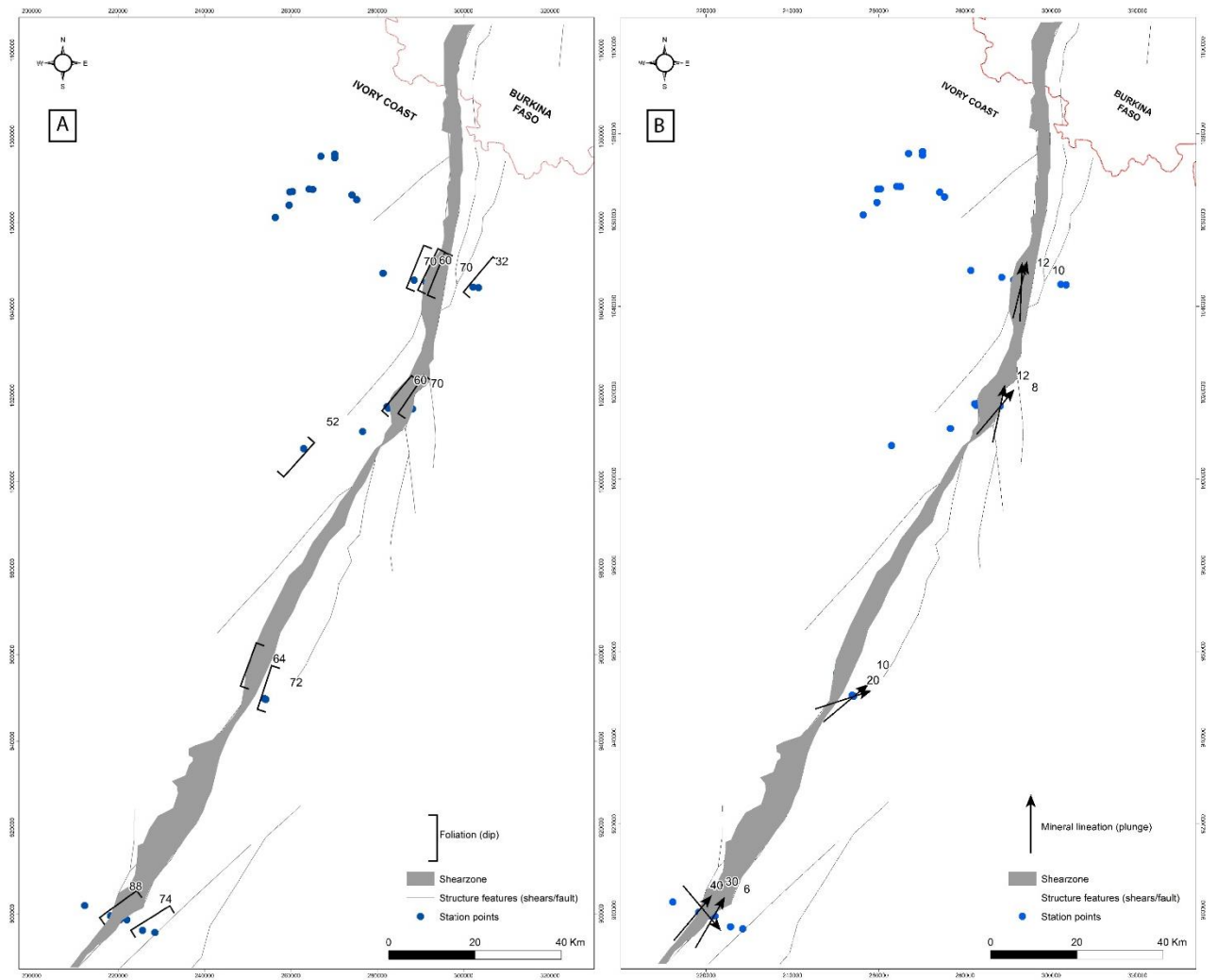


Figure 5.3: Schematic structural geology map of Domain A along the Yédandiekaha-Niakaramandougou branch (YNB). **(a)** Foliation data collected along the shear zone, steeply dipping to the east. **(b)** Mineral lineation data measured along the shear zone, indicating shallow to sub-horizontal plunges to north-northeast.

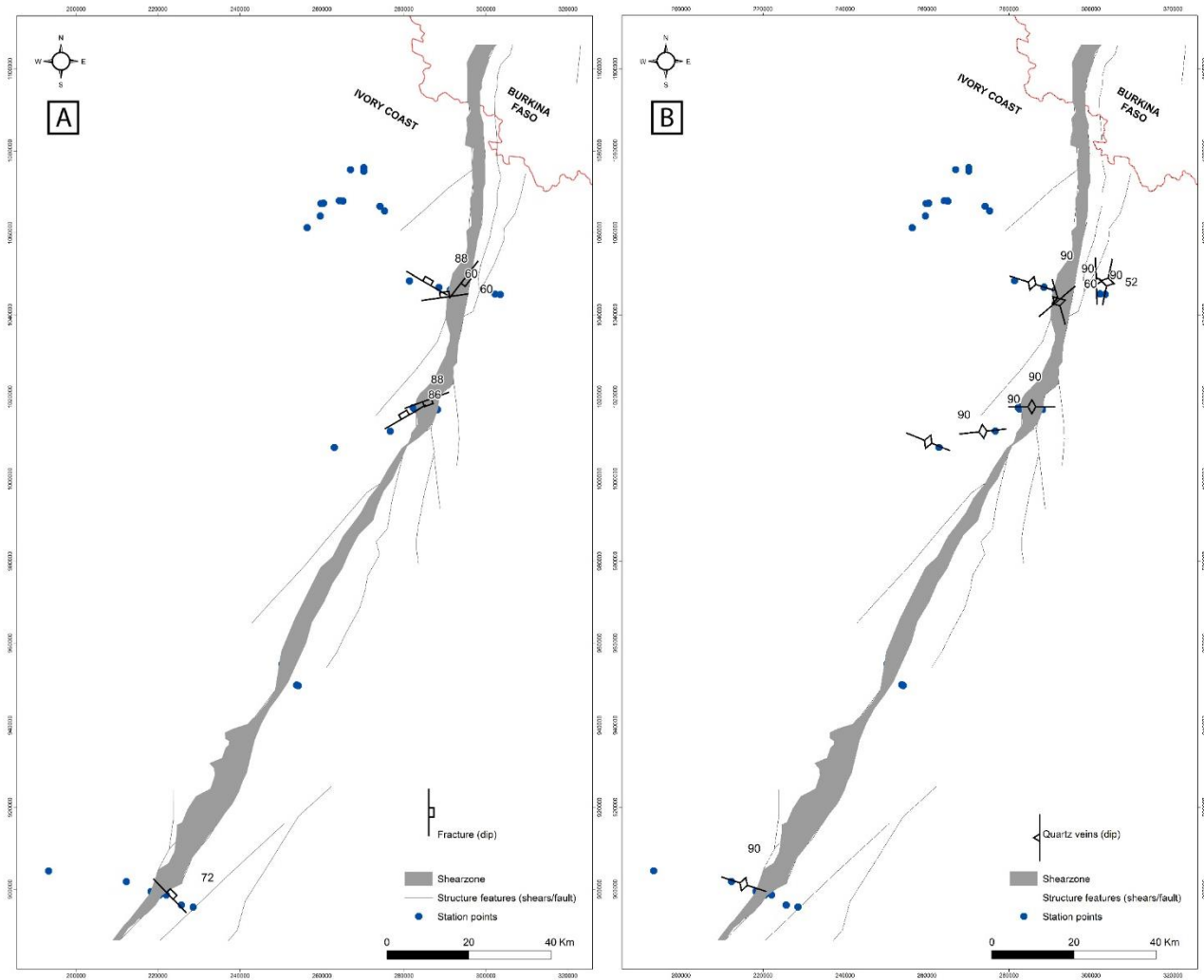


Figure 5.4: Schematic structural geology map of Domain A along the Yédandiekaha-Niakaramandougou branch. **(a)** Shear fracture data collected along the shear zone, indicating sub-vertical to steep dips. **(b)** Quartz vein (1-5cm) data measured along the shear zone, indicating steep to sub-vertical dips.

5.2.1.1 D_1 Deformation

D_1 deformation is dominant across Domain A. The general trend of the batholith, volcano-sedimentary and sedimentary rocks in this domain is north-northeast with foliation and bedding steeply dipping to the east. These rock units are deformed by the crosscutting north-northeast trending mylonite and schist zones of the YNB.

This deformation is manifested by the north-northeast to northeast trending S_1 foliation. The S_1 foliation is ubiquitous throughout the study area often sub-vertical to steeply dipping. In an outcrop scale, the S_1 foliation is marked by the alignment of mica minerals that include biotite and muscovite, flattened to elongated quartz and hornblende $\pm$ plagioclase. This foliation is

generally penetrative. Based on structural analysis on different rock units, S_1 foliation can be classified into (a) S_{1intr} within intrusive units (Figure 5.5) and (b) S_{1met} within metasedimentary and volcano-sedimentary units (Figure 5.6). Moreover, the convention used to represent planar readings is “strike/dip/dip direction”. S_{1intr} foliation in the eastern margin of the batholith generally dips to the east, with a calculated mean orientation of $025^\circ/65^\circ E$ (Figure 5.7a). S_{1met} foliation dips to the east, with a calculated mean orientation of $031^\circ/64^\circ E$ (Figure 5.7b). Generally S_{1met} foliation forms as an axial planar foliation to isoclinal F_1 folds in metasedimentary units (Figure 5.7c). Therefore, S_1 foliation is parallel to axial planes of F_1 folds and has a calculated mean orientation of $019^\circ/90^\circ$. F_1 folds show asymmetric geometry, verging to the west away from the Yédandiekaha-Niakaramandougou branch.



Figure 5.5: Outcrop photograph of granite of the Ferké Batholith showing a north-northeast trending S_{1intr} foliation. The foliation is defined by aligned and flattened quartz, plagioclase, K feldspar, hornblende and mica minerals. S_{1intr} foliation is steeply dipping to the east and crosscut by relatively younger east trending shear fractures (UTM 30P, 0293015, 1045410).



Figure 5.6: Outcrop photograph of a meta-volcaniclastic greywacke crosscut by north-northeast trending and steeply dipping S_{1met} foliation. Other structures crosscutting meta-volcaniclastic greywacke include northwest to north-northwest trending fractures. The rock unit is located along the YNB at UTM 30P, 0225493, 896652.

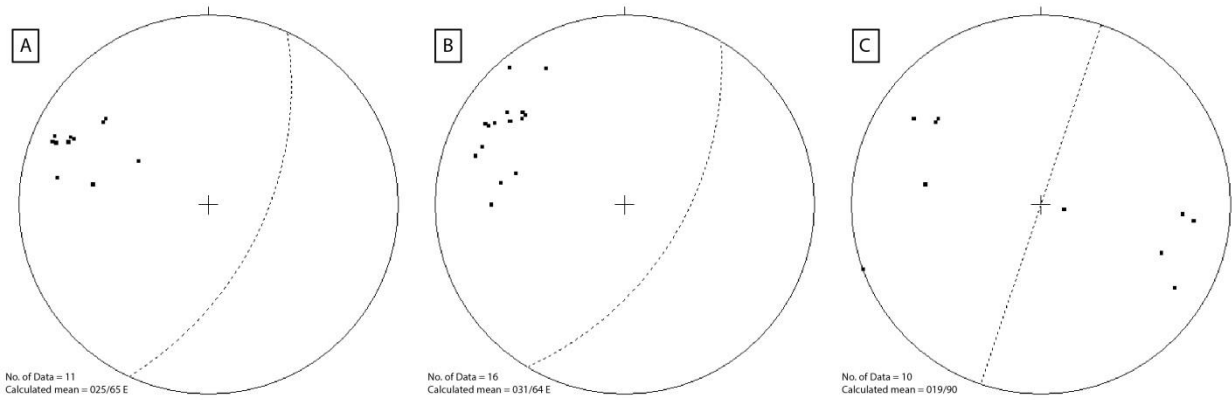


Figure 5.7: Equal area stereographic projection of poles of S_1 foliation data measured along Yédandiekaha-Niakaramandougou branch. **(a)** North-northeast trending S_{intr} foliation has a calculated mean principal orientation of 025°/65° E. **(b)** North-northeast trending S_{imet} foliation has a calculated mean principal orientation of 031°/64° E. **(c)** S_1 foliation parallel to axial planes of F_1 folds in metasedimentary units. It has a calculated mean principal orientation of 019°/90°.

The intensity of shearing has resulted in development of S-C fabric in schists and mylonites; quartz grain size reduction widespread in the matrix, together with the development of elongate asymmetric porphyroclasts of feldspar and quartz. D_1 ductile fabrics are characterised by penetrative and pervasive shear foliation (S_1 -C), herein termed, mylonitic foliation (S_1 -C_{my}) and schistose foliation (S_1 -C_{sch}). S_1 -C_{my} fabric is predominant in intrusive rocks, whereas the S_1 -C_{sch} fabric is predominant in metasedimentary and volcano-sedimentary rocks. The S_1 -C_{my} fabric indicates sinistral sense of displacement that is marked by σ - and δ -type grain-tail complexes (Figure 5.8) of quartz, plagioclase and K feldspar clasts and millimetre-scale extensional shear bands. The S_1 -C_{sch} fabric indicates sinistral sense of displacement observed in sericite-muscovite-quartz schists with rotated clasts of muscovite, quartz and biotite. In thin sections, microstructures such as asymmetric feldspar porphyroblasts, pressure shadows and mica-laths (Figure 5.9 a-b), display kinematics that are consistent with the macroscopic observations, such as mylonitic granites and granodiorites.

The S_1 -C foliation is associated with the development of shallow plunging (0°-11°) stretching and mineral lineation (L_{1my} and L_{1sch}) towards the north and north-northeast (358°-030°) directions (Figure 5.9). The S_1 -C foliation in this domain indicates component of both strike-slip and oblique displacement thus sinistral-normal, with the hanging wall or east block down (EBD). The overall displacement is dominantly sinistral strike-slip. Yédandiekaha-Niakaramandougou branch have a calculated mean principal orientation of S_{1my} 028°/62E°

(Figure 5.10a), C_{my} 351°/81°E (Figure 5.10b) and L_{1my} of 09° → 026° (Figure 5.10c). This data was collected from mylonitic granite and granodiorite near towns of Kouloukorosso and Yédandiekaha along the YNB.



Figure 5.8: Rotated mineral (K-feldspar, plagioclase, quartz) clasts in a proto-mylonite indicating sinistral sense of displacement along the north-northeast trending Yédandiekaha-Niakaramandougou branch (UTM 30P, 0293304, 1046026). The interpretation of shear-sense indicators were completed after [Van der Pluijm and Marshak \(2004\)](#).

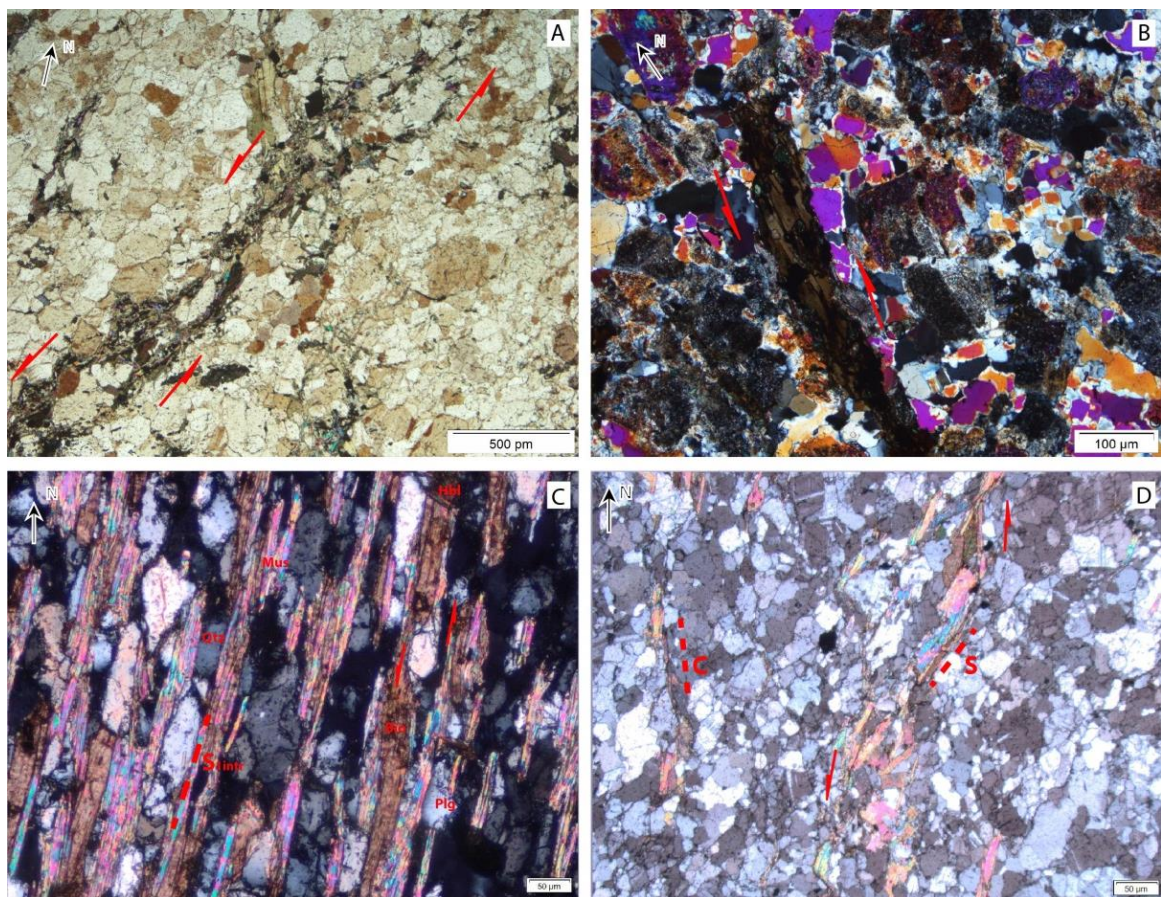


Figure 5.9: (a) Photomicrograph of mylonite (sample CidF_048) from the YNB in the northeast of the town of Kouloukorosso. The original rock is granite. It shows white bands of quartz, dark hornblende, biotite and large broken crystals of rotated feldspar indicating sinistral sense of displacement (UTM 30P, 0293297, 1045965). (b) Microgranite (sample CidF_063) with north-northeast trending aggregates of hornblende and biotite indicating sinistral sense of displacement. Groundmass consists of quartz, plagioclase, hornblende, mica-laths and K-feldspar. Some of these crystals are flattened, rotated and aligned to define foliation (S_1 , S-C). Most crystals of quartz exhibit undulose extinction, deformation bands, sub-grains and new grains in their boundaries (UTM 30P, 0293442, 1045160). (c) Photomicrograph of the strongly foliated granodiorite (sample CidF_136). The north-northeast trending foliation is formed mainly by mica-laths, matrix and by a small amount of quartz and plagioclase porphyroclasts (Qtz, Plg). Microstructures indicate sinistral sense of displacement defined by rotated porphyroclasts of quartz and plagioclase parallel to foliation, occasionally with visible shape asymmetry (UTM 30P, 0212309, 902181). (d) Photomicrograph of mylonitic granite (sample CidF_046) cut by an S-C fabric along the branch. Strongly aligned mica laths, flattened quartz and plagioclase define the S-C foliation and sinistral sense of displacement (UTM 30P, 0293329, 1046172).

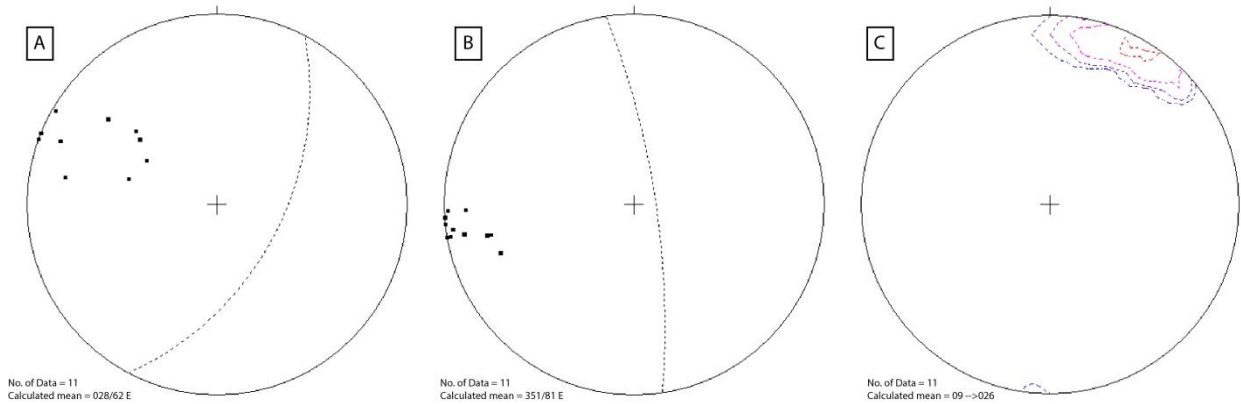


Figure 5.10: Equal area stereographic projection of poles of S_{1C} foliation and L_{1my} data measured along Yédandiekaha-Niakaramandougou branch. **(a)** S_{1my} foliation data with calculated mean orientation of $028^{\circ}/62^{\circ}E$. **(b)** C_{my} foliation data with calculated mean orientation of $351^{\circ}/81^{\circ}E$. **(c)** L_{my} has a mean principal direction of $09^{\circ} \rightarrow 026^{\circ}$.

Boudinage structures can be observed in north-northeast trending albite-quartz veins (V_1). The intrusive units contained both symmetrical and asymmetrical boudins with a general sinistral sense of shearing. These boudins are occurring in 3-10cm veins crosscutting the intrusive units. Asymmetric boudins are characterised by the domino-type boudin based on blocky-shape with angular edges (Figure 5.11). The asymmetric boudins are aligned parallel to the S_1 foliation and reflect a general sinistral sense of shearing.

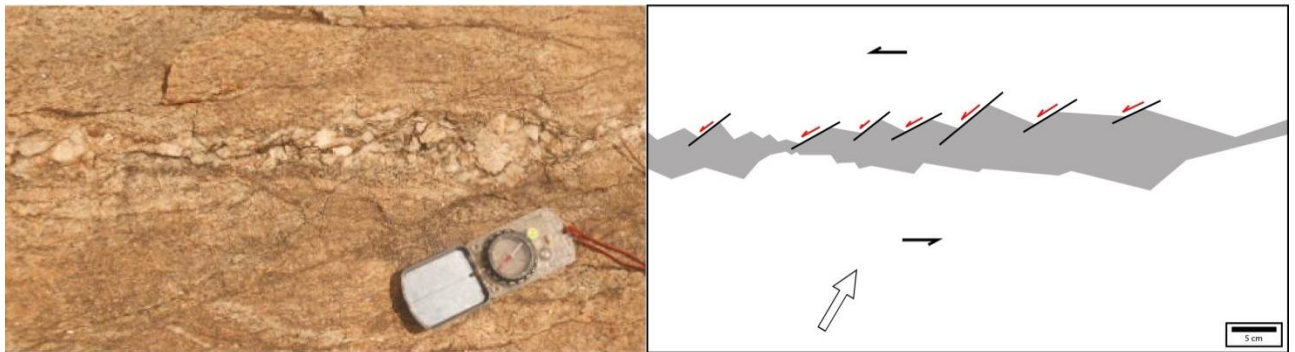


Figure 5.11: Photograph and sketch of domino-type structured vein indicating sinistral shear sense and crosscutting two-mica granodiorite (UTM 30P, 0244444, 1029992).

Northeast of the village of Kouloukorosso, D_1 deformation is associated with the intrusion of microgranite that later gets deformed by north-northeast trending shears. This reoccurrence involves the development of microgranite-phenocrystic granite pattern (Figure 5.12) in a space of approximately 100 metres. This pattern is north-northeast trending and herein postulated to be a

representation of a recrystallisation event. The rotated grains indicate a sinistral sense of displacement.

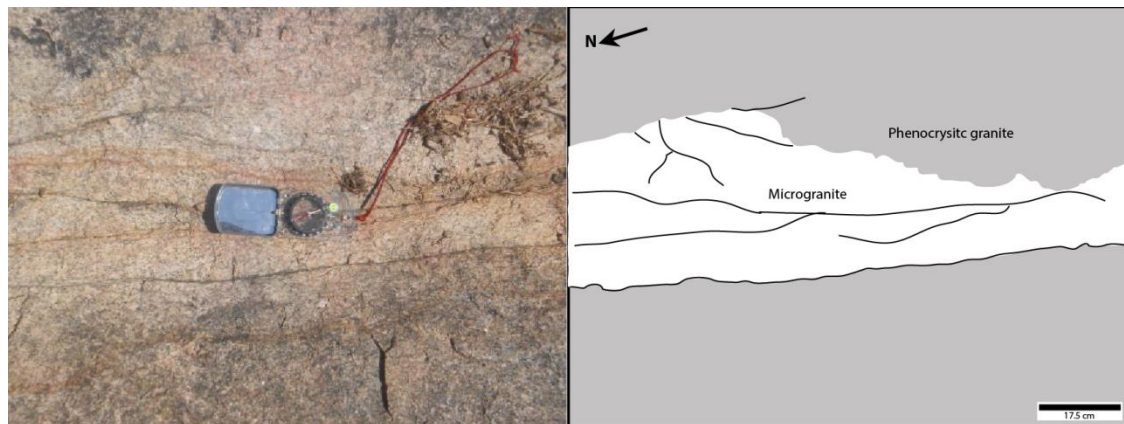


Figure 5.12: Intrusion of microgranite with rotated grains indicating a sinistral sense of displacement along the YNB (UTM 30P, 0291266, 1046163). The distinctive change in grain size from microgranite to phenocrystic granite occurs parallel to the YNB.

Late D_1 deformation is mainly characterised by brittle and semi-brittle structures. In the south of Yédandiekaha, sub-vertical, northwest to west northwest trending en-echelon and right stepping fractures also indicate sinistral sense of shear. West-northwest oriented dilational jogs and faults can also be observed in this region (Figure 5.13). Dilational jogs display fault with initial bend and infill with breccia or precipitated minerals, indicating early and later development stages, respectively. Southwest of the village of Yédandiekaha, north-northwest trending formation of sub-vertical sigmoidal en-echelon fractures (possibly veins) indicate dextral shear sense, due to rotation of the older, central part of the fracture (vein) at approximately 45° to the shear surface (Figure 5.14).

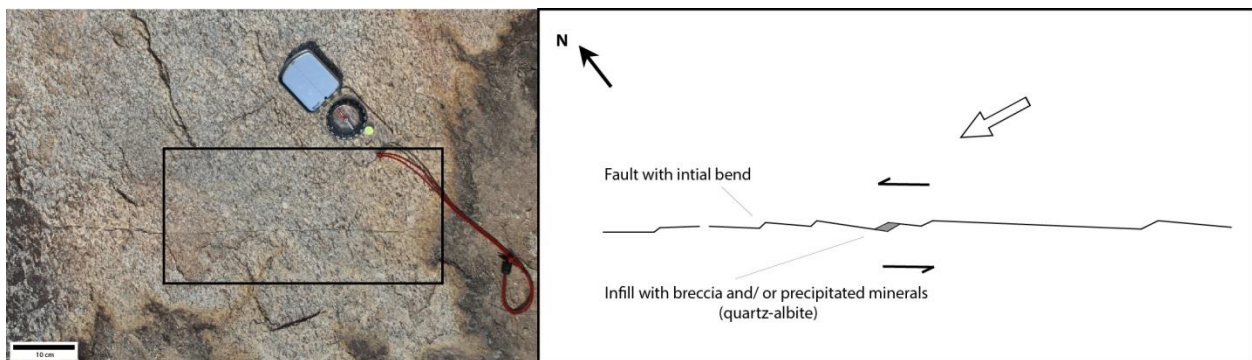


Figure 5.13: Photograph and schematic diagram showing the shear sense and the development of a dilational jog. In part, the dilational jog has subsequently been filled with mineral precipitates (UTM 30P, 0293015, 1045410).

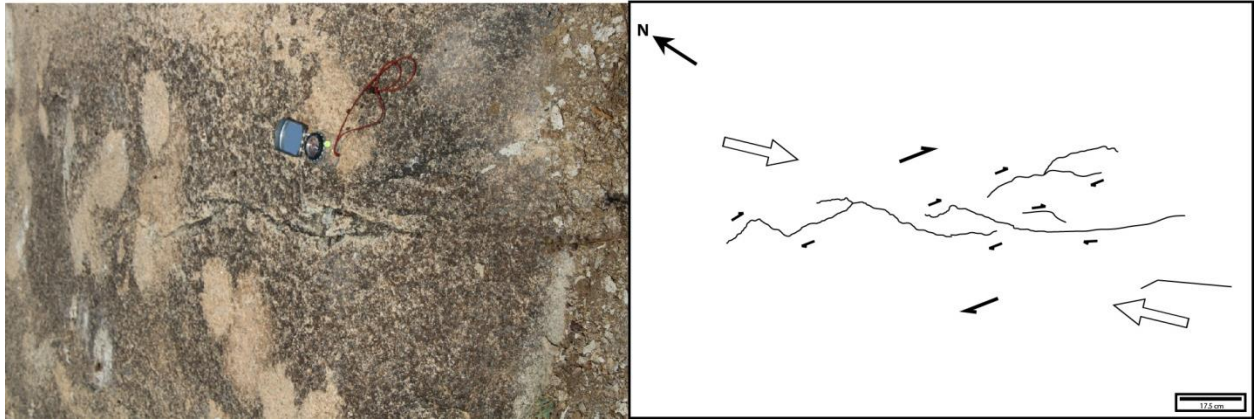


Figure 5.14: Photograph and schematic model of dextral, brittle-ductile, en echelon pattern of sigmoidal fractures developed in mylonitic granites of the Ferké Batholith (UTM 30P, 0282924, 1017530).

Late D_1 structures are also evident mostly in the southern parts of the study area (e.g. south west of Bouandougou), defined by a set of fractures. These fractures are northeast trending and sub-vertical to steeply dipping. The displacement regime on the north-northeast trending indicates a sinistral sense and east-northeast factures have a dextral shear sense (Figure 5.15). In general, throughout the study area the late D_1 structures represent a general northwest-southeast shortening.



Figure 5.15: Photograph and the sketch diagram of late D_1 fractures crosscutting the phenocrystic granodiorite. The shear sense regime of the fractures is illustrating a general (north)-northeast extension and southeast compression character (UTM 30P, 0184243, 905196).

In summary, D_1 is a progressive deformation is ductile-brittle in character and is associated with a sinistral-strike slip to normal displacement along Yédandiekaha-Niakaramandougou branch. Structures defining the deformation include:

- The general northeast orientation of Férké Batholith long-axes that is parallel to FSZ.
- Sinistral strike-slip north-northeast trending mylonite-schist zones.
- North-northeast trending and penetrative S foliation that is steeply dipping.
- North-northeast trending S_1 - C_{my} foliation, defining sinistral strike slip displacement.
- North-northeast trending albite-quartz veins (V_1), boudinaged in place.
- North-northeast oriented intrusion of narrow microgranite with rotated grains indicating a sinistral sense of displacement along the YNB.
- Later semi-brittle and brittle sub-vertical structures i.e. northwest to west northwest trending en-echelon and right stepping fractures indicating sinistral sense of shear.
- North-northwest trending formation of sub-vertical sigmoidal en-echelon fractures indicating dextral shear sense.
- Northeast to east trending and sub-vertical to steeply dipping displaced fractures representing a general northwest-southeast shortening.

Kinematic analysis has indicated that the shortening was north-northwest to south-southeast directed during D_1 deformation. D_1 structures are classified and compared with Riedel shear structures in the Riedel model (Figure 5.16).

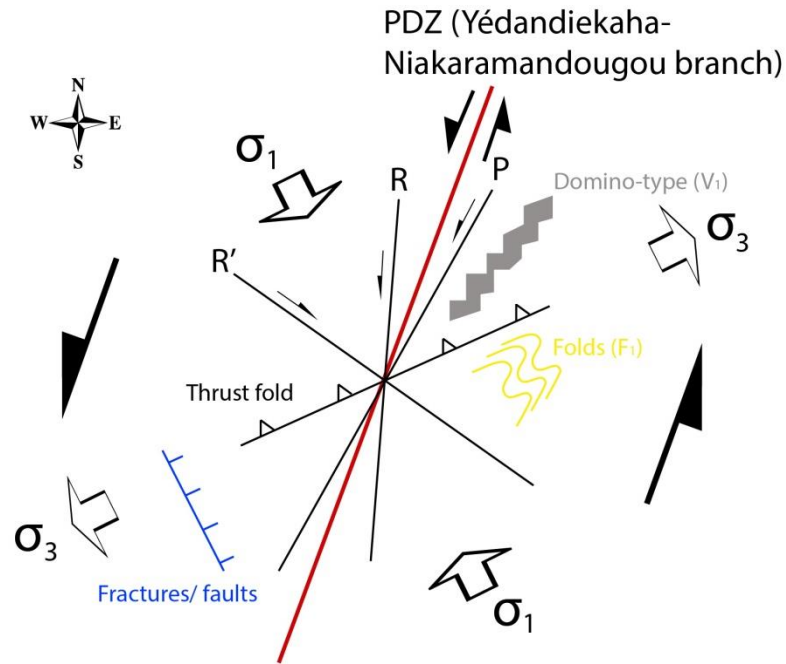


Figure 5.16: Schematic diagram of the Riedel shear model and structures that develop from a sinistral strike-slip dominated movement. The approximate orientations of the Yédandiekaha-Niakaramandougou branch, P synthetic shear faults, V_1 veins and F_1 folds denote north-northwest shortening direction.

5.2.1.2 D_2 Deformation

The D_2 deformation was observed in the southern parts of the village of Yédandiekaha, along the Yédandiekaha-Niakaramandougou branch. In this region, this deformation event is more localised and affected the metasedimentary units. D_2 is manifested by the development of S_2 foliation on the schistose and folded metasedimentary. The north-northwest trending S_2 is steeply dipping and crosscuts the north-northeast trending S_1 foliation. S_2 foliation is parallel and axial planar to north-northwest plunging fold axes (F_2), as shown in Figure 5.17. The F_2 folds exhibit sub-vertical folds axes; thus they have sub-vertical plunges with a north-northwest trend with a calculated mean orientation of S_2 of $289^\circ/86^\circ\text{E}$ (Figure 5.18a). The intersection lineations ($L_{2\text{int}}$) on these folds develop at the intersection point between S_1 and S_2 foliation (van der Pluijm and Marshak, 2004) and have a calculated mean orientation of $L_{2\text{int}}$ of $86^\circ \rightarrow 123^\circ$ (Figure 5.18b). The F_2 folds contain mineral stretching lineation ($L_{2\text{sch}}$) defined by mica and quartz, plunging sub-horizontally to the north-northeast and south-southwest with a calculated mean orientation of $L_{2\text{sch}}$ of $13^\circ \rightarrow 055^\circ$ (Figure 5.18c) and $L_{2\text{sch}}$ of $13^\circ \rightarrow 253^\circ$ (Figure 5.18d).

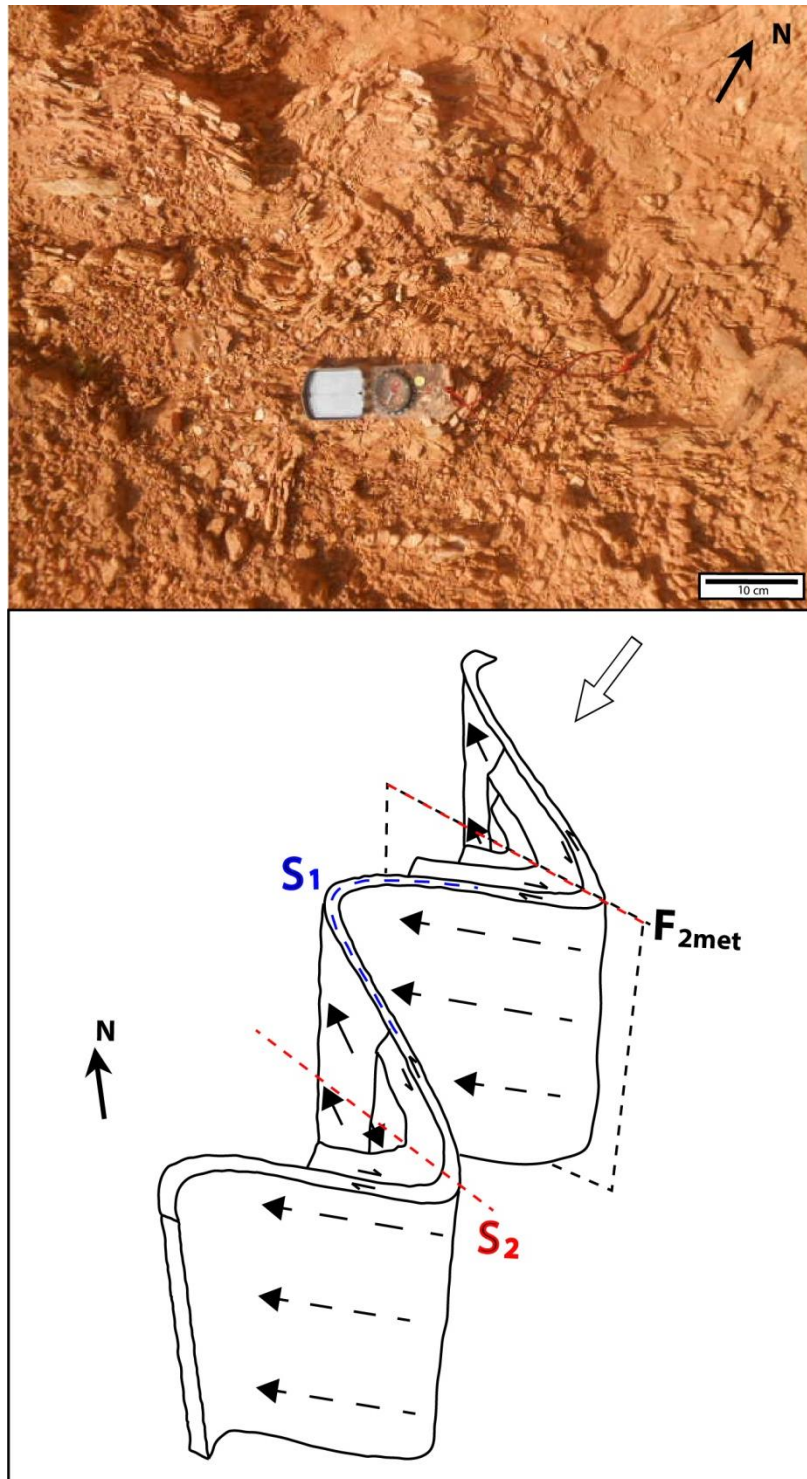


Figure 5.17: Photograph and sketch of an outcrop showing folded metasedimentary rocks and the development of the (north)-northwest trending S_2 foliation parallel to F_2 associated with D_2 deformation (UTM 30P, 0288340, 1017105).

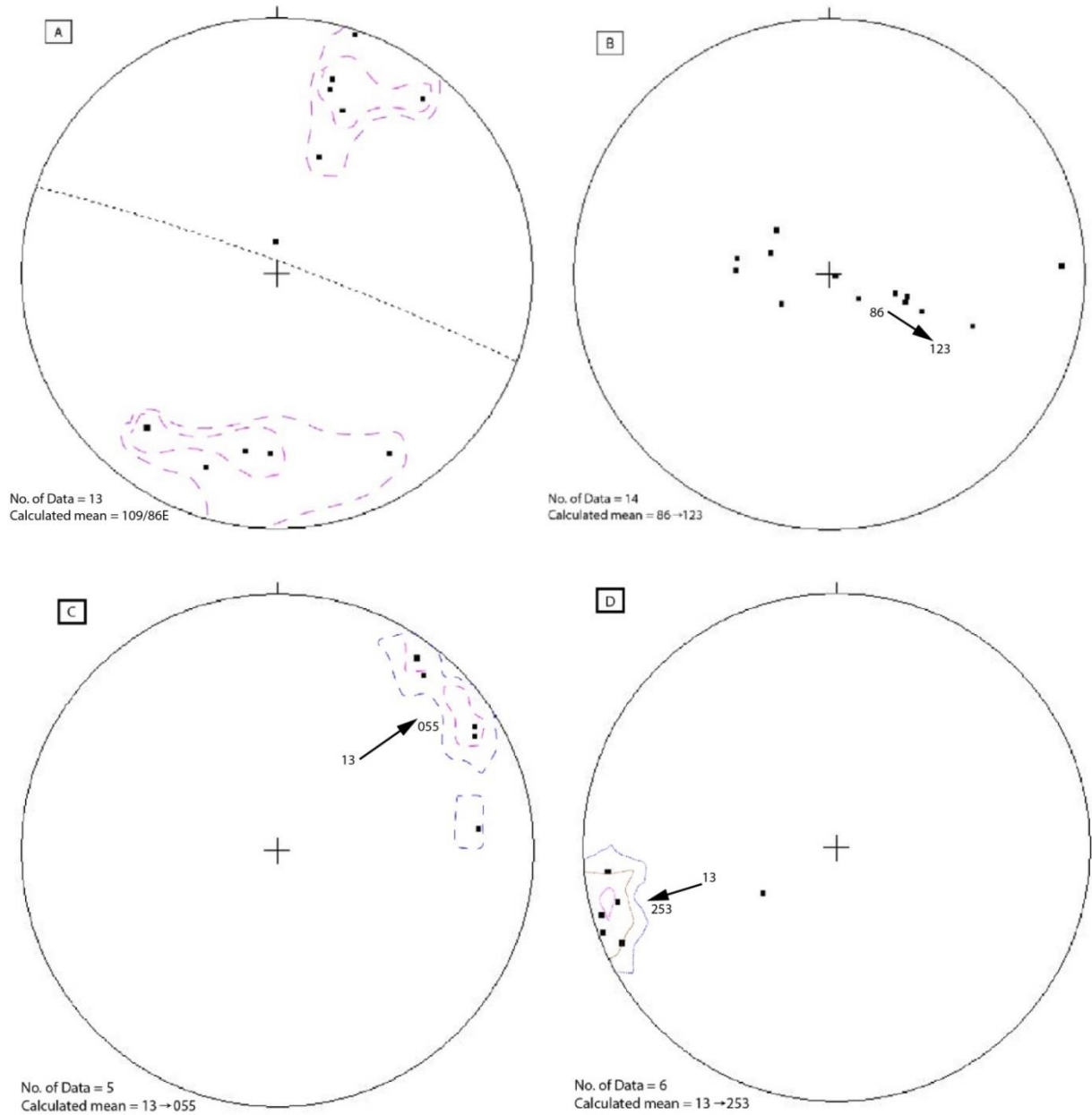


Figure 5.18: Equal area stereographic projection of poles of S_2 foliation, F_2 axes and contour plot of lineation data measured on folded metasedimentary units. **(a)** Northwest trending S_2 foliation from folded metasedimentary with a calculated mean principal orientation of $289^\circ/86^\circ\text{E}$. **(b)** Intersection lineation data with a mean direction of $L_{2\text{int}}$ of $86^\circ \rightarrow 123^\circ$, defining orientation of F_2 fold axes. **(c)** The stretching mineral lineation data has a mean direction of $L_{2\text{sch}}$ of $13^\circ \rightarrow 055^\circ$ and **(d)** $L_{2\text{sch}}$ of $13^\circ \rightarrow 253^\circ$.

D₂ deformation along the Yédandiekaha-Niakaramandougou branch is characterised by ductile structures i.e. north-northwest to south-southeast trending F₂ folds. Structures defining the deformation include:

- North-northwest trending and penetrative S₂ foliation that is steeply dipping.
- Southeast plunging intersection lineation defining the orientation of F₂ folds axes.

Kinematic analysis has indicated that the principal compressive strain axis was north-northeast or northeast directed during D₂ deformation.

5.2.1.3 D₃ Deformation

D₃ deformation observed in this domain is marked by semi-brittle and brittle structures. D₃ structures are constantly discernible throughout the study area. They are characterised by east-west to west-northwest oriented fractures and shear faults. These D₃ structures crosscut both D₁ and D₂ structures, therefore younger (Figure 5.19a and b).

Set of fractures are west-northwest to northwest trending and could range from 1mm to a centimetre thin. This set is mostly sub-vertical to steeply dipping, ubiquitous, closely spaced and subparallel with a calculated mean orientation of 292°/86°N (Figure 5.20). Furthermore, in the south of the village of Yédandiekaha, D₃ deformation is defined by north-northeast trending conjugate shear fractures indicating sinistral sense of shear (Figure 5.21).

In summary, D₃ deformation along the Yédandiekaha-Niakaramandougou branch is characterised by semi-brittle and brittle structures. Structures defining the deformation include:

- Northwest trending parallel fractures.
- North-northeast trending conjugate shear fractures indicating sinistral and dextral sense of displacement.

Kinematic analysis has indicated that the principal compressive strain was north-northeast or northeast directed during D₃ deformation.

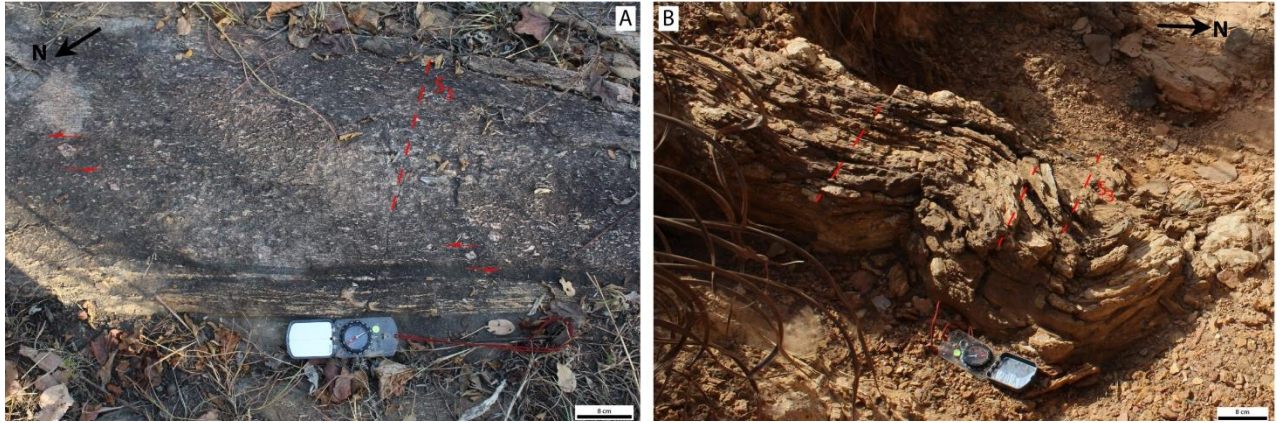


Figure 5.19: (a) D_3 associated with the formation of west-northwest trending S_3 fracture cleavage (red) crosscutting D_1 sinistral mylonite zone along YNB (UTM 30P, 0293304, 1046026). (b) West-northwest trending S_3 fracture cleavage (red) crosscutting D_2 folds (F_2) in metasedimentary units at UTM 30P, 0288250, 1017117.

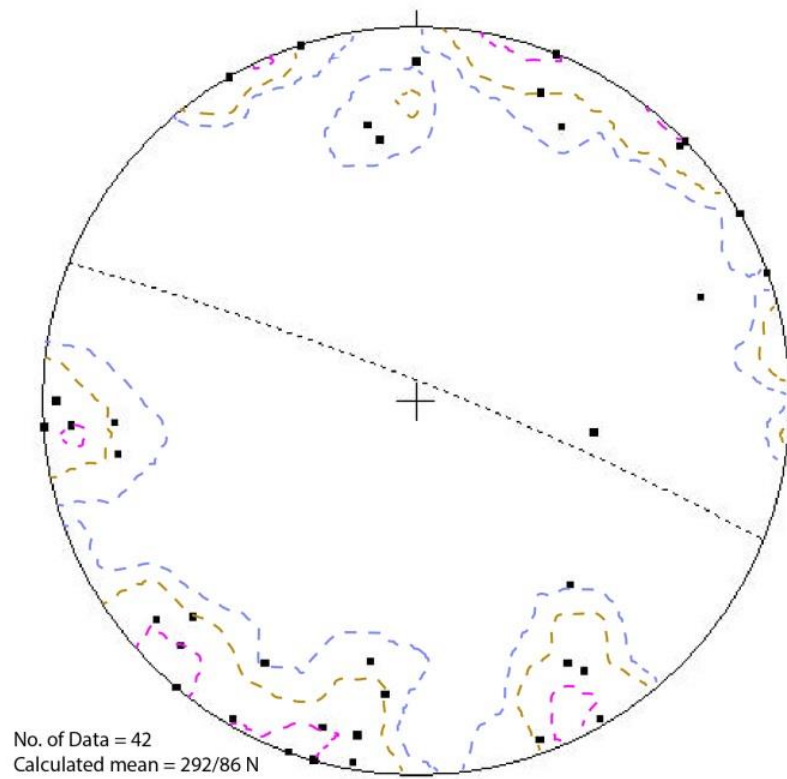


Figure 5.20: Equal area stereographic projection of poles and contour plot of regional S_3 fracture cleavage data with a calculated mean principal orientation of 292 °/86°N.

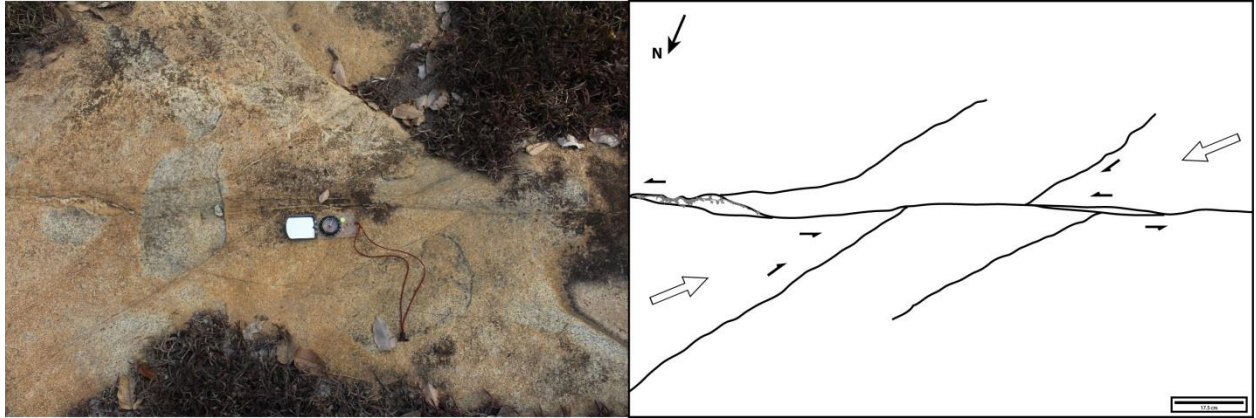


Figure 5.21: D₃ deformation shear fractures crosscutting granodiorite indicating a sinistral sense of displacement. Minor quartz veins have precipitated along the structures during displacement. The displacement regime displayed by these structures complement an overall north-northeast to northeast maximum shortening direction (UTM 30P, 0184243, 905196).

5.2.2 The Ferké-Bandama branch

The Ferké-Bandama branch (FBB) is the circumscribing feature in the western margin of the Ferké Batholith (Domain B in [Figure 5.22 a-c](#)). This branch extends along the Bandama River, through the town of Ferkéssédougou and the village of Kogbala. Volcano-sedimentary sequences and the batholith are indented by this 500m-2km wide Ferké-Bandama branch. The degree of metamorphism and intensity of deformation decreases from west to east for batholith and east to west on volcano-sedimentary sequences.

Structures proximal and or along FBB include north-northeast trending shears, foliation (S and S-C) that is steeply west-dipping, folds F₁, veins, lineation L₁ and lithologies ([Figure 5.23 a and b](#)). The FBB is complex; the northern part of the branch shows sinistral sense of displacement, while the southern part from Kogbala to the south displays a dextral regime. Sets of northwest to north-northwest trending fractures discernible along the FBB are analogous with the set of S₃ fracture cleavage in the Yédandiekaha-Niakaramandougou branch and the rest of the study region ([Figure 5.24](#)). In the FBB, these brittle structures crosscut all the rocks and ductile structures, therefore are younger. The crosscutting relationships coupled with multiple senses of displacement denote different deformation events.

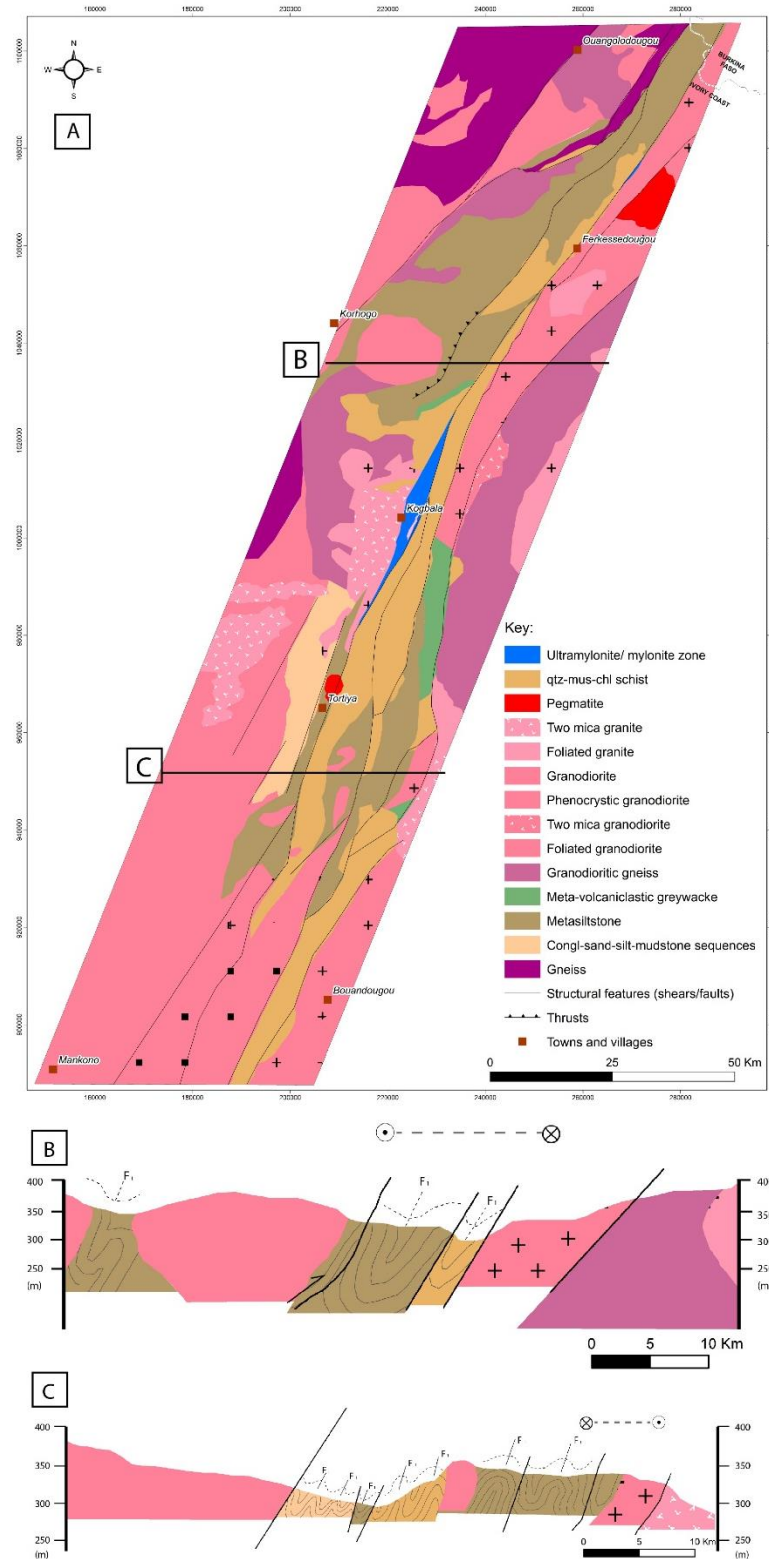


Figure 5.22: (a) The geology map of Domain B, outlining Ferké-Bandama branch and the adjacent lithologies. The bold black east-west lines are cross-section lines. **(b-c)** Cross-sections of the northern and southern parts of the Ferké-Bandama branch and adjacent area. The colours correspond to the legend in Fig. 5.20a.

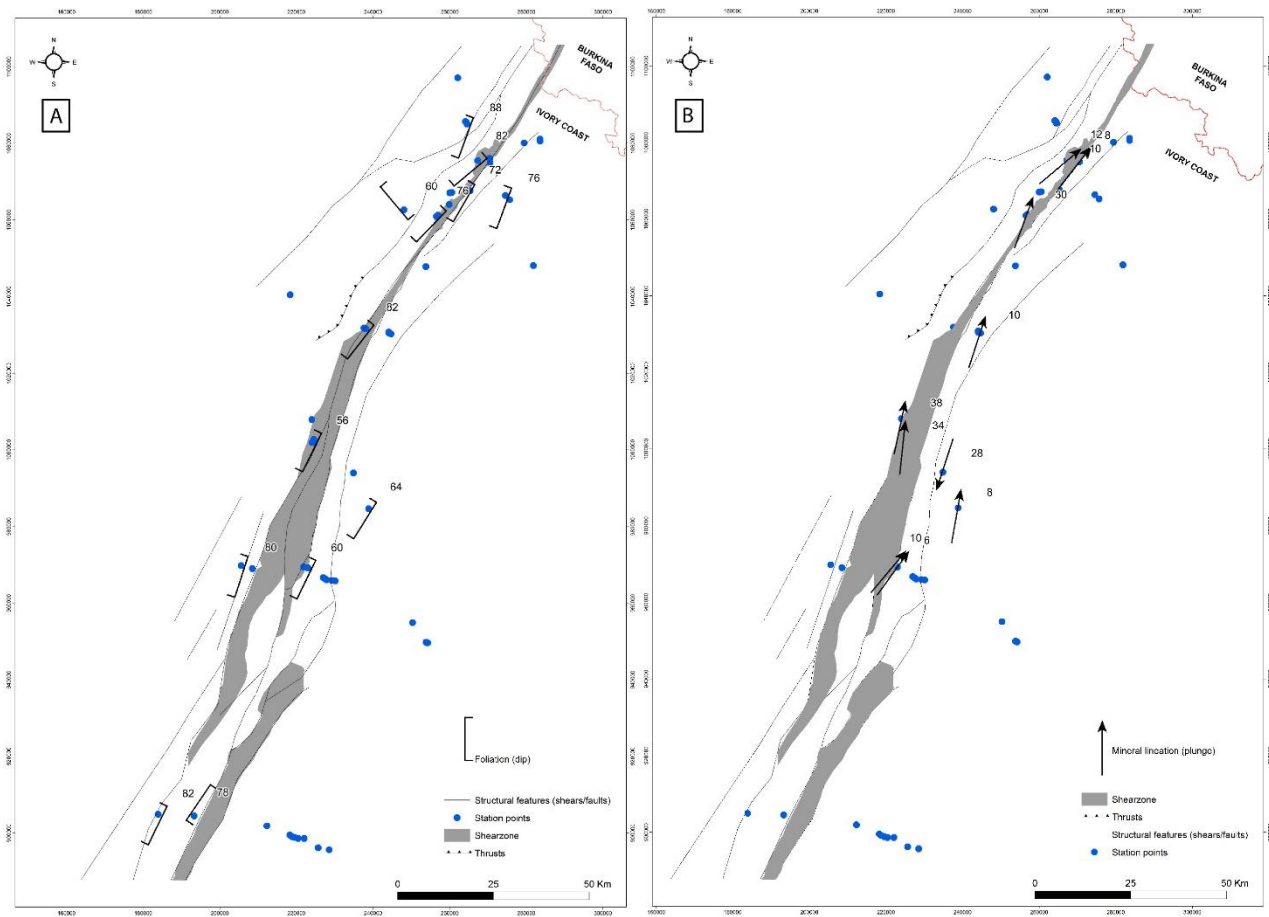


Figure 5.23: Schematic structural geology map of Domain B along the Ferké-Bandama branch. **(a)** Foliation data collected along the shear zone, indicating west and steep dips. **(b)** Mineral lineation data measured along the shear zone, indicating shallow to sub-horizontal plunges.

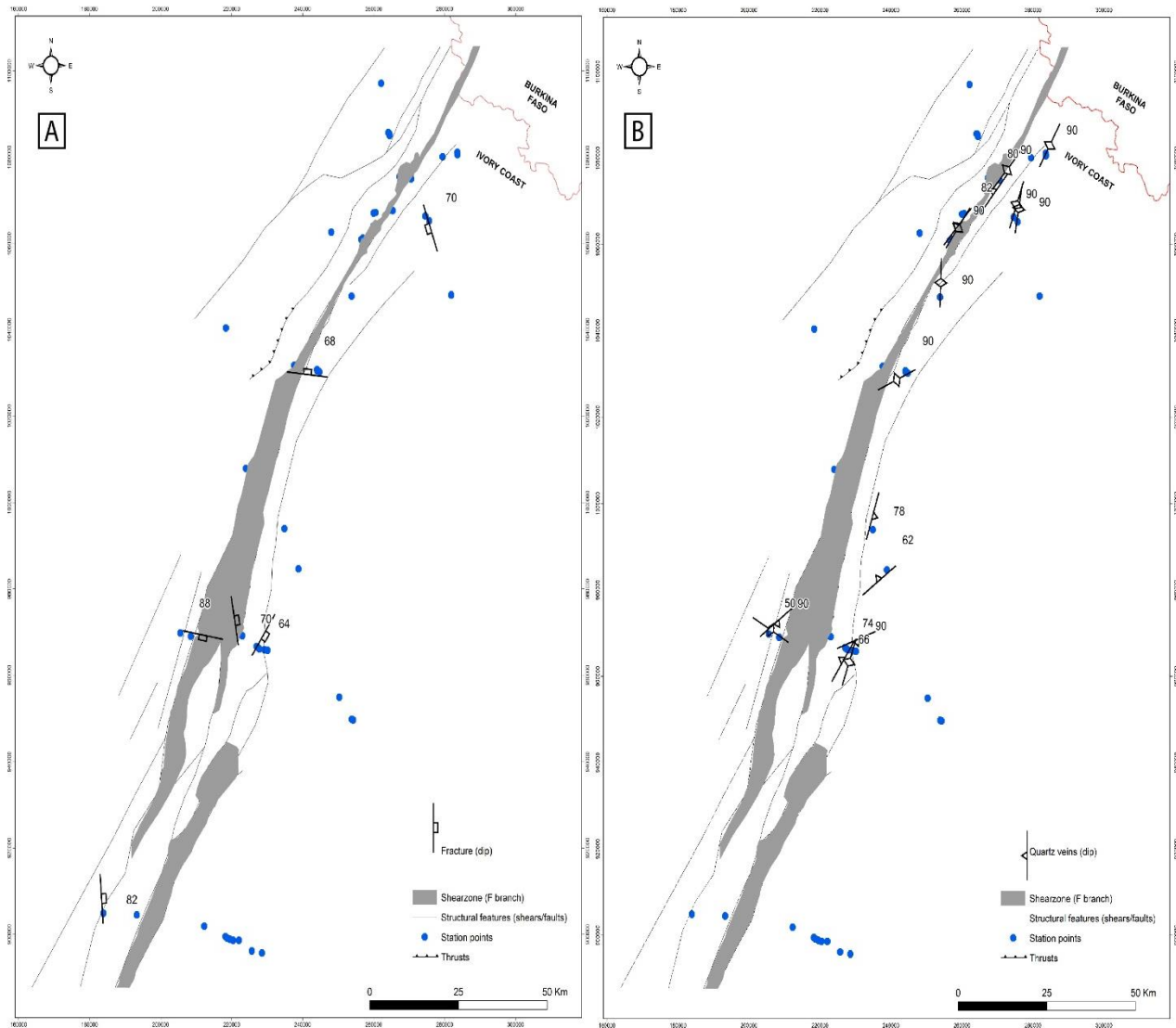


Figure 5.24: Schematic structural geology map of Domain B along the Ferké-Bandama branch. **(a)** Fracture data collected along the shear zone, indicating sub-vertical to steep dips. **(b)** Quartz vein data measured along the shear zone, indicating steep to sub-vertical dips.

5.2.2.1 D_1 Deformation

D_1 deformation is the most prominent deformation event and affected the majority of the rock units across the study area. D_1 in this domain is manifested by north-northeast to northeast trending S_1 foliation. S_1 foliation is generally west dipping and is classified as: S_{1intr} for intrusive units (Figure 5.25a and b) and S_{1met} for metasedimentary and volcano-sedimentary units (Figure 5.26a and b). The granodiorites along this branch are intensely foliated and the S_{1intr} foliation is defined by aligned and elongated hornblende, micas (biotite and muscovite), quartz and plagioclase as monomineralic bands.

The Ferké-Bandama branch is marked by quartz-chlorite-muscovite $\pm$ sericite schist that in places grades with shearing intensity into mylonite and ultra-mylonite. The northern segment of the Ferké-Bandama branch, near the town of Ferkéssédougou, metamorphosed rocks contain steeply to sub-vertical S_1 foliation and sub-horizontal L_{1my} lineation (Figure 5.25 a-c). The rocks in this region are mostly granodiorites (mylonitic) and schists (meta-sedimentary rocks) containing north and north-northeast trending S_1 (mean orientation of $021^\circ/82^\circ W$, Figure 5.26b) and S_{1my} -C foliation. The lineation is also plunging sub-parallel to the foliation and has calculated mean principal direction of $14^\circ \rightarrow 033^\circ$ (Figure 5.25c). The general sense of displacement is sinistral in this segment, indicated by shear bands, rotated sigma clasts, lineation, S_1 -C foliation and displaced veins.

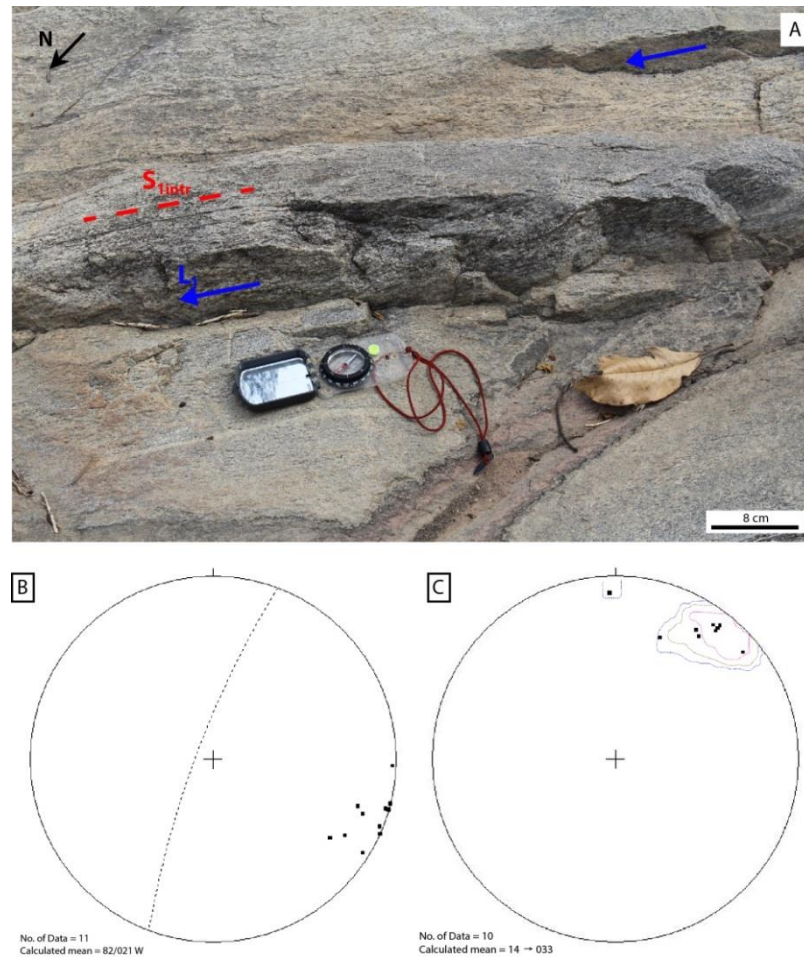


Figure 5.25: (a) Photograph of a foliated granodiorite (sample CidF_019) showing north-northeast trending S_{1met} foliation and associated lineation. (b) Equal area stereographic projection of poles of S_1 foliation data measured along FBB, north-northeast trending S_{1intr} foliation has a calculated mean principal orientation of $021^\circ/82^\circ W$. (c) L_1 lineation plunges towards the (north)-northeast has a mean principal direction of $14^\circ \rightarrow 033^\circ$.

Metasedimentary units are folded to the west of the FBB representing the main F_{1met} folds in this domain. These tight upright to overturned folds are generally asymmetric with subvertical to steeply northwest dipping (Figure 5.26b, calculated mean orientation of $037^{\circ}/80^{\circ}W$), verging to the east, axial planes with sub-horizontal north-northeast plunging hinges, parallel to S_1 foliation and shear zone. In the northern segment, these metavolcano-sedimentary units are folded along the thrust fault.

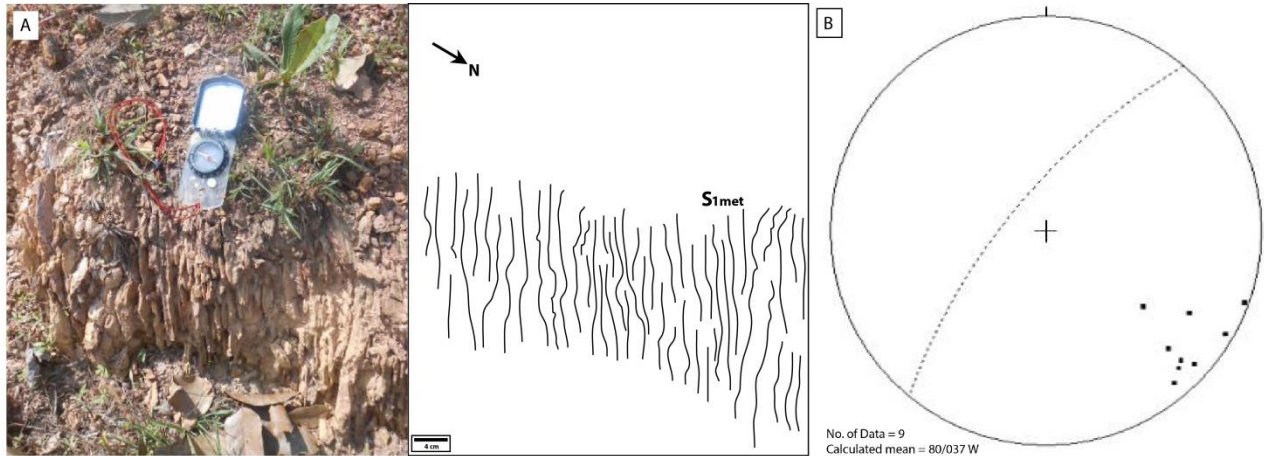


Figure 5.26: (a) Photograph and a sketch of metasedimentary unit crosscut by sheeted quartz veins parallel to the north-northeast trending S_{1met} foliation (UTM 30P 0260158 1067020). (b) Equal area stereographic projection of poles of S_1 foliation data with a calculated mean principal orientation of $037^{\circ}/80^{\circ}W$.

Sheeted quartz veins, north of the town of Ferkéssédougou, are sub-vertical with north-northeast trend and crosscut metasedimentary units (Figure 5.27). These sheeted veins are brecciated and boudinaged with the thickness of 1-3cm and spacing of 5-8 cm. In the intrusive units, northeast of Ferkéssédougou, north-northeast trending veins crosscut and displace north trending pegmatite veins to indicate sinistral displacement. Pegmatite veins generally consist of (1-5 cm) quartz, albite and plagioclase feldspar $\pm$ tourmaline $\pm$ muscovite $\pm$ biotite. Crosscutting the intrusive units are north-northeast trending pinch-and-swell structured veins characterising symmetrical boudins that are stretched and align parallel to the S_1 foliation (Figure 5.28).



Figure 5.27: Sheeted quartz veins crosscut the metasedimentary sequences parallel to foliation. These veins are generally northeast trending, brecciated and fractured (UTM 30P, 0264373, 1084681).



Figure 5.28: North-northeast trending quartz-albite veins, pinch-and-swell structured vein crosscutting a granodiorite (UTM 30P, 0270514, 1075133).

The metasedimentary units in the east of the town of Tortiya are crosscut by north-northeast trending buck quartz-albite veins. These veins are 1-1.5 m thick and crosscut by brittle structures (fractures). The observed buck quartz-albite veins were aligned up to more than 50 m in length (Figure 5.29).

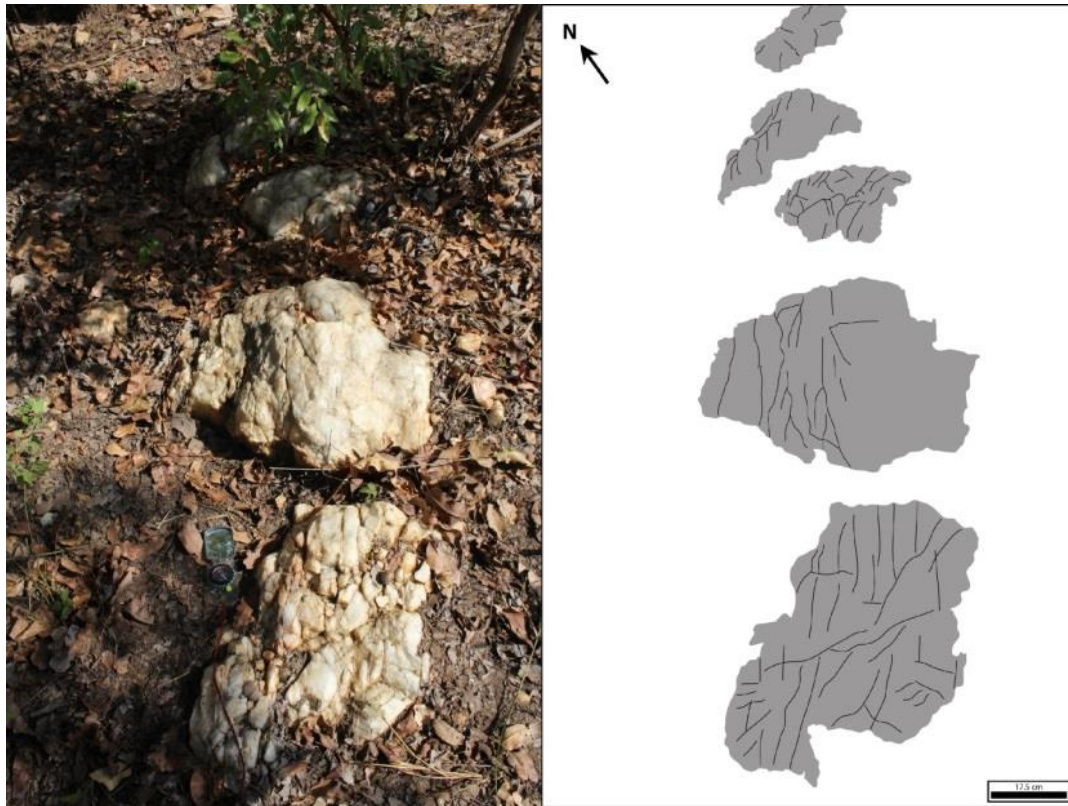


Figure 5.29: Buck quartz veins crosscutting the meta-sediments along the northeast orientation. The veins are 1-1.5m thick crosscut by fractures (UTM 30P, 0227774, 966443).

In summary, D_1 deformation has a ductile-brittle character defined by north-northeast mylonite and schist zones along FBB. Structures defining the deformation include:

- North-northeast trending mylonite-schist zones.
- North-northeast trending and penetrative S foliation that is steeply dipping to the west.
- North-northeast trending S_1 - C_{my} foliation, defining sinistral regime.
- North-northeast trending albite-quartz veins (V_1), boudinaged (pinch and swell) and buck quartz, in place.
- Northeast to north-north east trending sheeted quartz veins.
- The general northeast orientation of Férké Batholith long-axes that is parallel to FSZ.

Kinematic analysis has indicated that the principal compressive strain axis was north-northwest to south-southeast directed during D_1 deformation.

5.2.2.2 D_2 Deformation

The eastern margin of the batholith is controlled by the north-northeast trending, west steeply-dipping shear zone which is the major structure defining D_2 deformation.

The FBB is defined by mylonitic foliation (S_2-C_{my}) and schistose foliation (S_2-C_{sch}) that is penetrative and essential for kinematic criteria. The rotation of the clasts in quartz-biotite-muscovite-chlorite $\pm$ sericite $\pm$ hornblende $\pm$ talc schist near the village of Kogbala and east of Tortiya (Figure 5.30a and b) defines northeast to north-northeast trending S_2-C_{sch} fabric in metasedimentary rocks. In this region, FBB have a calculated mean principal orientation of S_{2sch} of $037^\circ/70^\circ SE$ (Figure 5.30c), C_{sch} of $081^\circ/90^\circ W$ (Figure 5.30d) and L_{2sch} of $33^\circ \rightarrow 002^\circ$ (Figure 5.30e). Stretching mineral lineation (L_{2my}) is defined by flattened and elongated quartz, hornblende $\pm$ plagioclase $\pm$ muscovite $\pm$ talc $\pm$ biotite. L_{2sch} shallowly plunges towards the north and north-northeast (Figure 5.30e). The $S_{2my}-C$ foliation indicates dextral sense of displacement.

S_2-C_{my} is marked by very fine matrix, σ - and δ -type grain-tail complexes of $\pm$ pyrite $\pm$ quartz, plagioclase $\pm$ K feldspar and shears bands (Figure 5.31) in intrusive rocks. The $S_{2my}-C$ fabric along the corridor of the FBB is dominant in this domain and indicates component of both strike-slip and oblique displacement, hence, dextral-reverse with the footwall or east block down (EBD). The overall displacement is dominantly dextral strike-slip. Along the FBB corridor, northern part of the branch displays sinistral component and the southern part is dominated by dextral sense of displacement. This can be referred to as the reactivation of north-northeast trending D_1 shear zones in the southern part of the branch.

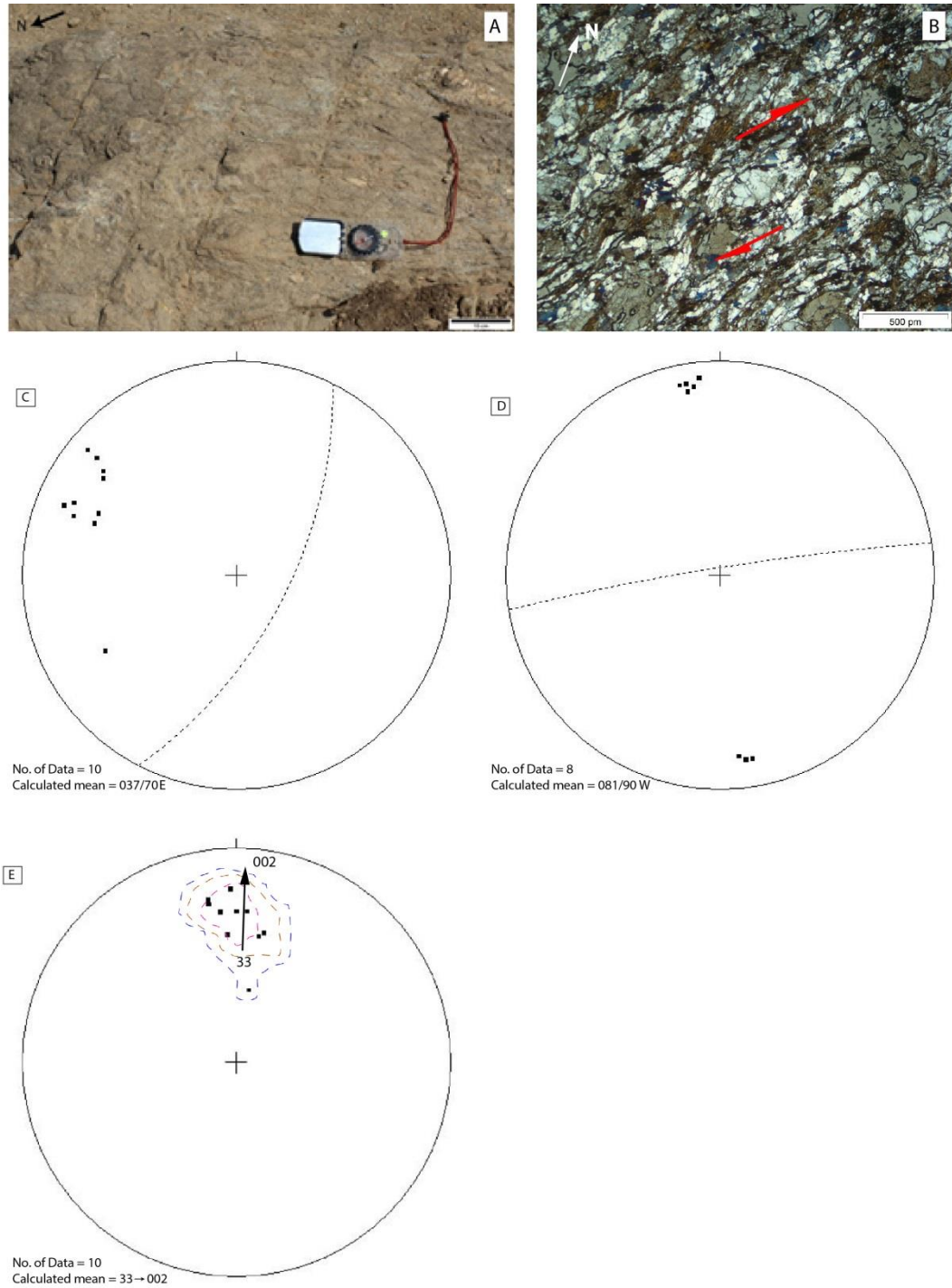


Figure 5.30: S_{2my} -C foliation observed along the corridor of the shear zone. **(a-b)** Photograph and microphotograph of biotite schist indicative of dextral sense of displacement and crosscut by (west)-northwest trending fracture cleavage (UTM 30P, 0222001, 969610). Equal area stereographic projection of poles of S-C foliation and contour plot of lineation data measured along

FBB. (a) Ferké-Bandama branch have a calculated mean principal orientation of S_{2sch} $037^{\circ}/70^{\circ}$ SE. (b) This zone has a mean principal direction of C_{sch} of $081^{\circ}/90^{\circ}$ W. (c) L_{2sch} has a mean principal direction of $33^{\circ}\rightarrow 002^{\circ}$.

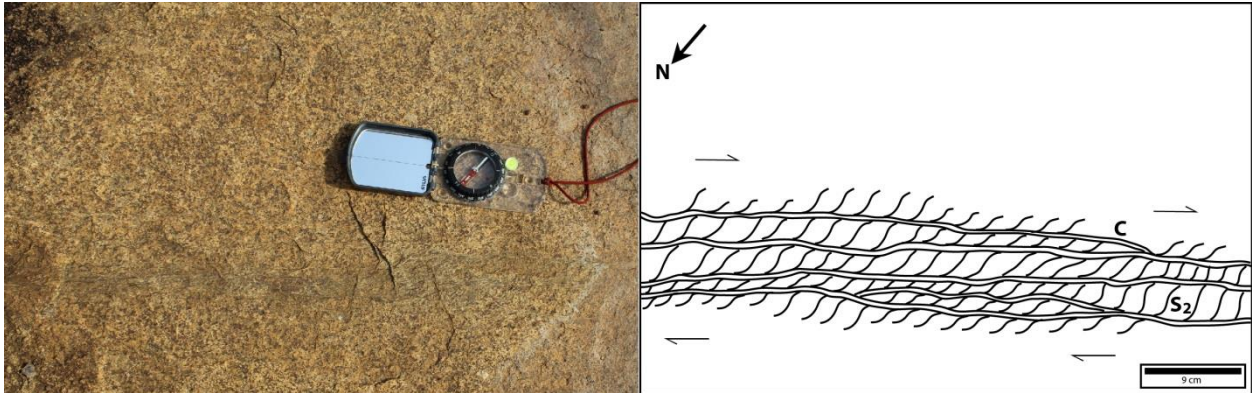


Figure 5.31: Photograph and sketch of an outcrop showing a northeast trending shear band with S_{2my} -C fabric crosscutting granodiorite indicating a dextral sense of displacement (UTM 30P, 0212309, 902181). Shear bands indicating dextral sense of displacement are dominant southern parts of the FBB.

Several quartz-albite veins are observed within the shear zones in the study area under this deformational episode. In [figure 5.32](#), east-west and west-northwest trending veins (V_2) crosscut the S_1 foliation and displace the north to north-northeast trending veins (V_1). V_2 veins are generally sub-vertical to steeply dipping. These veins are mostly fractured and develop as boudin structures. North of the town of Ferkéssédougou, V_2 vein margins are confined by thin shears indicating dextral sense of displacement ([Figure 5.33](#)). North-northeast of the village of Kogbala, west-northwest trending tourmaline-quartz-albite (10 cm) veins are characterised by tourmaline mineral-growth lineation (L_{2tml}) plunging towards the north. Tourmaline mineral-growth lineation has a calculated mean principal orientation of L_{tml} of $10^{\circ}\rightarrow 009^{\circ}$ ([Figure 5.34](#)).

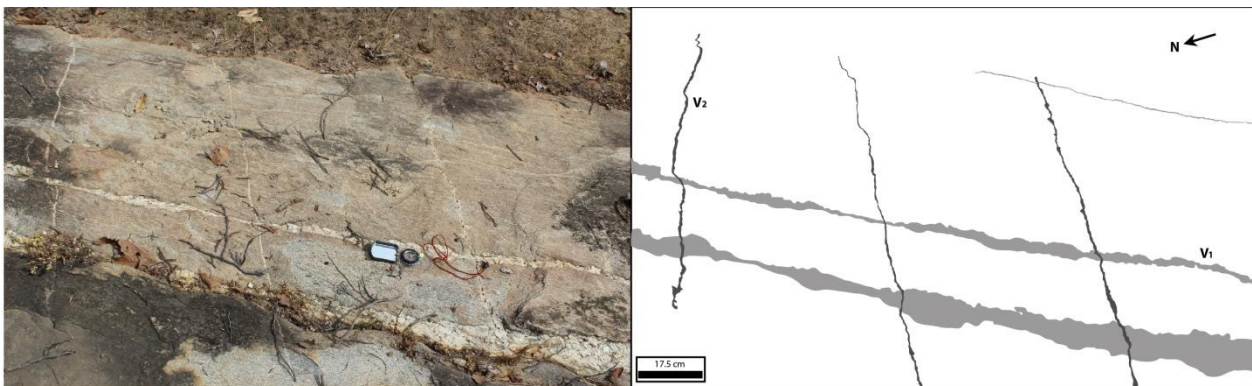


Figure 5.32: Two generations of veins crosscutting a granodiorite. The generation of north-northeast (V_1) trending veins crosscut by younger generation of east-west to east-northeast (V_2) trending veins (UTM 30P, 0270614, 1075116).

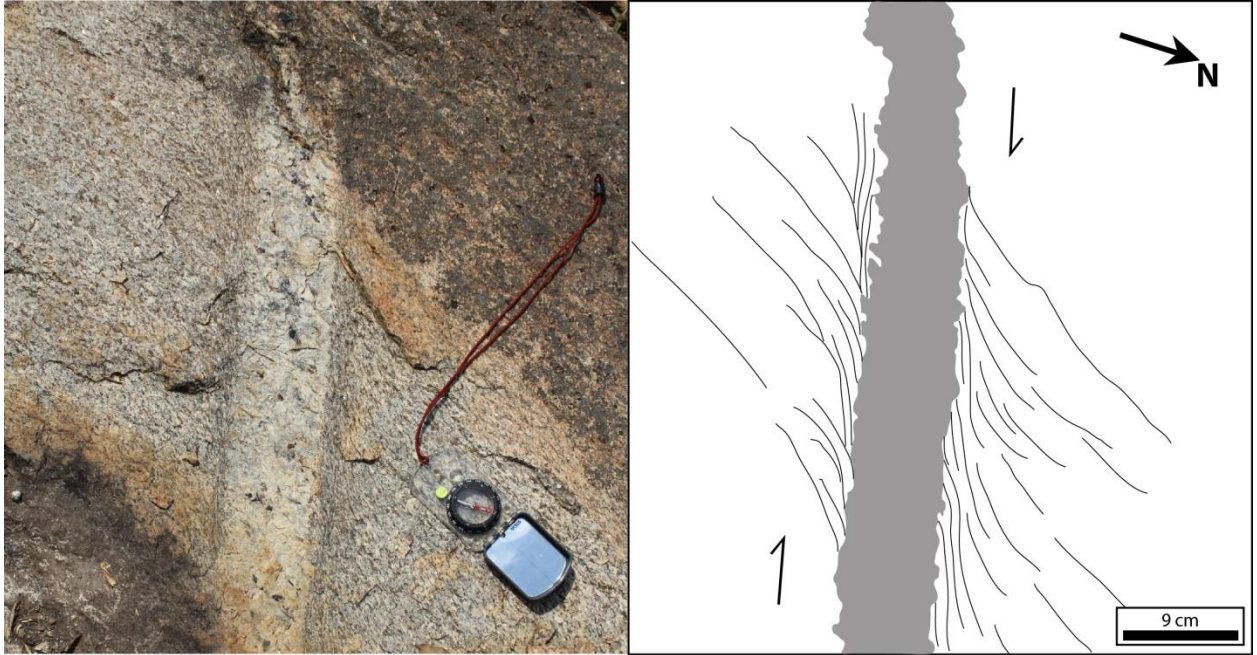


Figure 5.33: Photograph and sketch of east-west trending and steeply dipping quartz vein confined by thin shears indicating dextral sense of displacement. The veins are syn- D_2 and crosscut D_1 structure, north-northeast trending S_1 foliation. The vein crosscuts the foliated granodiorite (UTM 30P, 0270568, 1074999).

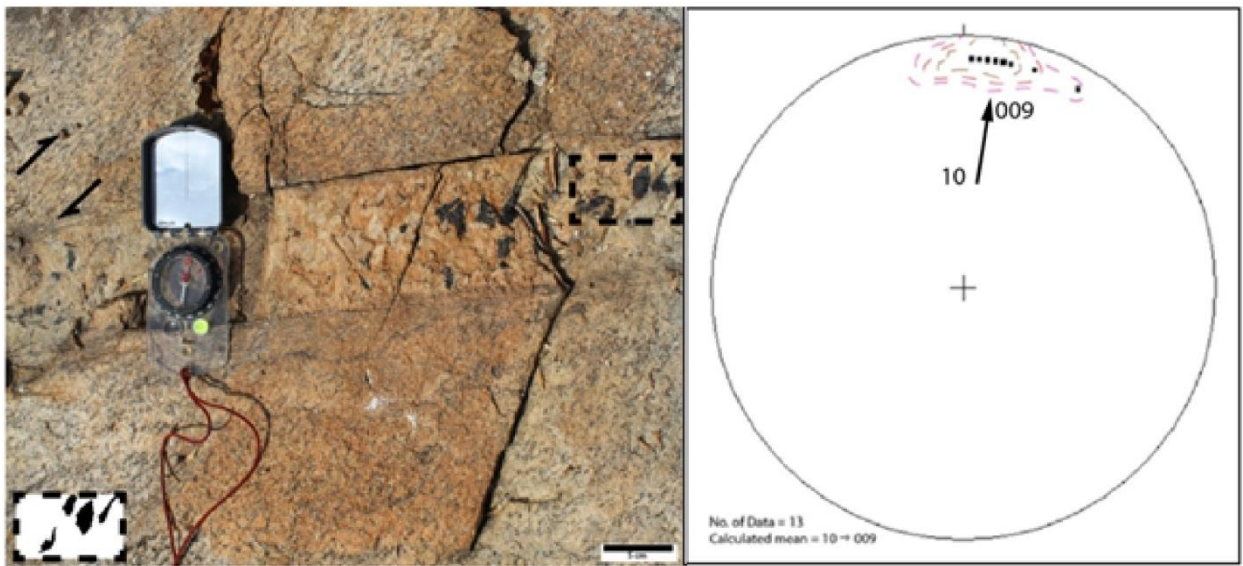


Figure 5.34: Photograph of east-northeast trending tourmaline-quartz-albite veins are characterised by tourmaline mineral-growth lineation (insert) plunging towards the north (UTM 30P, 0244444, 1029992). Equal area stereographic projection of poles of S-C foliation and contour plot of lineation L_{tml} has a mean principal direction of $10^\circ \rightarrow 009^\circ$.

D₂ deformation along the FBB is characterised by ductile structures i.e. north-northwest to south-southeast trending F₂ folds and S-C foliation. Structures defining the deformation include:

- North-northeast trending S₂-C foliation, defining dextral regime with strike-slip to reverse displacement. Foliation is steeply dipping to the west, defining FBB dip direction.
- Steeply to sub-vertical dipping, east-west and west-northwest trending veins (V₂) crosscut the north to north-northeast trending veins (V₁).
- East-west quartz vein confined by thin shears indicating dextral sense of displacement.

Kinematic analysis has indicated that the principal compressive strain axis was east-northeast or northeast directed during D₂ deformation.

5.2.2.3 D₃ Deformation

In the north of the town of Ferkéssédougou, formation of extensional fractures (en echelon tension gashes) were observed and indicated a sinistral sense of displacement. These tension gashes are observed within the intrusive units (granodiorite) which may have been affected by non-coaxial (rotational) shearing ([Figure 5.35](#)). In addition, [Figure 5.35](#) shows earlier northeast trending veins (V₁) indicating dextral sense of displacement as a result of northwest shortening during D₁ deformation, which have re-crystallised within the fabric. Northwest trending en echelon tension gashes crosscut these earlier structures during D₃ deformation, indicating sinistral shear sense, complimenting with a northeast main shortening direction.

These D₃ structures appear in the form of “straight” mineral filled lenses in an en echelon fashion, similar to those reported by [Diatta et al. \(2017\)](#) in Senegal. The “straightness” of these structures indicates an incipient development stage ([Lisle, 2013](#)). These tension gashes can be potentially used as strain markers for assessing strain localisation in the shear zones. D₃ fractures crosscut lithology units along the FBB corridor. Moreover, these D₃ structures crosscut both the D₁ and D₂ structures, as shown in [Figure 5.30](#) and [Figure 5.36](#), denoting an overall northeast maximum shortening direction.

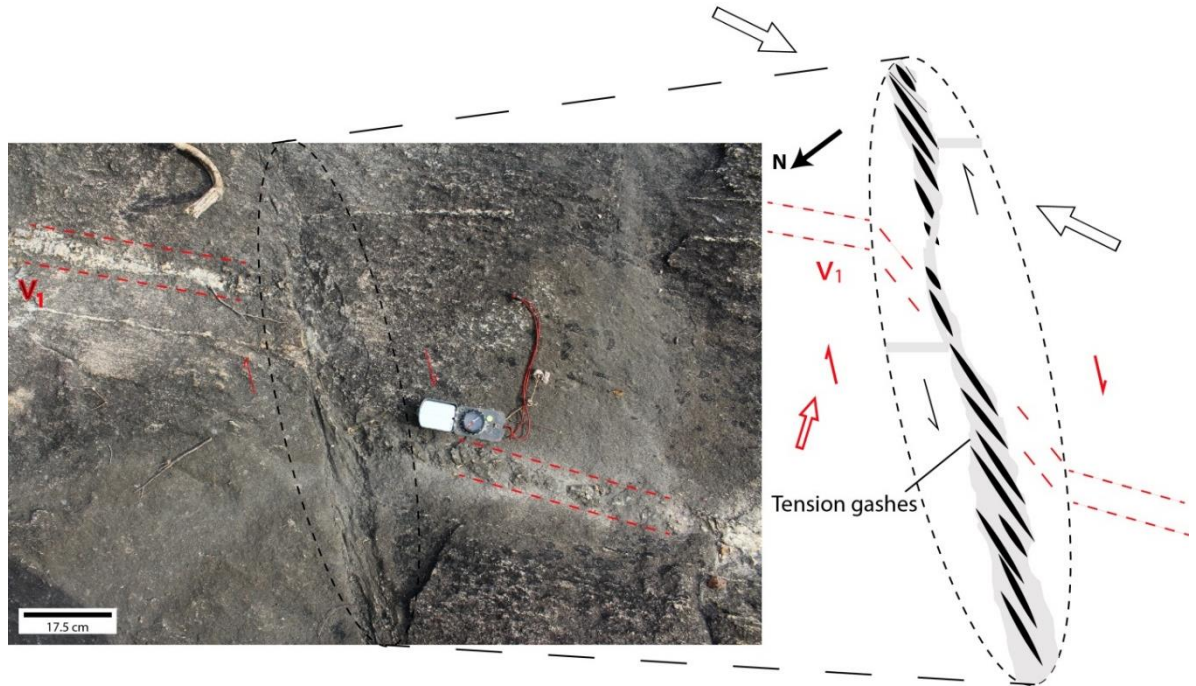


Figure 5.35: The structures associated with the D_3 deformation: tension gashes in an intrusive unit (granodiorite), indicating sinistral shear sense, complimenting with a northeast main shortening direction (UTM 30P, 0270568, 1074999). It crosscuts an antithetical dextral kinematics indicated by northeast trending V_1 veins. Highlighted in red are earlier structures and in black/grey are D_3 deformation structures.



Figure 5.36: Granodiorite crosscut by northeast trending D_1 structures (S_1 foliation and V_1 vein). D_3 northwest trending fracture crosscut these D_1 structures.

5.3 Revision of deformation events

The geological overview of the study area comprises volcano-sedimentary and sedimentary sequences intruded by syn- to post-tectonic intrusive units (Doumbia et al., 1998; Pouclet et al., 2006; Vidal et al., 2009). Geometric data related to various ductile and brittle structures observed during geological mapping of the study area, have helped to identify:

- Domain A: three main deformational events
- Domain B: three main deformational events

These deformational events were recognised crosscutting the region, which can be correlated with regional tectonism occurring in the central part of the Ivory Coast and ultimately the WAC.

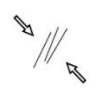
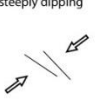
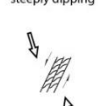
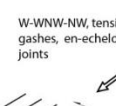
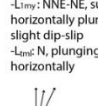
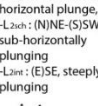
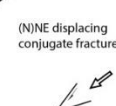
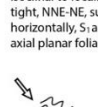
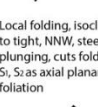
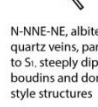
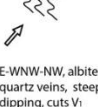
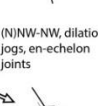
However, it is important to note that these distinctive deformation phases do not necessarily represent temporally isolated events but may be transitional and belong to one single deformation episode. Therefore, two consequent stages may be transitional with just a slight change to various conditions. Nevertheless, they represent augmentations or distinct phases that can be distinguished by their structures.

Structural analysis across the study area indicates that D_1 from Domain A and D_1 from Domain B correlate in terms of structural trend and principal compressive strain axis therefore define Deformation D_1 of the entire study area. The same reasoning was applied for D_2 and D_3 deformations from these domains. Therefore, three ductile-brittle deformations, D_1 – D_3 for the study area are herein presented in Table 9 and are as follows:

- North-northeast to northeast trending schist and mylonite zones define YNB and FBB. Along these zones north-northeast trending foliation (S_1), F_1 folds, shear bands (S-C foliation), buck quartz veins and quartz veins (V_1) are deduced to be the earliest structures (D_1). YNB and the northern segment of the FBB denote sinistral sense of displacement. D_1 deformation character is generally ductile, progressive to brittle. Brittle and semi-brittle structures include northwest to north-northwest trending dilational jogs, en echelon sigmoidal fractures and a set of displaced fractures. D_1 deformation symbolises north-northwest and south-southeast shortening.

- D₂ deformation structures comprise northwest trending F₂ folds and foliation (S₂) from refolding of D₁ structures S₁ and F₁. S-C foliation develops in the southern segment of FBB from north-northeast trending schist and mylonite zone indicating dextral-reverse sense of displacement. Northwest, east-west, west-northwest to east-northeast trending veins (V₂), conjugate shear fractures also formed during D₂. D₂ deformation character is generally ductile-brittle and denotes north-northeast to south-southwest shortening.
- D₃ deformation is defined by northwest to west trending fractures and shear faults. The traces of D₃ fractures crosscut those of D₁ and D₂ features throughout the study area. Northwest trending tension gashes indicating sinistral sense of displacement also formed during D₃. North-northeast trending set of shear fractures define D₃ deformation. The overall orientation and crosscutting relationship indicate that this deformation was formed during an overall north-northeast to northeast maximum shortening.

Table 9: Structural history of the FSZ and adjacent area after field investigation and structural analyses. D₁, D₂ and D₃ are deformational events recognised crosscutting the region, which can be correlated with regional tectonism occurring in the central part of the Ivory Coast and ultimately the WAC.

D ₁ → D ₂ → D ₃		
S₁ NNE-NE, penetrative, steeply dipping 	S₂ (NNW, very localised in fold hinges, steeply dipping 	Parallel sets of thin fractures, closely spaced, steeply dipping & NNW-NW-WNW trend 
S₁-C NNE-NE, penetrative, steeply dipping 	S₂-C NNE-NE, penetrative, steeply dipping. 	W-WNW-NW, tension gashes, en-echelon joints 
L₁ -L_{1my}: NNE-NE, sub-horizontally plunging, slight dip-slip -L_{1ms}: N, plunging sub-horizontally 	L₂ -L_{2my}: N-NNE-NE, sub-horizontal plunge, -L_{2sch}: (N)NE-(S)SW, sub-horizontally plunging -L_{2int}: (E)SE, steeply plunging 	(N)NE displacing conjugate fractures 
F₁ isoclinal to locally tight, NNE-NE, sub-horizontally, S₁ as axial planar foliation 	F₂ Local folding, isoclinal to tight, NNW, steeply plunging, cuts folded S₁, S₁ as axial planar foliation 	constrained at < 2054 ± 11 Ma
V₁ N-NNE-NE, albite-quartz veins, parallel to S₁, steeply dipping, boudins and domino-style structures 	V₂ E-WNW-NW, albite-quartz veins, steeply dipping, cuts V₁ 	
(NNW-(S)SE trending, set of fractures, steeply dipping 		
(NNW-NW, dilational jogs, en-echelon joints 		
(NNW, en-echelon sigmoidal fractures 		
constrained at < 2091 ± 6 Ma		
(σ ₁ = NNW-SSE to NW-SE)	(σ ₁ = NNE-SSW to NE-SW)	(σ ₁ = NNE-SSE to NE-SW)

5.4 Gold mineralisation

Gold mineralisation associated with the FSZ occurs in the southwest (Tortiya region) and northeast (north of Kouloukorosso) of the Ferké Batholith (Figure 5.37). Orpailage workings in both Tortiya and Kouloukorosso regions were recognised in metasedimentary units crosscut by multiple brittle structures i.e. extensional zones. Most gold deposits occur within “locally extensional” secondary and tertiary structures associated with the first order shear zones (Cox, 1999; Murray et al. 2019) that are northeast to east-northeast trending. Sinistral sense of displacement in YNB and BNSZ resulted in a zone of transtension associated with bends along the two shear zones. Gold occurrence in this extensional setting is associated with migration of mineralised fluids through low-order structures i.e. faults. The case in the Tortiya region is similar as the mineralised area is crosscut by various quartz veins and extensional faults. These gold hosting regions are structurally controlled and spatially associated with shear zones and hydrothermal veins form in response to the regional stress field (Sibson and Scott, 1998). Faults and shear zones are potential pathways of fluids.

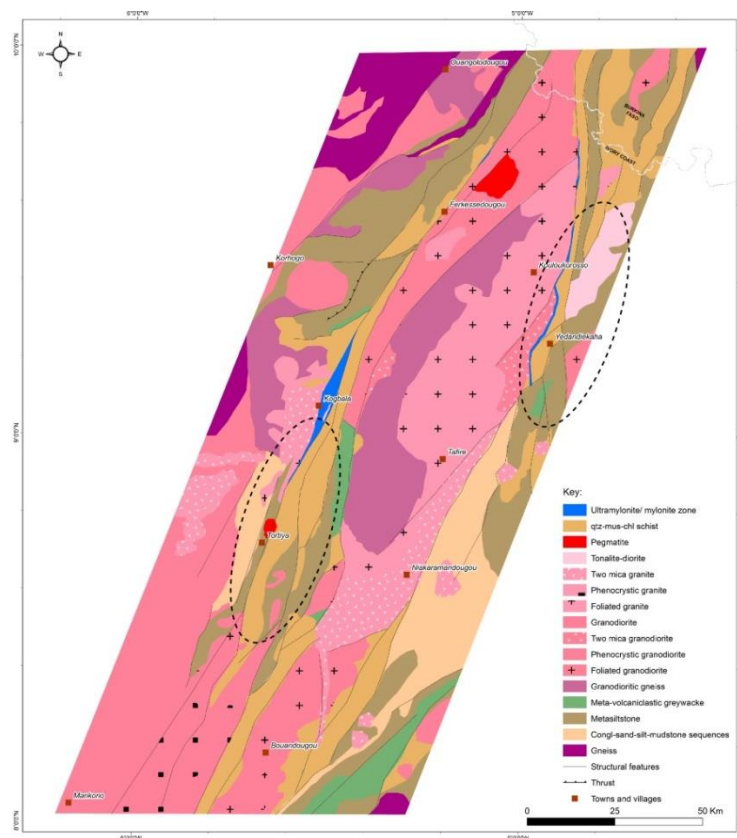


Figure 5.37: Geology map of the study area with markings of both Tortiya and Kouloukorosso regions with gold deposits.

6 DISCUSSION AND SYNTHESIS

6.1 Introduction

This dissertation allowed production of a complete geodynamic evolution of the FSZ, which collectively integrated desktop studies, field mapping (structural), petrological-geochemical and geochronological studies. These data from the FSZ in collaboration with analytical techniques yielded various geological events. The data was used to chronologically constrain time and incipient stages of these geological events. Geological events are herein referred to as structural, magmatic, mineralisation and metamorphic events.

This dissertation also provides a view of the tectonic history from published data of WAC compared with the established tectono-magmatic history of the FSZ. The timing of gold mineralisation will be described within the framework of the tectono-magmatic history of the FSZ. Finally, a geodynamic model regarding the FSZ in the north-central Ivory Coast is established in this manner.

6.2 Stratigraphic overview of the north-central Ivory Coast

In the north-central Ivory Coast, study area exhibits analogous lithostratigraphic and magmatic evolution as described by [Doumbia \(1997\)](#), [Doumbia et al. \(1998\)](#), [Pouclet et al. \(2006\)](#) and [Vidal et al. \(2009\)](#). U-Pb ages from geochronological data suggest that the oldest rocks in the study area are formed by gneissic granitoids, specifically orthogneiss of granodioritic composition. Rocks of this composition are also reported as basement units in Mali, Senegal, Ghana, Niger, Burkina Faso and parts of Guinea ([Lemoine et al., 1990](#); [Pons et al., 1995](#); [Hirdes et al., 1996](#); [Gueye et al., 2008](#); [De Kock et al., 2009](#); [Tshibubudze, 2015](#); [Fernie et al., 2018](#)). Within the study area, volcano-sedimentary and sedimentary sequences uncomfortably overlie gneissic units. This lithostratigraphic relationship is exposed extensively in the western and north-western portion of the study area, particularly in the Ouangolodougou region. A similar lithostratigraphic relationship is reported by [Doumbia et al. \(1998\)](#) and [Pouclet et al. \(2006\)](#) stating that metasedimentary units unconformably overlie both greenstone belt formations and earlier generation granitoids.

The units making up the volcano-sedimentary and sedimentary sequences, from base to top, include (a) meta-conglomerate-sandstone-siltstone-mudstone succession and (b) meta-volcaniclastic greywacke. These units are fining upwards and interpreted to have been deposited in subsidence. According to [Pouclet et al. \(2006\)](#) the subsidence was controlled by normal faults that allowed rhyodacitic activity and fining upward detrital deposition. Subsequent to deposition, northwest-southeast compression caused folding with steep foliation, parallel to the axial plane striking north-northeast coeval with Ferké Batholith emplacement. Emplacement occurred along north-northeast transcurrent shear zone corridors indicating a (north)-northwest and oblique compressional deformation ([Vidal and Iric, 1994](#)), i.e., the Ferké Batholith is a syn-tectonic intrusion ([Doumbia et al., 1998](#); [Ouattara, 1998](#); [Pouclet et al., 2006](#)). Contact and thermal metamorphism between the batholith and the volcano-sedimentary units displayed prehnite-pumpellyite facies to general greenschist facies metamorphic grades ([Doumbia et al., 1998](#)).

6.2.1 Syn-tectonic emplacement of the Ferké Batholith

Recent studies in the Palaeoproterozoic granitoids of the WAC have produced geochronological data, suggesting that vast granitoid plutons were dated between 2.26 Ga and 2.0 Ga ([Boher et al., 1992](#), [Egal et al., 2002](#), [Feybesse et al., 2006](#), [Gueye et al., 2008](#), [Tapsoba et al., 2013a](#), [Tshibubudze et al., 2013](#)). In addition to [Leube et al. \(1990\)](#), [Hirdes and Davis \(2002\)](#) research, [Pawlig et al. \(2006\)](#) and [Gueye et al. \(2008\)](#) also suggest that TTG and diorite emplacement at 2200 Ma and 2160-2130 Ma preceded the Eburnean Orogeny, while granite-leucogranite emplacement at 2100-2070 Ma was concurrent with the Eburnean Orogeny. The later stage of the Eburnean Orogeny at around 2100 Ma, is marked by the emplacement of leucogranite batholiths into the upper crust, coeval with a west-northwest oriented regional-scale shortening ([Doumbia, 1997](#); [Pouclet et al., 2006](#)).

Criteria for syn-tectonic emplacement of plutons or batholiths are normally ambiguous. The strong single criterion is commonly referred to as the preservation of structures displaying the transition from magmatic to solid-state deformation ([Benn et al., 1999](#); [Moyen et al., 2003](#); [Li et al., 2018](#)). This transition serves as a key point and providentially Ferké Batholith is no exception as it displays variety of syn-tectonic structures within its shear zone boundaries.

Structural data collected in the field demonstrating that the Ferké Batholith was syn-tectonically emplaced within an active strike-slip shear zone is evidenced by;

- (a) Steep foliation.
- (b) Sub-horizontal lineation mostly parallel to the long axis of the batholith.
- (c) The Ferké Batholith is generally an elongate intrusion, emplaced in the vicinity of high-strain zones.
- (d) The discernible mylonitic structures are ubiquitously parallel to the deformation features (i.e. foliation) also recognised in the country rocks (i.e. metavolcano-sedimentary rocks). This implies that the fabrics orientations are consistent in both the batholith and country rocks. Therefore, deformation during this phase was synchronous with 'regional' deformation in the wall rocks.

Furthermore, [Vidal et al. \(2009\)](#) provided magmatic and magnetic foliation sub-parallel to the shear zone fabrics; this data was obtained by [Ouattara \(1998\)](#) in the same study area. In addition, during D₁ steeply dipping foliations developed parallel to the batholith margins with sub-horizontal lineation, this postulates that D₁ structures are attributed to transpressive regional deformation. This is marked by development of two groups of folds with fold axis parallel to the batholith: (a) folds of quartz veins within the batholith and (b) folding of metasedimentary units formed during the lateral movement of the FSZ, squeezing and displacing incompetent metasedimentary rocks against the competent batholith ([Figure 6.1](#)). This implies that the batholith was entirely crystallised when the shear zone system was active ([Miller and Paterson, 1994](#)).

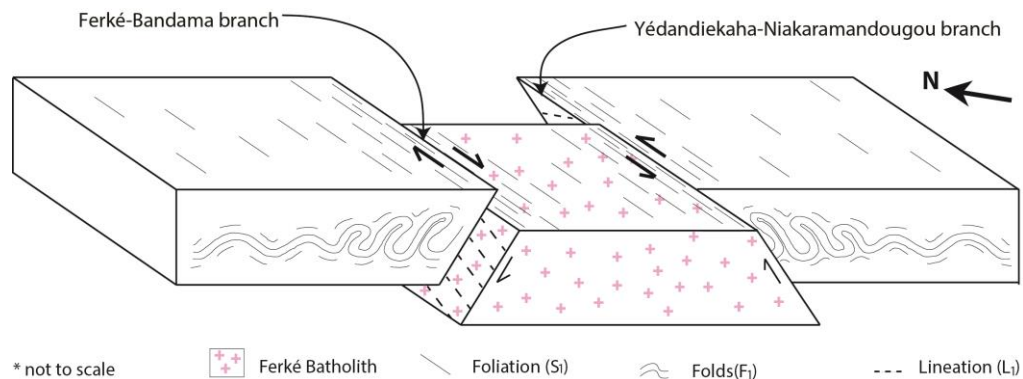


Figure 6.1: Schematic diagram of the study region showing the structural relationship between the country rock and the batholith. The intensity of deformation decreases away from the shear zones.

Vidal et al. (2009) reported that Ferké Batholith displays magmatic fabric, but did not preserve as much evidence for syn-tectonic deformation. Syn-tectonic features are most likely preserved in plutons cooled at slow to moderate rates (Miller and Paterson, 1994). The majority of the syn-tectonic features are obscured by post emplacement deformation. Igneous features in the study area include: schlieren layering, enclaves and xenoliths. The long axes of these features are parallel to the batholith and solid-state features related to the regional deformation. The presence of both magmatic and solid-state deformation features demonstrates that this strike-slip event has been active during and after complete crystallisation of the magma (Miller and Paterson, 1992; 1994). For these reasons, emplacement of the Ferké Batholith is considered syn-tectonic.

6.3 Tectonic overview of the FSZ and adjacent regions

D₁, D₂ and D₃ deformational events are recognised crosscutting the study area, which can be correlated with regional tectonism occurring in the central part of the Ivory Coast and ultimately the WAC.

Succeeding the deposition of meta-sedimentary and volcano-sedimentary units, and emplacement of the Ferké Batholith, D₁ deformed the region to form a (north)-northeast trending structures. These structures include batholith-controlling shear zones, tight upright to inclined folds (F₁), foliation (S₁ and S-C), and lineation (L₁) as well as quartz-albite veins (V₁). Late D₁ event is recognised by its ductile to semi-brittle character. Semi-brittle structures are dominated by brittle deformation mechanisms but contain some ductile aspects, e.g. en echelon, tension gashes and dilational jogs. Late D₁ is marked by (a) north-northwest trending sub-vertical sigmoidal en echelon fractures (possibly veins) indicate dextral shear sense, (b) sub-vertical en echelon and right stepping fractures indicating sinistral sense of shear and (c) northeast to east trending and sub-vertical to steeply dipping displaced fractures. D₁ resulted in development of steeply dipping and sinistral crustal-scale shear zones i.e. FSZ. FSZ is defined by mylonites and schists zones. This deformation event is progressive and generally characterised by ductile to (semi)-brittle structures. It is stated in Chapter 5 that principal compressive strain axis is to the north-northwest and south-southeast directions.

Subsequent to D_1 , metasedimentary units and the FBB were subjected to north-northeast and south-southwest directed principal compressive strain axis (in D_2). D_2 is characterised by dextral displacement and reactivation along the north-northeast trending shear zone, i.e. southern segment of the FBB. This branch is defined by mylonites and schists (S_2 -C foliation). Northwest trending S_2 foliation develops by crosscutting S_1 foliation on F_2 fold associated with lineation (L_{2int} and L_{2my}). V_2 veins are northwest to north-northwest trending and crosscut V_1 veins.

D_3 deformation is discernible throughout the study area and is marked by semi-brittle and brittle structures. Steeply dipping and east-west to west-northwest oriented fractures are closely spaced. Tension gashes, en echelon structures and micro faults dominate the southern part of the study area and correlate with D_3 characteristics i.e. overall north-northeast to northeast maximum shortening direction.

6.3.1 Comparison to regional tectonics events

The principal compressive strain axis direction in D_1 across the study area is interpreted to be north-northwest-directed based on foliation (S_1), fold (F_1) vergence, lineations, orientation of vein (V_1), late (semi)-brittle structures and sinistral sense on northeast shear zones. This can be correlated with the broader Eburnean Orogeny as reported by [Milési et al. \(1991, 1992\)](#), [Feybesse et al. \(2006\)](#), [Hein \(2010\)](#), [De Kock et al. \(2011, 2012\)](#), [Baratoux et al. \(2011\)](#), [Perrouy et al. \(2012\)](#), [Tshibubudze \(2015\)](#), [Murray et al. \(2019\)](#). D_1 compares well with north-northwest directed principal compressive strain axis of D_2 of: (a) [Hein \(2010\)](#) for the Goren Greenstone Belt in Burkina Faso. (b) [Tshibubudze \(2015\)](#) for north-northeast trending shear zones such as the Koreziéna Branch of the Markoye Shear Zone, and the Waho Branch of the Kargouna Shear Zone Complex in the Oudalan-Gorouol volcano-sedimentary Belt, northern Burkina Faso. (c) [Baratoux et al. \(2011\)](#) defined a northeast oriented shear zones that operated under lower greenschist facies conditions and high strain zones with a seldom shallow-dipping lineation. (d) [Milési et al. \(1989\), \(1991\), \(1992\)](#); [Castaing et al. \(2003\)](#) stated that gold mineralisation and peraluminous granitoids are frequently associated with such (north)-northeast trending regional-scale shear zones. The orientation of σ_1 of D_{ext} and D_1 reported by [Murray et al. \(2019\)](#) has a notable correlation with D_1 deformation from this study.

During D₂, principal compressive strain axis direction in the study area is interpreted to be north-northeast directed. D₂ is marked by (north)-northwest trending foliation (S₂) and folds (F₂), these features crosscut D₁ structures. This event is responsible for dextral sense of displacement shown by north-northeast trending shear zones. The direction of the principal compressive strain axis can be correlated with D₃ northeast-southwest trending ductile strike-slip faults reported by [Feybesse et al. \(1990\)](#) and [Milesi et al. \(1991\)](#) in Burkina Faso.

In the study area, D₃ denote north-northeast principal compressive strain axis and characterised by the formation of east-west to west-northwest oriented fractures that are steeply dipping to the north and south. Similar structures were reported as D₃ event by [Hein \(2010\)](#), [de Kock et al. \(2011\)](#), [Baratoux et al. \(2011\)](#) and [Tshibubudze \(2015\)](#). Within the study area (semi)-brittle fractures crosscut D₁ and D₂ structures, and are associated with tension gashes, en echelon structures and micro faults. The event is termed the Wabo-Tampelse Event and post-dates the Eburnean Orogeny ([Hein et al., 2004](#)). According to [Tapsoba et al. \(2013b; 2018\)](#) Wabo Templese event is constrained at 1984–1918 Ma.

6.4 Geochronological and geochemical data overview

The major interest in absolute geochronology (zircon U-Pb) is to constrain the relative chronologies and information gathered in the north-central Ivory Coast. U-Pb analysis of zircon from specific rock samples can provide insight into both the nature of protoliths and the sequence of subsequent geological events ([Hanchar and Miller, 1993](#); [Vavra et al., 1996, 1999](#); [Müller et al., 2002](#); [Aleinikoff et al., 2006](#); [Corfu, 2007](#)). Complex zonation present in zircon denotes multi-stage history from initial magmatic crystallisation, partial melting, hydrothermal alteration, magma mixing and later events in magmatic rims ([Griffin et al. 2002](#); [Van Lichtenvelde et al. 2009](#); [El-Bialy and Ali 2013](#)). Therefore, U-Pb zircon ages of north-central Ivory Coast constrain the maximum and minimum ages of rock units and geological events.

The granitoid samples from the north-central part of Ivory Coast generally contain more metamict zircons than unaffected zircons. Metamict zircons or “low zircons” indicate that sufficient uranium and thorium has undergone radioactive decay substituting for zirconium ([Nasdala et al., 1998](#); [Nasdala et al., 2001](#)). This results in destruction of core structure leading to

local stress and formation of micro-fissures and cracks due to heterogeneous expansion (Nasdala et al., 2001).

Sample (CidF_028A) yielded crystallisation age of 1985 ± 6 Ma obtain from pegmatite. This relatively young age marks the late stages of the Eburnean orogenic event (Feybesse et al., 2006; Perrouty et al., 2012; Ouattara et al., 2013b, Traoré et al., 2016; Feng et al., 2018). Inherited zircon age 2109 ± 6 Ma correlates with the minimum age limit of the first generation granitoid intrusions and maximum age for deposition of metasedimentary units (Doumbia et al., 1998; Pouclet et al., 2006). Rim age 690 ± 1 Ma corresponds with metamorphic events associated with the Pan-African Orogeny (Granath and Dickson, 2018). In CL image, recrystallisation patches show truncation of oscillatory-zoned inner parts. Truncations of the oscillatory zones are generally interpreted as chemical corrosion events (Vavra, 1990, 1994). Core analyses on zircon no.7 yielded age at 2138 ± 1 Ma that is herein inferred as an inherited core, i.e. defined as age considerably older than the main population. Geochemically, this sample suggests syn-tectonic emplacement as it plots in the syn-collision field on the R1-R2 major element geotectonic discrimination diagram of Batchelor and Bowden (1985).

U-Pb ages at 2150 ± 1 Ma, 2146 ± 1 Ma and 2132 ± 12 Ma from two-mica granite (sample CidF_100) correspond to ages of Bavé-type granodiorite dated at 2137 ± 9 Ma and 2152 ± 2 Ma for the Comoé type granodioritic biotite gneiss (Doumbia et al., 1998). Weighted mean age of 2132 ± 12 Ma is herein deduced as the crystallisation age. These U-Pb ages as well as 2175 ± 1 Ma and 2174 ± 1 Ma, herein interpreted as an inherited age, define the early stages of the first generation volcanic activity in Ghana and Ivory Coast (Hirdes et al., 1992; Pouclet et al., 2006).

Sample CidF_113A is a pegmatite containing gneissic xenoliths. U-Pb age of 2015 ± 1 Ma is interpreted as a crystallisation age. Inherited zircon ages at 2211 ± 1 Ma and 2387 ± 19 Ma could correlate to magmatic ages of gneissic xenoliths contained by pegmatite. In CL images, rapid crystal growth is connoted by oscillatory zones that are represented as medium grey inner rims, followed by darker outer rims.

Sample CidF_113B is an orthogneiss that produced U-Pb ages of 2271 ± 1 Ma and 2270 ± 5 Ma whereas orthogneiss sample (Cid_102a) yielded U-Pb zircon magmatic age of 2282 ± 4 Ma. These ages correlate with Lilengo gneiss complex $^{207}\text{Pb}/^{206}\text{Pb}$ ages in Burkina Faso dated at 2284 ± 23 and 2272 ± 33 Ma (Tshibubudze, 2015). U-Pb ages 2271 ± 1 and 2270 ± 5 Ma are inferred as crystallisation ages. U-Pb ages 2338 ± 1 , 2328 ± 1 , 2493 ± 1 Ma are herein interpreted as inherited. U-Pb ages 2062 ± 1 , 2053 ± 1 , 2044 ± 1 Ma are interpreted as recrystallisation ages associated with new younger zircons. Sample CidF_113B CL images indicated bright structures reveal cores; are interpreted to be inherited, because they are structurally discontinuous to the outer growth zones, show truncated zoning as well as recrystallisation patches and convoluted zoning. This is interpreted as metamictisation, evident from radial cracks in the cutting growth zones, surrounded by relatively brightly luminescent zones, followed by low luminescent zones. Geochemically, the Th/U ratio is greater than 0.1, i.e. magmatic zircons and it can be inferred that they crystallised early in the evolution of granitic magma (Zeng et al., 2017).

For sample Cid_102a, two zircons rims returned younger age of ~ 2097 Ma which is herein interpreted as metamorphic age correlating with the age constrained by granodiorite for D_1 and intrusion of the Ferké Batholith.

Orthogneiss sample (Cid_005) with granodioritic composition yielded U-Pb zircon age of 2172 ± 4 Ma and weighted mean age of 2173 ± 8 Ma, which are the crystallisation ages of the pre-metamorphic protolith.

In the study area, U-Pb zircon ages of 2091 ± 6 Ma (sample CidF_038) obtained from granodiorite corresponds with the ages of other post-basin type plutons elsewhere in the Birimian domain, such as two-mica granodiorite from Bambéla basin dated at 2097 ± 3 Ma (Hirdes et al., 1996; Dombia et al., 1998) and in the Comoé basin where a granodiorite is dated at 2095 ± 10 Ma and 2079 ± 11 Ma (Yao et al., 1995). In Senegal, post-basin granites are dated at 2082 ± 1 , 2080 ± 1 and 2076 ± 2 Ma (Hirdes and Davis, 2002). Egal et al. (2002) obtained ages between 2087 ± 1 and 2072 ± 4 Ma from granites intruding a basin in Guinea. The age (2091 ± 6 Ma) of obtained from the granodiorite sample constrains the emplacement of the Ferké batholith, folding (F_1) of metasedimentary units, development of foliation (S_1 and $S_1\text{-C}$), lineation (L_1) and ultimately D_1 .

In the field, orthogneiss sample (CidF_086) is intruded by a granodiorite. The contact is exposed and is associated with steeply plunging lineation ([subsection 4.2.3](#)). The sample returned a magmatic population presenting a weighted mean age at 2066 ± 10 Ma and one inherited zircon returned an age of 2153 ± 16 Ma. The age 2153 ± 16 Ma is herein interpreted as the magmatic age of the source rock (orthogneiss) that underwent partial melting to form granitic melt, i.e. emplacement of granodiorite at 2066 ± 10 Ma, the magmatic age.

In summary:

- (a) Ferké Batholith constrains emplacement age between U-Pb age of 2097 and 1842 Ma.
- (b) U-Pb age of 2097 Ma constrains FSZ, D₁ and maximum age for folding event.
- (c) U-Pb age of 2109 ± 6 Ma constrains minimum age of the first generation granitoid intrusions and the maximum age for deposition of metasedimentary units.
- (d) U-Pb age of 2132 Ma constrains the age of extensional phase (D_{ext}).
- (e) Orthogneiss are emplaced between 2282 and 2211 Ma.

Geochemically, all six analysed samples display high SiO₂ content (≥ 70 wt %) and indicate true granite characteristics. In the classification diagrams (R1 - R2 binary diagram by [De la Roche et al. \(1980\)](#), Ab-An-Or normative triangular plot by [Barker \(1979\)](#), QAP diagram by [Streckeisen \(1976\)](#) and TAS for plutonic rocks diagram of [Cox et al. \(1979\)](#) adapted by [Wilson \(1989\)](#)) these samples plot in the granite field. This correlates with the data presented by [Doumbia et al. \(1998\)](#) on Ferkéssédougou intrusions.

In binary A/NK against A/CNK plot (after [Shand, 1943](#)) the Ferké Batholith samples suggest peraluminous character, indicating that all the granites were derived from a source of narrow chemical composition and also incorporation of sedimentary protolith material. This peraluminous nature can be compared to Hercynian leucogranites of the French southern Armorican Massif ([Gapais et al., 2015](#)) and the Himalayan Manaslu leucogranites ([Searle and Godin, 2003](#)) which are described as syn-collisional granitoids. Presence of pegmatites, abundant mica-silica content and peraluminous nature corroborates the idea that the Ferké Batholith may well be the melting product of the migmatitic mica-rich gneiss. Tectonic discrimination diagrams

confine these I-type and calc-alkaline samples to volcanic arc granite types and syn-collision field. However, only sample Cid_F 028A is plotting in the S-type field.

6.5 Geodynamic model

In the study area, the oldest rocks are gneissic units i.e. orthogneiss with granodioritic composition dated between 2282 ± 4 and 2132 ± 12 Ma. The gneissic units were affected by extensional phase (D_{ext}) from ca. 2132 ± 12 to 2109 ± 6 Ma. The D_0 deformation produced subsidence setting controlled by normal faults (Pouclet et al., 2006). The regime rifted gneissic units apart to the east and west resulting in basin formation. The deposition of volcano-sedimentary and sedimentary units began ca. 2109 ± 6 to 2097 Ma. Subsequent to deposition of metasedimentary units, D_1 was concurrent with emplacement of a peraluminous Ferké Batholith (2097 Ma) (Figure 6.2) and development of upright folds (F_1) with parallel foliation (S_1 and $S_1\text{-C}$) and sub-horizontal lineation (L_1).

During D_1 all units attained greenschist metamorphism throughout the region. Omnipresent greenschist facies conditions, similar structural features (foliation and lineation) on both batholith and surrounding rocks, and lack of tectonic thickening means the genesis for Ferké Batholith emplacement cannot be advocated by classical “modern type” orogenic models (Vidal et al., 2009; Doumbia et al., 1998). Plausible mechanism would result from partial melting of basement units during D_1 with shear zones acting as transfer sutures for magma heat and water “hydrothermal solution”. This also complements the elongated shape of the batholith. This highlights the coeval plutonic and tectonic activities during emplacement of the Ferké Batholith (Doumbia et al., 1998; Vidal et al 2009; Baratoux et al., 2011).

Subsequent to D_1 deformation and emplacement of 2097-1842 Ma aged plutons, the north-northeast directed shortening affected parts of the region. D_2 is responsible for refolding of F_1 folds to form northwest trending F_2 folds and reactivation of D_1 shears to develop dextral (reverse) sense. The reactivation of D_1 shears by D_2 is represented by conversion in sense of displacement from sinistral to dextral on the north-northeast trending shear zones. D_3 structures denote north-northwest shortening, characterised by east-west to west-northwest oriented fractures, tension gashes, en echelon structures and micro faults.

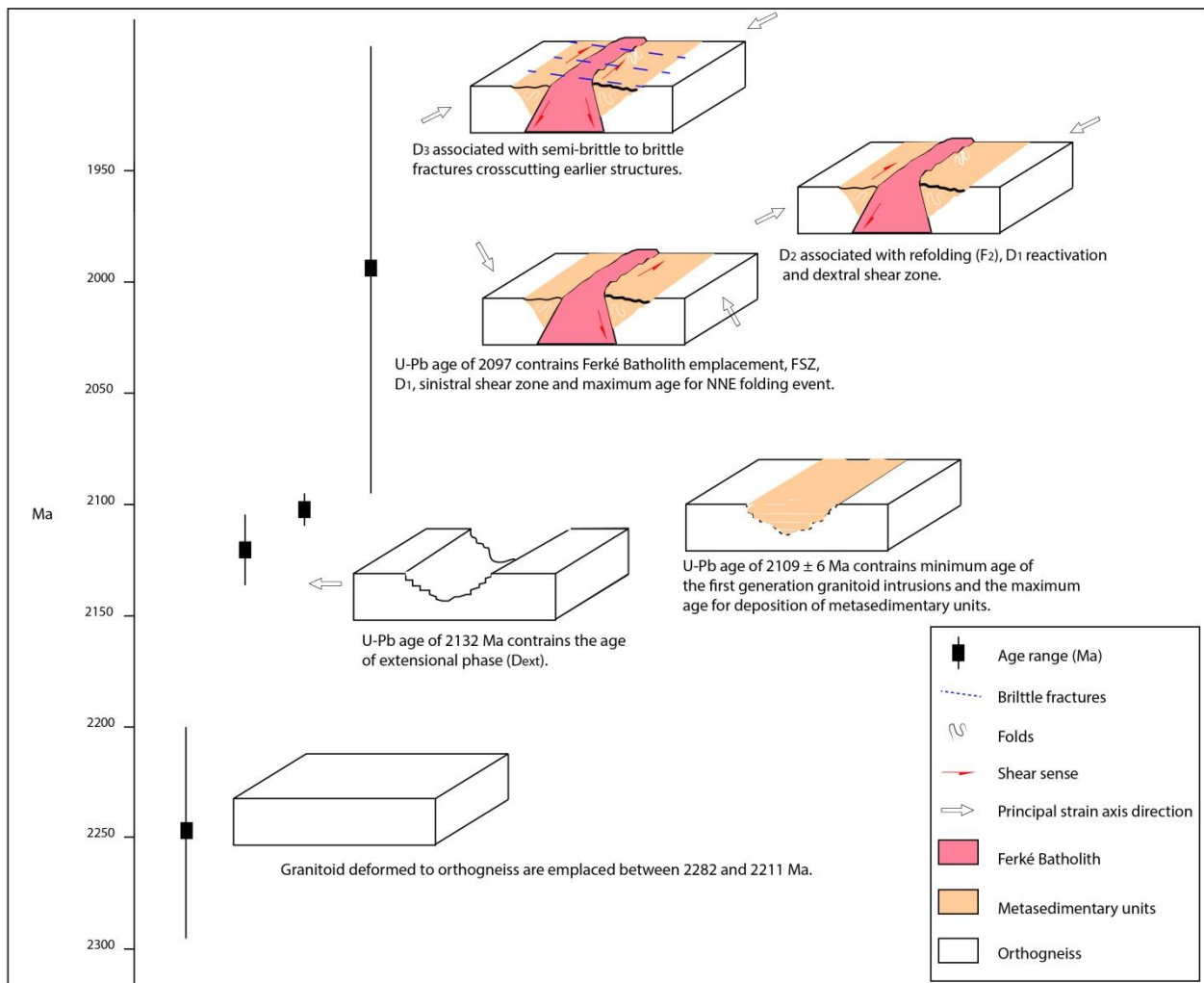


Figure 6.2: Absolute timing of litho-stratigraphic units and deformational events established using U-Pb ages from the north-central Ivory Coast.

7 CONCLUSIONS

In north-central Ivory Coast, tectono-magmatic evolution is established for the FSZ, Ferké Batholith and adjacent regions. Approach included desktop, field, data analytical, geochemical and geochronological studies. The principal conclusions drawn from this dissertation are:

- (1) The oldest units in the study area are orthogneiss which are granodioritic in composition. The geochronological data dated these basement units at U-Pb zircon magmatic ages of 2282 ± 4 and 2132 ± 12 Ma. These ages are interpreted as protolith ages prior to multiple geological events.
- (2) The gneissic units were affected by extensional phase (D_{ext}) from ca. 2132 ± 12 to 2109 ± 6 Ma. This phase is responsible for basin formation.
- (3) Volcano-sedimentary and sedimentary units were deposited ca. 2109 ± 6 to 2097 Ma in a subsidence setting.
- (4) Metasedimentary units (i.e. meta-volcaniclastic greywacke and conglomerate-sandstone-siltstone-mudstone succession) define a fining-upward succession that is folded and metamorphosed during D_1 , approximately 2097 Ma. D_1 is responsible for emplacement of syn-tectonic Ferké Batholith and development of north-northeast sinistral (normal) shear zones (S_1 , $S_1\text{-C}$ and L_1).
- (5) Emplacement age of the Ferké Batholith has a range between 2097 and 1842 ± 20 Ma constrains D_1 and provides minimum age for deposition of metasedimentary sequences. D_1 event denotes north-northwest and south-southeast directed principal compressive strain axis.
- (6) Plausible mechanism for batholith emplacement results from partial melting of the gneissic basement units during D_1 with shear zones acting as transfer sutures for magma heat and water “hydrothermal solution”. This also complements the elongated shape of the batholith.
- (7) The late D_1 structures are recognised in the eastern and southern parts of the study area. This is characterised by ductile to (semi-brittle) structures. Late D_1 is marked by north-northwest trending sub-vertical sigmoidal en-echelon fractures (possibly veins) indicate dextral shear sense, sub-vertical en-echelon and right stepping fractures indicating sinistral sense of shear and northeast trending and sub-vertical, displaced fractures.

- (8) Subsequent to D_1 , D_2 is characterised by (north)-northwest F_2 folds, S_2 foliation and L_2 lineation. D_2 is responsible for dextral (reverse) sense of displacement and reactivation of north-northeast trending shear zone. The event denotes north-northeast and south-southwest directed principal compressive strain axis.
- (9) D_3 structures include steeply dipping east-west to west-northwest oriented brittle fractures that are closely spaced. Tension gashes, en-echelon structures and micro faults dominate the southern part of the study area and correlate with D_3 characteristics i.e. overall north-northeast to northeast maximum shortening direction.
- (10) Gold mineralisation is hosted by metasedimentary units along the FSZ and occurs in the extensional settings (northeast trending 3rd or 4th order structures) in the southwest (Tortiya region) and northeast (north of Kouloukorosso) of the Ferké Batholith. Extensional settings occur on the releasing bends due to the shape of the batholith and/or shear zone.
- (11) Geochemically, Ferké Batholith is true granite and is represented in granite fields for most classification diagrams. Presence of pegmatites, abundant mica-silica content and peraluminous nature corroborates the idea that the Ferké Batholith may well be the melting product of the migmatitic mica-rich gneiss with incorporation of sedimentary material. Tectonic discrimination diagrams confine the batholith within syn-collision fields.

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9 APPENDICES

Appendix A

Research data: Ferké Shear Zone and Ferké Batholith

STN P	NORTHING'S	EASTING'S	HOST ROCK TYPE	CHARACTER	STR	DIP	DIP DIR	STRUC	STRUC TYPE	DISPLT	UP/DOWN	FACING	SAMPLE NO	GEOCHRONOLOGY	GEOCHEMISTRY
001	1096409	0262050	laterite profile/ gneiss	heavily weathered material of fine matrix of laterites with mm-4cm clasts. Underlain by gneiss composed of plagioclase, quartz, hornblende, biotite, muscovite											
002	1085116	0264135	quartz veining on laterite profile	brecciated (5-15 cm) quartz fragments											
003	1084681	0264373	metasiltstone	quartz veining parallel to cleavage	020	88	W	cleavage	S1						
003	1084681	0264373	metasiltstone	quartz veining parallel to cleavage	030	86	W	cleavage	S1						
004	1075244	0267186	plagioclase-quartz-chlorite schist	plagioclase, quartz, chlorite. boudinaged and sheeted quartz veins	050	82	W	cleavage	S1						
004	1075244	0267186	plagioclase-quartz-chlorite schist			10	050	lineation	mineral						
005	1064037	0259856	quartz-chlorite-muscovite schist + metasiltstone	quartz veining parallel to cleavage. Kaolinization on metasediments.	050	82	W	cleavage	S1						
005	1064037	0259856	quartz-chlorite-muscovite schist + metasiltstone		044	76	W	cleavage	S1						
005	1064037	0259856	quartz-chlorite-muscovite schist + metasiltstone		044	68	W	cleavage	S1						
006	1066980	0259921	metasiltstone	composed of plagioclase, muscovite											
007	1066979	0260144	metasiltstone	poorly exposed, quartz veining	038	48	W	cleavage	S1						
008	1067020	0260158	quartz veining on laterite profile	parallel quartz veins (3 cm spacing)	042	82	W	trend							
009	1067126	0260644	metasiltstone	quartz veining (3 cm spacing and thickness) parallel to cleavage	026	78	W	cleavage	S1						
010	1067616	0265314	granodiorite gneiss	0.5 cm bands, muscovite (1-3 cm) phenocrysts, plagioclase, biotite, hornblende, quartz. Partial melts coarser 10 m to the E	056	70	W	cleavage	S1				cidf-010		
010	1067616	0265314	granodiorite gneiss		040	68	W	cleavage	S1						
010	1067616	0265314	granodiorite gneiss		034	66	W	cleavage	S1						
011	1067585	0264444	foliated granodiorite	composed of plagioclase, muscovite, biotite, hornblende, quartz. Crosscut by pegmatite veins (plagioclase, quartz, tourmaline) and albite veins (plagioclase, quartz)	030	72	W	cleavage	S1				cidf-011		
012	1067665	0264466	foliated granodiorite	composed of plagioclase, muscovite, biotite, hornblende, quartz. Crosscut by pegmatite veins (plagioclase, quartz, tourmaline) and albite veins (plagioclase, quartz)											
013	1074977	0270553	laterite profile	scattered granodiorite boulders											
013	1075870	0269985	laterite profile	scattered granodiorite boulders											
014	1075744	0270358	laterite profile	scattered granodiorite boulders (15 cm)											
015	1075133	0270514	foliated granodiorite	composed of plagioclase, muscovite, biotite, hornblende, quartz. Albite veins parallel to foliation	038	78	W	cleavage	S1				cidf-015		
016	1075116	0270614	granodiorite	composed of plagioclase, hornblende, quartz. Boudinaged 3-5 cm pegmatite veins (quartz, plagioclase) parallel to foliation. Small shear bands.	040	80	W	cleavage	S1	sinistral			cidf-016		
016	1075116	0270614	granodiorite		044	78	W	cleavage	S1						
016	1075116	0270614	granodiorite		12	038		lineation	mineral						
017	1075044	0270567	granodiorite	composed of plagioclase, hornblende, quartz. Pegmatite vein (plagioclase, quartz, tourmaline, muscovite) NE< E-W.	038	78	W	cleavage	S1						
017	1075044	0270567	granodiorite		022	90		trend	V1						
017	1075044	0270567	granodiorite		092	90		trend	V2						
018	1074997	0270578	granodiorite	composed of plagioclase, muscovite, biotite, hornblende, quartz. Foliated pegmatite veins (plagioclase, quartz, tourmaline) and crosscut by albite veins (plagioclase, quartz). Albite veins folded and fold axis parallel to foliation.	038	76	W	cleavage	S1						
018	1074997	0270578	granodiorite		040	80	W	trend	V1						
018	1074997	0270578	granodiorite		098	90		trend	V2			dextral			
018	1074997	0270578	granodiorite		042	78	W	cleavage	S1						
018	1074997	0270578	granodiorite		044	74	W	cleavage	S1						
018	1074997	0270578	granodiorite		032	86	W	cleavage	S1						
018	1074997	0270578	granodiorite		10	036		lineation	mineral						
019	1074999	0270568	foliated granodiorite	crosscut by veins (plagioclase and quartz) and fractures with melts	040	78	W	cleavage	S1				cidf-019		
019	1074999	0270568	foliated granodiorite		140	88	W	cleavage	S1						
019	1074999	0270568	foliated granodiorite		036	90		trend	V2						
019	1074999	0270568	foliated granodiorite		042	90		trend	V2						
019	1074999	0270568	foliated granodiorite		358	90		trend	V1						
019	1074999	0270568	foliated granodiorite		276	90		trend	V1						
019	1074999	0270568	foliated granodiorite		136	88	W	fracture							

020	1074958	0270437	foliated granodiorite	composed of plagioclase, hornblende, quartz.	036	80	W	cleavage	S1										
020	1074958	0270437	foliated granodiorite		036	80	W	cleavage	S1										
020	1074958	0270437	foliated granodiorite		10	038		lineation	mineral										
021	1074898	0270372	foliated granodiorite	composed of plagioclase, hornblende, quartz.	042	82	W	cleavage	S1										
021	1074898	0270372	foliated granodiorite		8	038		lineation	mineral										
021	1074898	0270372	foliated granodiorite		040	84	W	cleavage	S1										
021	1074898	0270372	foliated granodiorite		10	038		lineation	mineral										
021	1074898	0270372	foliated granodiorite		042	82	W	cleavage	S1										
022	1079701	0278827	quartz veining	brecciated (5-15 cm) quartz fragments															
023	1079786	0279147	foliated granodiorite	composed of plagioclase, muscovite, biotite, hornblende, quartz. 15 cm boulders															
024	1080267	0283122	foliated granodiorite	composed of biotite and muscovite (1.5 cm) phenocrysts, plagioclase, quartz, hornblende. Crosscut by veins (plagioclase, albite, quartz, hornblende (green))	358	50	E	cleavage	S1										
025	1080282	0283175	foliated granodiorite	composed of biotite, muscovite, plagioclase, quartz, hornblende. Albite vein (plagioclase, quartz, tourmaline, muscovite, biotite)	040	32	E	cleavage	S1										
025	1080282	0283175	foliated granodiorite		030	90		trend	V1										
025	1080282	0283175	foliated granodiorite		086	90		trend	V2										
026	1080800	0283184	foliated granodiorite	composed of biotite, muscovite, plagioclase, quartz, hornblende. Albite vein (plagioclase, quartz, tourmaline, muscovite, biotite)	016	20	W	cleavage	S1										
026	1080800	0283184	foliated granodiorite		018	22	E	cleavage	S1										
027	1066321	0274344	foliated granodiorite	composed of biotite, muscovite, plagioclase, quartz, hornblende. pegmatite veins (plagioclase, quartz, tourmaline, muscovite, biotite) crosscut by shear fractures	020	76	W	cleavage	S1										
027	1066321	0274344	foliated granodiorite		040	90		cleavage	S1										
027	1066321	0274344	foliated granodiorite		036	90		trend											
027	1066321	0274344	foliated granodiorite		020	90		trend											
027	1066321	0274344	foliated granodiorite		002	88	W	fracture											
027	1066321	0274344	foliated granodiorite		160	70	E	fracture											
027	1066321	0274344	foliated granodiorite		360	86	E	fracture											
027	1066321	0274344	foliated granodiorite		10	358		lineation	stretched mineral										
027	1066321	0274344	foliated granodiorite		056	90		fracture	shear fractures	dextral									
027	1066321	0274344	foliated granodiorite		356	90		fracture	shear fractures	sinistral									
028	1065317	0275373	foliated granodiorite	composed of biotite, muscovite, plagioclase, quartz, hornblende. pegmatite veins (plagioclase, quartz, emerald, muscovite, biotite)	026	64	E	cleavage	S1										
028	1065317	0275373	foliated granodiorite		036	40	E	cleavage	S1										
028	1065317	0275373	foliated granodiorite		030	64	E	cleavage	S1										
028	1065317	0275373	foliated granodiorite		300	90		trend											
029	1065296	0275402	foliated granodiorite	composed of biotite, muscovite, plagioclase, quartz, hornblende. pegmatite veins (plagioclase, quartz, emerald, muscovite, biotite, phlogopite)	034	56	E	cleavage	S1										
029	1065296	0275402	foliated granodiorite		032	60	E	cleavage	S1										
029	1065296	0275402	foliated granodiorite		120	90		trend											
030	1065280	0275450	foliated granodiorite	composed of biotite, muscovite, plagioclase, quartz, hornblende. pegmatite veins peraluminous (plagioclase, quartz, emerald, muscovite, biotite, phlogopite). Late fractures	010	60	E	cleavage	S1										
030	1065280	0275450	foliated granodiorite		010	90		trend	V1										
030	1065280	0275450	foliated granodiorite		280	90		trend	V2										
030	1065280	0275450	foliated granodiorite		090	80	N	fracture											
030	1065280	0275450	foliated granodiorite		286	80	N	fracture											
030	1065280	0275450	foliated granodiorite		280	80	N	fracture											
031	1061302	0257052	metasiltstone	foliated and kaolinized. Quartz veins parallel to the foliation	042	72	W	cleavage	S1										
031	1061302	0257052	metasiltstone		054	78	W	cleavage	S1										
031	1061302	0257052	metasiltstone		044	80	E	cleavage	S1										
031	1061302	0257052	metasiltstone		042	76	E	cleavage	S1										
032	1061319	0257055	metasiltstone	interbedded with quartz-muscovite-schist. Crosscut by brecciated quartz-tourmaline vein	052	80	W	cleavage	S1										
032	1061319	0257055	metasiltstone		046	68	E	cleavage	S1										
032	1061319	0257055	metasiltstone		048	72	E	cleavage	S1										
032	1061319	0257055	metasiltstone		050	78	W	cleavage	S1										
032	1061319	0257055	metasiltstone		045	80	E	cleavage	S1										
032	1061319	0257055	metasiltstone		024	78	W	cleavage	S1										
032	1061319	0257055	metasiltstone		18	032		lineation	mineral										
032	1061319	0257055	metasiltstone		036	90		trend	V1										
032	1061319	0257055	metasiltstone		100	90		trend	V2										
032	1061319	0257055	metasiltstone		030	80	E	cleavage	S1										
032	1061319	0257055	metasiltstone		042	62	W	fracture											
032	1061319	0257055	metasiltstone		040	78	W	cleavage	S1										
032	1061319	0257055	metasiltstone		20	034		lineation	mineral										
032	1061319	0257055	metasiltstone		052	80	W	cleavage	S1										
032	1061319	0257055	metasiltstone		032	72	W	cleavage	S1										
033	1061047	0256797	Sericite-Muscovite-Quartz schist	poorly exposed, quartz veining															
034	1061117	0256755	metasiltstone	poorly exposed, quartz veining	052	72	W	cleavage	S1										
034	1061117	0256755	metasiltstone		050	82	W	cleavage	S1										

035	1061178	0256693	Sericite-Muscovite-Quartz schist	poorly exposed, quartz veining. Composed of sericite, muscovite, quartz. Contains cubic crystals of pyrite	036	80	W	cleavage	S1										
035	1061178	0256693	Sericite-Muscovite-Quartz schist		032	84	W	cleavage	S1										
035	1061178	0256693	Sericite-Muscovite-Quartz schist		038	80	W	cleavage	S1										
035	1061178	0256693	Sericite-Muscovite-Quartz schist		030	68	W	cleavage	S1										
035	1061178	0256693	Sericite-Muscovite-Quartz schist			30	020	lineation	mineral										
036	1061227	0256646	Sericite-Muscovite-Quartz schist	poorly exposed. Quartz-tourmaline veins	044	76	W	cleavage	S1										
036	1061227	0256646	Sericite-Muscovite-Quartz schist		042	80	W	cleavage	S1										
037	1062663	0248268	metasiltstone	kaolinization., 3-10 cm quartz veins	140	60	W	cleavage	S1										
038	1039917	0218508	granodiorite	composed of biotite and muscovite (1.5 cm) phenocrysts, plagioclase, quartz, hornblende (2 cm). 3 cm veins composed of plagioclase, k feldspar, hornblende	030	90		cleavage	S1									Dated at 2091 ± 6 Ma and 2054 ± 11 Ma	
038	1039917	0218508	granodiorite		046	90		cleavage	S1										
039	1031321	0237650	Sericite-Muscovite-Quartz schist	altered, composed of quartz, muscovite, sericite. Quartz vein	042	72		cleavage	S1									cidf-038	
039	1031321	0237650	Sericite-Muscovite-Quartz schist		046	68		cleavage	S1										
039	1031321	0237650	Sericite-Muscovite-Quartz schist	altered, composed of quartz, muscovite, sericite. Quartz vein	050	66		cleavage	S1										
040	1048347	0281429	2 mica granite	composed plagioclase, quartz, muscovite, biotite, hornblende. 1-2 cm phenocrysts of biotite and muscovite														cidf-040	
041	1046235	0291282	phenocrystic granite	composed of 3 cm k feldspar, 1.5 cm quartz, 2 cm muscovite, 1.5 cm biotite, 0.5 cm hornblende. Pegmatite veins crosscut the granite														cidf-041	
042	1046175	0291283	phenocrystic granite	composed of 4 cm k feldspar, 1.5 cm quartz, 2 cm muscovite, 1.5 cm biotite, 0.5 cm hornblende. Pegmatite veins (5 cm k feldspar, 3 cm plagioclase, 4 cm biotite and muscovite)	024	78	E	cleavage	S1										
042	1046175	0291283	phenocrystic granite		026	70	E	cleavage	S1										
042	1046175	0291283	phenocrystic granite		108	90		trend											
043	1046163	0291266	fine mylonite	composed of 0.5 cm k feldspar, 0.3 cm quartz, 0.3 cm muscovite, 0.3 cm biotite, 0.2 cm hornblende. Pegmatite veins (3 cm k feldspar, 2 cm plagioclase, 2 cm biotite and muscovite)	026	68	E	cleavage	S1										
043	1046163	0291266	fine mylonite		022	76	E	cleavage	S1										
043	1046163	0291266	fine mylonite		024	70	E	cleavage	S1										
043	1046163	0291266	fine mylonite		164	90		trend	V1										
043	1046163	0291266	fine mylonite		124	90		trend	V2										
043	1046163	0291266	fine mylonite		014	90		trend	V3										
044	1046167	0292962	coarse mylonite	composed of 4 cm k feldspar, 1.5 cm quartz, 2 cm muscovite, 1.5 cm biotite, 0.5 cm hornblende. Pegmatite veins (5 cm k feldspar, 3 cm plagioclase, 4 cm biotite and muscovite)														cidf-044	
045	1046034	0293425	fine mylonite	composed of 0.5 cm k feldspar, 0.3 cm quartz, 0.3 cm muscovite, 0.3 cm biotite, 0.2 cm hornblende. Pegmatite veins (3 cm k feldspar, 2 cm plagioclase, 2 cm biotite and muscovite)														cidf-045	
046	1046172	0293329	fine mylonite	composed of 0.5 cm k feldspar, 0.3 cm quartz, 0.3 cm muscovite, 0.3 cm biotite, 0.2 cm hornblende. Pegmatite veins (3 cm k feldspar, 2 cm plagioclase, tourmaline, quartz, 2 cm biotite and muscovite)	040	82	E	cleavage	S1									cidf-046	
046	1046172	0293329	fine mylonite		036	88	E	cleavage	S1										
046	1046172	0293329	fine mylonite		089	90		trend											
047	1046026	0293304	coarse mylonite	composed of 4 cm k feldspar, 1.5 cm quartz, 2 cm muscovite, 1.5 cm biotite, 0.5 cm elongated hornblende. Pegmatite veins (5 cm k feldspar, 3 cm plagioclase, 4 cm biotite and muscovite)														sinistral	
048	1045965	0293297	mylonite	composed of 3-1 cm k feldspar, 1.5 cm quartz, 2 cm muscovite, 1.5 cm biotite, 0.5 cm hornblende. Mafic component. k feldspar clasts are rotated and define the sense of displacement.	030	72	E	cleavage	S1									cidf-048	
049	1045977	0293517	Muscovite-Quartz-Chlorite schist	in contact with mylonite. Composed of muscovite, chlorite, quartz.	012	86	W	cleavage	S1										
049	1045977	0293517	Muscovite-Quartz-Chlorite schist		018	72	W	cleavage	S1										
049	1045977	0293517	Muscovite-Quartz-Chlorite schist		018	88	W	cleavage	S1										

057	1045410	0293015	granitic mylonite	composed of 3 cm elongated plagioclase and hornblende, 1 cm biotite, muscovite, quartz. Intruded by quartz-plagioclase vein. Fractures are right stepping, contain glassy material and small scale shear bands. Lamination defined by elongated plagioclase, quartz and hornblende.	022	90		cleavage	S1	sinistral						
057	1045410	0293015	granitic mylonite		032	36	E	cleavage	S1							
057	1045410	0293015	granitic mylonite			36	014	lineation	mineral							
057	1045410	0293015	granitic mylonite		016	40	E	cleavage	S1							
057	1045410	0293015	granitic mylonite			22	028	lineation	mineral							
057	1045410	0293015	granitic mylonite		010	70	E	cleavage	S1							
057	1045410	0293015	granitic mylonite		340	64	E	fabric	C'							
057	1045410	0293015	granitic mylonite		356	90		fabric	C'							
057	1045410	0293015	granitic mylonite		290	32		surface								
057	1045410	0293015	granitic mylonite			40	052	lineation	mineral							
057	1045410	0293015	granitic mylonite			10	002	lineation	mineral	sinistral	WSU					
057	1045410	0293015	granitic mylonite		072	90		fracture	F1	dextral						
057	1045410	0293015	granitic mylonite		082	60	N	fracture	F1	dextral						
057	1045410	0293015	granitic mylonite		118	72	W	fracture	F2							
057	1045410	0293015	granitic mylonite		112	78	W	fracture	F2							
058	1044923	0292877	granitic mylonite	composed of 3 cm elongated plagioclase and hornblende, 1 cm biotite, muscovite, quartz. Fractures are right stepping, contain glassy material and small scale shear bands. Intruded by quartz-tourmaline vein (1-3 cm).	034	90		fracture								
058	1044923	0292877	granitic mylonite		072	90		trend		dextral						
059	1044836	0292904	granitic mylonite	composed of plagioclase, hornblende, biotite, muscovite, quartz. Extremely fine grained and more silicified.											cidf-059	
060	1044902	0292973	granitic mylonite	composed of k feldspar phenocryst (1.5 cm), hornblende, quartz, plagioclase											cidf-060	
061	1044981	0293120	granitic mylonite	composed of k feldspar phenocryst (1.5 cm), hornblende, quartz, plagioclase											cidf-061	
062	1045125	0293410	phenocrystic granite	composed of k feldspar phenocryst (2 cm), hornblende, quartz, plagioclase	022	70	E	cleavage	S1							
062	1045125	0293410	phenocrystic granite		024	68	E	cleavage	S1							
063	1045160	0293442	microgranite	composed of extremely fine k feldspar, hornblende, quartz, plagioclase. Microgranite interbedded with phenocrystic granite at 10-15m thickness intervals.												
064	1045922	0293663	Sericite-Muscovite-Quartz schist	composed of sericite, muscovite, quartz. Steeply dipping to the west, whereas the shearzone dips to the east.	010	72	W	cleavage	S1							
064	1045922	0293663	Sericite-Muscovite-Quartz schist		030	74	W	cleavage	S1							
064	1045922	0293663	Sericite-Muscovite-Quartz schist		018	56	W	cleavage	S1							
065	1046770	0288563	diorite??/ tonalite	composed of plagioclase, quartz, hornblende, muscovite, biotite. Veins composed of plagioclase & quartz (3 cm), biotite (2-4 cm). Veins are folded in places. Fractures contain fine to glassy material.	022	60	E	cleavage	S1						cidf-065	
065	1046770	0288563	diorite??/ tonalite		020	54	E	cleavage	S1							
065	1046770	0288563	diorite??/ tonalite		288	90		trend	V1							
065	1046770	0288563	diorite??/ tonalite		014	90		trend	V2							
065	1046770	0288563	diorite??/ tonalite		300	88	S	fracture								
066	1046770	0288564	granodiorite	composed of muscovite & biotite phenocrysts (1 cm), plagioclase & quartz. Probably not in-situ											cidf-066	
067	1048064	0253935	foliated granite	composed of plagioclase, quartz, hornblende, k feldspar, muscovite, biotite. Intruded by veins	036	50	E	cleavage	S1						cidf-067	
067	1048064	0253935	foliated granite		002	90		trend								
068	1029992	0244444	2 mica granodiorite	composed of phenocrysts of muscovite & biotite (0.5-1 cm), plagioclase (0.5 cm), hornblende, quartz. Intruded by pegmatite veins older than foliation. V1 composed of quartz, plagioclase, tourmaline, phlogopite??, biotite. Thin shears border V2. composed of quartz & tourmaline. late stage fractures crosscut all deformations	030	78	E	cleavage	S1	sinistral					cidf-068 A&B	
068	1029992	0244444	2 mica granodiorite		034	70	E	cleavage	S1							
068	1029992	0244444	2 mica granodiorite		032	76	E	cleavage	S1							
068	1029992	0244444	2 mica granodiorite		038	74	E	cleavage	S1							
068	1029992	0244444	2 mica granodiorite		022	48	E	cleavage	S1							
068	1029992	0244444	2 mica granodiorite		356	74	E	fabric	C'							
068	1029992	0244444	2 mica granodiorite		350	70	E	fabric	C'							
068	1029992	0244444	2 mica granodiorite			20	070	lineation	mineral							
068	1029992	0244444	2 mica granodiorite			10	030	lineation	mineral							
068	1029992	0244444	2 mica granodiorite			10	018	lineation	tourmaline growth							
068	1029992	0244444	2 mica granodiorite			10	030	lineation	tourmaline growth							

068	1029992	0244444	2 mica granodiorite		10	004	lineation	tourmaline growth									
068	1029992	0244444	2 mica granodiorite		8	008	lineation	tourmaline growth									
068	1029992	0244444	2 mica granodiorite		10	006	lineation	tourmaline growth									
068	1029992	0244444	2 mica granodiorite		10	002	lineation	tourmaline growth									
068	1029992	0244444	2 mica granodiorite		10	010	lineation	tourmaline growth									
068	1029992	0244444	2 mica granodiorite		10	008	lineation	tourmaline growth									
068	1029992	0244444	2 mica granodiorite		10	006	lineation	tourmaline growth									
068	1029992	0244444	2 mica granodiorite		10	012	lineation	tourmaline growth									
068	1029992	0244444	2 mica granodiorite		10	012	lineation	tourmaline growth									
068	1029992	0244444	2 mica granodiorite		10	004	lineation	tourmaline growth									
068	1029992	0244444	2 mica granodiorite		10	004	lineation	tourmaline growth									
068	1029992	0244444	2 mica granodiorite		266	90	trend	V1		dextral	NBU						
068	1029992	0244444	2 mica granodiorite		254	90	trend	V1		dextral							
068	1029992	0244444	2 mica granodiorite		246	90	trend	V2									
068	1029992	0244444	2 mica granodiorite		228	90	trend	V2									
068	1029992	0244444	2 mica granodiorite		230	90	trend	V2									
068	1029992	0244444	2 mica granodiorite		276	68	S	fracture									
069	1030280	0243930	foliated granodiorite	composed of muscovite & biotite phenocrysts (0.5-1 cm). Hornblende, plagioclase & quartz. Crosscut by 1-2 cm veins	032	64	E	cleavage	S1							cidf-069/008	
069	1030280	0243930	foliated granodiorite		028	62	E	cleavage	S1								
069	1030280	0243930	foliated granodiorite		252	90	trend	V1									
069	1030280	0243930	foliated granodiorite		328	90	trend	V2									
070	1031204	0237882	metasiltstone	foliated and kaolinized.	034	68	E	cleavage	S1								
070	1031204	0237882	metasiltstone		026	72	E	cleavage	S1								
070	1031204	0237882	metasiltstone		038	70	E	cleavage	S1								
071	1031188	0237913	metasiltstone	foliated and kaolinized. 50m West of 070	038	82	W	cleavage	S1								
072	1031155	0237961	metasiltstone	70 m west of 071, foliated and kaolinized. Sheeted quartz veins intruded along the foliation. 1-10 cm veins are boudenaged and contain quartz, tourmaline, ankerite??	042	72	E	cleavage	S1								
072	1031155	0237961	metasiltstone		040	64	E	cleavage	S1								
072	1031155	0237961	metasiltstone		044	60	E	cleavage	S1								
072	1031155	0237961	metasiltstone		038	76	E	cleavage	S1								
073	1007948	0263178	foliated granite	composed of k feldspar, plagioclase, quartz, muscovite & phenocryst of biotite. Crosscut by 3-6 cm quartz-tourmaline veins	042	52	W	cleavage	S1							cidf-073	
073	1007948	0263178	foliated granite		040	62	W	cleavage	S1								
073	1007948	0263178	foliated granite		292	90	trend										
074	1011939	0276722	2 mica granodiorite	composed of phenocrysts of muscovite & biotite (0.5-1 cm), plagioclase (0.5 cm), hornblende, quartz and 20 cm mafic xenoliths. Intruded by pegmatite veins composed of plagioclase, biotite & muscovite. V1 (10-5 cm), V2 (2-4 cm).	264	90	trend	V1								cidf-074	
074	1011939	0276722	2 mica granodiorite		038	90	trend	V2									
075	1017589	0282476	2 mica granodiorite	composed of phenocrysts of muscovite & biotite (1.5-2 cm), plagioclase (1.5 cm), hornblende (0.5 cm), quartz and 20 cm mafic xenoliths. Intruded by pegmatite veins composed of plagioclase, quartz.	090	90	trend									cidf-075	syn-collision, calc-alkaline, i-type, peraluminous granite
076	1017530	0282924	2 mica granodiorite	composed of phenocrysts of muscovite & biotite (1.5-2 cm), plagioclase (1.5 cm), hornblende (0.5 cm), quartz.	300	70	N	fracture	F1								
076	1017530	0282924	2 mica granodiorite		080	64	S	fracture	F1								
076	1017530	0282924	2 mica granodiorite		240	70	N	fracture	F2								
076	1017530	0282924	2 mica granodiorite		238	74	N	fracture	F2								
076	1017530	0282924	2 mica granodiorite		230	54	S	fracture	F2								
076	1017530	0282924	2 mica granodiorite		240	70	S	fracture	F2								
076	1017530	0282924	2 mica granodiorite		240	88	S	fracture	F2								
076	1017530	0282924	2 mica granodiorite		250	86	N	fracture	F2								
077	1017252	0282697	2 mica granodiorite	composed of phenocrysts of muscovite & biotite (1.5-2 cm), plagioclase (1.5 cm), hornblende (0.5 cm), quartz.	240	88	S	fracture	F2								
078	1017701	0283363	Sericite-Muscovite-Quartz schist	altered, composed of quartz, muscovite, sericite. 3-25 cm Quartz vein	038	60	E	cleavage	S1								
078	1017701	0283363	Sericite-Muscovite-Quartz schist		040	60	E	cleavage	S1								
078	1017701	0283363	Sericite-Muscovite-Quartz schist		010	52	E	cleavage	S1								
078	1017701	0283363	Sericite-Muscovite-Quartz schist		340	90	trend										
079	1017728	0283088	intrusive-schist contact	last intrusive outcrop below laterite profile. Indicating that contact is close.													

080	1017328	0286966	Sericite-Muscovite-Quartz schist	altered, composed of quartz, muscovite, sericite. Interbedded with muscovite-chlorite schist and crosscut by Quartz veins	006	70	W	cleavage	S1										
080	1017328	0286966	Sericite-Muscovite-Quartz schist		012	10	W	cleavage	S1										
080	1017328	0286966	Sericite-Muscovite-Quartz schist		004	64	W	cleavage	S1										
080	1017328	0286966	Sericite-Muscovite-Quartz schist		022	58	W	cleavage	S1										
080	1017328	0286966	Sericite-Muscovite-Quartz schist		032	72	W	cleavage	S1										
080	1017328	0286966	Sericite-Muscovite-Quartz schist		034	70	E	cleavage	S1										
081	1017100	0288374	Sericite-Muscovite-Quartz schist	altered, folded, composed of quartz, muscovite, sericite. Interbedded with muscovite-chlorite schist and crosscut by Quartz veins.	080	76	N	cleavage	S1										
081	1017100	0288374	Sericite-Muscovite-Quartz schist			68	310	lineation	intersection										
081	1017100	0288374	Sericite-Muscovite-Quartz schist		330	60	N	cleavage	S1										
081	1017100	0288374	Sericite-Muscovite-Quartz schist		050	80	W	cleavage	S1										
081	1017100	0288374	Sericite-Muscovite-Quartz schist			64	106	lineation	intersection										
081	1017100	0288374	Sericite-Muscovite-Quartz schist		070	70	W	cleavage	S1										
081	1017100	0288374	Sericite-Muscovite-Quartz schist			60	280	lineation	intersection										
081	1017100	0288374	Sericite-Muscovite-Quartz schist		340	50	W	cleavage	S1										
081	1017100	0288374	Sericite-Muscovite-Quartz schist			12	040	lineation	mineral										
081	1017100	0288374	Sericite-Muscovite-Quartz schist			62	238	lineation	mineral										
082	1017105	0288340	Muscovite-Quartz-Chlorite schist	altered, folded, composed of quartz, muscovite, chlorite. crosscut by folded quartz veins. 20m west of 081	020	62	W	cleavage	S1										
082	1017105	0288340	Muscovite-Quartz-Chlorite schist			68	106	lineation	intersection										
082	1017105	0288340	Muscovite-Quartz-Chlorite schist		062	60	E	cleavage	S1										
082	1017105	0288340	Muscovite-Quartz-Chlorite schist		060	70	W	cleavage	S1										
082	1017105	0288340	Muscovite-Quartz-Chlorite schist			60	272	lineation	intersection										
082	1017105	0288340	Muscovite-Quartz-Chlorite schist		348	60	W	cleavage	S1										
082	1017105	0288340	Muscovite-Quartz-Chlorite schist			78	130	lineation	intersection										
082	1017105	0288340	Muscovite-Quartz-Chlorite schist		180	70	W	cleavage	S1										
082	1017105	0288340	Muscovite-Quartz-Chlorite schist			70	290	lineation	intersection										
082	1017105	0288340	Muscovite-Quartz-Chlorite schist		060	64	E	cleavage	S1										
082	1017105	0288340	Muscovite-Quartz-Chlorite schist			10	264	lineation	mineral										
082	1017105	0288340	Muscovite-Quartz-Chlorite schist			12	060	lineation	mineral										
083	1017109	0288309	metasiltstone	folded, crenulated and interbedded with Sericite-Muscovite-Quartz schist. 50m west of 082	060	50	E	cleavage	S1										
083	1017109	0288309	metasiltstone		328	82	W	cleavage	S1										
083	1017109	0288309	metasiltstone		066	80	E	cleavage	S1										
083	1017109	0288309	metasiltstone		110	40	S	cleavage	S2										
083	1017109	0288309	metasiltstone		110	68	S	cleavage	S2										
083	1017109	0288309	metasiltstone		100	40	N	cleavage	S2										
083	1017109	0288309	metasiltstone		010	62	W	cleavage	S1										
083	1017109	0288309	metasiltstone		060	60	E	cleavage	S1										
083	1017109	0288309	metasiltstone		296	42	S	cleavage	S2										
083	1017109	0288309	metasiltstone			100	088	lineation	intersection										
083	1017109	0288309	metasiltstone			70	280	lineation	mineral										
083	1017109	0288309	metasiltstone			70	236	lineation	mineral										
083	1017109	0288309	metasiltstone			40	110	lineation	intersection										
083	1017109	0288309	metasiltstone			36	300	lineation	mineral										
083	1017109	0288309	metasiltstone			22	084	lineation	mineral										
084	1017117	0288250	Plagioclase-Sericite-Muscovite-Quartz schist	altered, folded, composed of quartz, muscovite, sericite, plagioclase	060	60	E	cleavage	S1									cidf-084	
084	1017117	0288250	Plagioclase-Sericite-Muscovite-Quartz schist		176	86	E	cleavage	S1										
084	1017117	0288250	Plagioclase-Sericite-Muscovite-Quartz schist		182	60	W	cleavage	S1										
084	1017117	0288250	Plagioclase-Sericite-Muscovite-Quartz schist		258	50	S	cleavage	S1										
084	1017117	0288250	Plagioclase-Sericite-Muscovite-Quartz schist			12	256	lineation	mineral										
084	1017117	0288250	Plagioclase-Sericite-Muscovite-Quartz schist			8	036	lineation	mineral										
084	1017117	0288250	Plagioclase-Sericite-Muscovite-Quartz schist			88	108	lineation	intersection										
084	1017117	0288250	Plagioclase-Sericite-Muscovite-Quartz schist			72	238	lineation	intersection										
084	1017117	0288250	Plagioclase-Sericite-Muscovite-Quartz schist			12	240	lineation	mineral										
084	1017117	0288250	Plagioclase-Sericite-Muscovite-Quartz schist			2	250	lineation	mineral										

087	993949	0234677	Quartz-biotite-muscovite-hornblende schist		012	80	E	trend											
087	993949	0234677	Quartz-biotite-muscovite-hornblende schist		012	64	W	cleavage	S1										
087	993949	0234677	Quartz-biotite-muscovite-hornblende schist		030	80	W	cleavage	S1										
088	993942	0234704	muscovite-sericite-talc-hornblende-biotite-quartz schist	composed of muscovite, sericite, talc, hornblende, biotite, quartz.	020	76	E	cleavage	S1	sinistral									
088	993942	0234704	muscovite-sericite-talc-hornblende-biotite-quartz schist		028	72	E	cleavage	S1										
088	993942	0234704	muscovite-sericite-talc-hornblende-biotite-quartz schist			30	010	lineation	mineral										
088	993942	0234704	muscovite-sericite-talc-hornblende-biotite-quartz schist		026	62	E	cleavage	S1										
088	993942	0234704	muscovite-sericite-talc-hornblende-biotite-quartz schist		024	80	E	cleavage	S1										
088	993942	0234704	muscovite-sericite-talc-hornblende-biotite-quartz schist			36	192	lineation	mineral										
088	993942	0234704	muscovite-sericite-talc-hornblende-biotite-quartz schist		018	76	E	cleavage	S1										
088	993942	0234704	muscovite-sericite-talc-hornblende-biotite-quartz schist			28	198	lineation	mineral										
088	993942	0234704	muscovite-sericite-talc-hornblende-biotite-quartz schist		022	64	E	cleavage	S1										
088	993942	0234704	muscovite-sericite-talc-hornblende-biotite-quartz schist			36	008	lineation	mineral										
088	993942	0234704	muscovite-sericite-talc-hornblende-biotite-quartz schist		034	90		cleavage	S1										
088	993942	0234704	muscovite-sericite-talc-hornblende-biotite-quartz schist		014	80	E	trend											
088	993942	0234704	muscovite-sericite-talc-hornblende-biotite-quartz schist		026	80	E	cleavage	S1										
088	993942	0234704	muscovite-sericite-talc-hornblende-biotite-quartz schist		026	86	E	cleavage	S1										
088	993942	0234704	muscovite-sericite-talc-hornblende-biotite-quartz schist		008	50	E	fabric	C'										
088	993942	0234704	muscovite-sericite-talc-hornblende-biotite-quartz schist		030	62	E	cleavage	S1										
088	993942	0234704	muscovite-sericite-talc-hornblende-biotite-quartz schist		008	74	E	fabric	C'										
088	993942	0234704	muscovite-sericite-talc-hornblende-biotite-quartz schist		030	70	E	cleavage	S1										
088	993942	0234704	muscovite-sericite-talc-hornblende-biotite-quartz schist		004	76	E	fabric	C'										
088	993942	0234704	muscovite-sericite-talc-hornblende-biotite-quartz schist		018	64	E	cleavage	S1										
088	993942	0234704	muscovite-sericite-talc-hornblende-biotite-quartz schist		002	80	E	fabric	C'										
089	993977	0234813	muscovite-sericite-talc-hornblende-biotite-quartz schist.	composed of muscovite, sericite, talc, hornblende, biotite, quartz. Crosscut by 5-15cm quartz veins	030	50	W	cleavage	S1									cidf-089	
089	993977	0234813	muscovite-sericite-talc-hornblende-biotite-quartz schist.		040	48	W	cleavage	S1										
089	993977	0234813	muscovite-sericite-talc-hornblende-biotite-quartz schist.		030	72	E	trend											
090	1007754	0224051	mynolite/ultramylonite	composed of plagioclase, quartz, k feldspar, hornblende. Muscovite and biotite occur as 0.5 cm clasts. Very fine and extremely foliated	020	60	W	cleavage	S1									cidf-090	
090	1007754	0224051	mynolite/ultramylonite			38	012	lineation	mineral										
091	1001754	0224085	ultramylonite	very fine grained and extremely foliated	008	80	W	cleavage	S1									cidf-091	
091	1001754	0224085	ultramylonite		360	80	E	cleavage	S1										
091	1001754	0224085	ultramylonite			30	354	lineation	mineral										
091	1001754	0224085	ultramylonite			40	010	lineation	mineral										
091	1001754	0224085	ultramylonite			30	360	lineation	mineral										
091	1001754	0224085	ultramylonite			40	356	lineation	mineral										
092	1001755	0224115	ultramylonite	very fine grained and extremely foliated. Contain silica minerals, pyrite and arsenopyrite.	026	60	W	cleavage	S1									cidf-092	
092	1001755	0224115	ultramylonite			64	264	lineation	mineral										
092	1001755	0224115	ultramylonite			30	004	lineation	mineral										
092	1001755	0224115	ultramylonite		020	60	W	cleavage	S1										
092	1001755	0224115	ultramylonite			20	358	lineation	mineral										
092	1001755	0224115	ultramylonite		356	30	W	cleavage	S1										
092	1001755	0224115	ultramylonite			62	010	lineation	mineral										
092	1001755	0224115	ultramylonite			60	274	lineation	mineral										
093	1001797	0224197	ultramylonite	increased grained size and extremely foliated. Contain silica minerals, pyrite and arsenopyrite.		350	024	lineation	mineral										

094	1001810	0224242	mynolite	composed of muscovite, quartz, chlorite. From ultramylonite to mynolite.	060	52	W	cleavage	S1										
094	1001810	0224242	mynolite			26	350	lineation	mineral										
095	1001820	0224276	strained granitoid	composed of 70% homblende, foliated, mynolitic and crenulated															cidf-095
096	1001848	0224343	strained granitoid	composed of 70% homblende, foliated, mynolitic and crenulated															cidf-096
097	1001833	0224585	strained granitoid	composed of plagioclase, k feldspar, homblende															
098	1002009	0224627	strained granitoid	composed of plagioclase, k feldspar, homblende, quartz. Multidirectional fracturing.															cidf-098
099	1002547	0224525	mynolite to biotite-muscovite-chlorite schist	mynolitic to schisty. Crenulated and crosscut by 5-10 cm.	026	56	W	cleavage	S1										
099	1002547	0224525	mynolite to biotite-muscovite-chlorite schist			30	010	lineation	mineral	dextral	EBU								
099	1002547	0224525	mynolite to biotite-muscovite-chlorite schist		038	40	W	cleavage	S1										
099	1002547	0224525	mynolite to biotite-muscovite-chlorite schist			34	006	lineation	mineral										
099	1002547	0224525	mynolite to biotite-muscovite-chlorite schist			60	090	lineation	intersection	dextral									
099	1002547	0224525	mynolite to biotite-muscovite-chlorite schist			64	276	lineation	intersection										
100	966097	0230076	2 mica granite	composed of plagioclase (0.5-1 cm), quartz, k feldspar (3-4 cm), phenocrysts of biotite & muscovite (2 cm). Mica minerals define foliation. Intruded by plagioclase-tourmaline vein.	006	60	W	cleavage	S1										cidf-100
100	966097	0230076	2 mica granite		010	64	W	cleavage	S1										
100	966097	0230076	2 mica granite		014	70	W	cleavage	S1										
100	966097	0230076	2 mica granite		290	90		trend											
101	966206	0229261	2 mica granite	composed of plagioclase (0.5-1 cm), quartz, k feldspar (3-4 cm), phenocrysts of biotite & muscovite (2 cm). Mica minerals define foliation. Intruded by pegmatite veins (7-10 cm).	200	90		trend	V1										cidf-101
101	966206	0229261	2 mica granite		120	90		trend	V2										
102	966557	0227803	muscovite-quartz-biotite-homblende schist	interbedded with schisty metasediments and intruded by 1cm-1m quartz veins	024	70	W	cleavage	S1										
102	966557	0227803	muscovite-quartz-biotite-homblende schist		030	50	W	cleavage	S1										
102	966557	0227803	muscovite-quartz-biotite-homblende schist		040	60	W	cleavage	S1										
103	966443	0227774	buck quartz	north-east trending vein lobes. Fractured along the trend	046	88	E	fracture											
103	966443	0227774	buck quartz		030	70	E	fracture											
103	966443	0227774	buck quartz		034	64	E	fracture											
104			buck quartz	north-east trending vein lobes. Fractured along the trend.	286	90		fracture											
105	966590	0227628	quartz veining	veins are deformed with tint of dark blue (metamorphism).	070	66	E	trend											
105	966590	0227628	quartz veining		066	66	E	trend											
105	966590	0227628	quartz veining		022	70	E	trend											
105	966590	0227628	quartz veining		018	80	W	trend											
106	966617	0227577	metasiltstone	interbedded with schisty metasediments (garnet) and intruded by 5 cm quartz veins	010	60	E	cleavage	S1										
106	966617	0227577	metasiltstone		034	74	W	trend											
106	966617	0227577	metasiltstone		044	54	W	cleavage	S1										
106	966617	0227577	metasiltstone		038	80	W	cleavage	S1										
106	966617	0227577	metasiltstone		046	70	W	cleavage	S1										
106	966617	0227577	metasiltstone		012	64	E	trend											
107	966977	0227014	volcanoclastic greywacke	contains quartz & lithic fragments. S0, S1, S2 preserved. S0 is parallel to S1 due to compositional layering.	004	90		cleavage	S0/S1										cidf-107
107	966977	0227014	volcanoclastic greywacke		018	90		cleavage	S0/S1										
107	966977	0227014	volcanoclastic greywacke		020	84	E	cleavage	S0/S1										
107	966977	0227014	volcanoclastic greywacke		016	70		cleavage	S2										
107	966977	0227014	volcanoclastic greywacke		014	76		cleavage	S0/S1										
107	966977	0227014	volcanoclastic greywacke		030	80		cleavage	S2										
107	966977	0227014	volcanoclastic greywacke			80	032	lineation	intersection										
108	969349	0223066	metasiltstone	schistose metasiltstone intruded by deformed quartz veins with dark blue tints	026	60	W	cleavage	S1										
108	969349	0223066	metasiltstone		020	64	W	cleavage	S1										
108	969349	0223066	metasiltstone		6	036		lineation	mineral										
108	969349	0223066	metasiltstone		6	034		lineation	mineral										
109	969670	0222044	highly deformed rock ??	composed of muscovite phenocrysts, homblende, quartz, biotite. Interbedded with plagioclase-garnet-quartz schist and intruded by deformed quartz veins.	314	80	E	fracture	F1										cidf-109 A&B
109	969670	0222044	highly deformed rock ??		350	70	E	fracture	F1										
109	969670	0222044	highly deformed rock ??		190	40	W	fracture	F1										
109	969670	0222044	highly deformed rock ??		280	60	N	fracture	F1										

109	969670	0222044	highly deformed rock ??		080	80	S	fabric	C'								
109	969670	0222044	highly deformed rock ??		330	60	E	cleavage	S1								
109	969670	0222044	highly deformed rock ??		262	76	S	fabric	C'								
109	969670	0222044	highly deformed rock ??		040	80	E	cleavage	S1								
109	969670	0222044	highly deformed rock ??			2	016	lineation	mineral								
109	969670	0222044	highly deformed rock ??			4	014	lineation	mineral								
109	969670	0222044	highly deformed rock ??			40	286	lineation	mineral								
109	969670	0222044	highly deformed rock ??			30	284	lineation	mineral								
110	969610	0222001	highly deformed rock ??	composed of muscovite phenocrysts, homblende, quartz, biotite. Interbedded with plagioclase-garnet-quartz schist and intruded by deformed quartz veins. To the west, the rock is incontact with the foliated granite	020	60	E	cleavage	S1						cidf-110		
110	969610	0222001	highly deformed rock ??		024	72	E	cleavage	S1								
110	969610	0222001	highly deformed rock ??			22	040	lineation	mineral								
110	969610	0222001	highly deformed rock ??			10	040	lineation	mineral								
111			foliated granite	composed of plagioclase, quartz, homblende, muscovite, biotite, k felspar	020	70	E	cleavage	S1								
111			foliated granite		022	68	E	cleavage	S1								
111			foliated granite		026	60	E	cleavage	S1								
112	969100	0208730	pegmatite intrusive body	composed of plagioclase, hornblende, quartz, k feldspar. 40 cm gneissic xenolith. Plagioclase-quartz veins, breaking en echelon pattern.	014	70	E	cleavage	S1						cidf-112		
112	969100	0208730	pegmatite intrusive body		010	70	E	cleavage	S1								
112	969100	0208730	pegmatite intrusive body		108	90		trend									
113	969238	0208817	pegmatite intrusive body	composed of plagioclase, hornblende (1.5-3 cm), quartz, k feldspar. intrudes gneiss and contains 40 cm gneissic xenolith. Younger veins are crosscut by fractures. Non penetrative foliation in pegmatite body	020	80	E	cleavage	S1						cidf-113A	Dated at 2015 ± 1 Ma	syn-collision, calc-alkaline, i-type, peraluminous granite
113	969238	0208817	pegmatite intrusive body		022	78	E	cleavage	S1						cidf-113B	Dated at 2271 ± 1 Ma and 2270 ± 3 Ma	syn-collision, calc-alkaline, i-type, peraluminous granite
113	969238	0208817	pegmatite intrusive body		300	90		trend									
113	969238	0208817	pegmatite intrusive body		250	90		trend									
113	969238	0208817	pegmatite intrusive body		280	88	N	fracture									
113	969238	0208817	pegmatite intrusive body		356	70	W	fracture									
114	970114	0205643	metasiltstone	interbedded with 5 m sandstone (conglomerate). Sequence intruded by multidirectional Quartz veins (1-10 cm). Conglomerate composed of gneiss, quartz, lithic clasts (0.5-3 cm).	016	78	W	cleavage	S1								
114	970114	0205643	metasiltstone		018	80	W	cleavage	S1								
114	970114	0205643	metasiltstone		290	90		fracture									
114	970114	0205643	metasiltstone		310	90		fracture									
114	970114	0205643	metasiltstone		282	90		trend									
114	970114	0205643	metasiltstone		252	90		trend									
115	970152	0205660	sandstone	sandstone (Conglomerate) composed of gneiss, quartz, lithic clasts (0.5-3 cm)													
115B	970085	0205693	Mudstone	muddy material composed of compositional layering interbedded with metasiltstone. Sequence is 10 m thick.	020	90		cleavage	S1								
115B	970085	0205693	Mudstone		022	90		cleavage	S1								
115B	970085	0205693	Mudstone		300	90		trend									
116	970074	0205713	sandstone	composed of gneiss, quartz, lithic clasts. 15 m thick, intruded by boudinage and sheeted veins	022	74	E	cleavage	S1								
116	970074	0205713	sandstone		020	80	E	cleavage	S1								
116	970074	0205713	sandstone		234	50	W	trend									
116	970074	0205713	sandstone		270	90		trend									
117	970073	0205731	metasiltstone	metasiltstone (10 m) interbedded with sandstone (conglomerate) (15 m).	030	64	E	cleavage	S1								
117	970073	0205731	metasiltstone		030	78	E	cleavage	S1								
118	970070	0205775	Mudstone	muddy material composed of compositional layering interbedded with metasiltstone. Folded in places.	024	70	E	cleavage	S1								
118	970070	0205775	Mudstone		016	72	E	cleavage	S1								

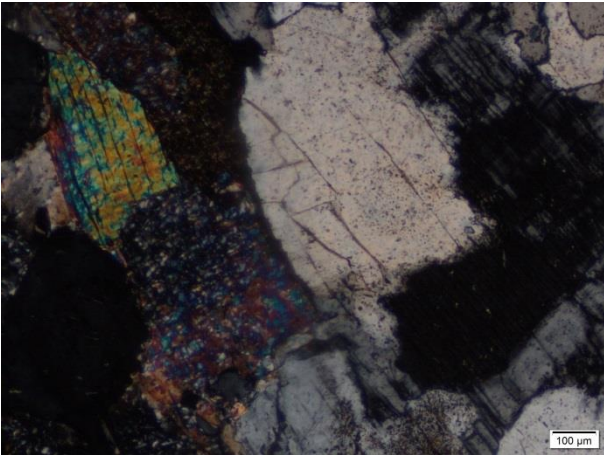
131	898931	0220390	quartz-muscovite-hornblende schist		72	138	lineation	mineral											
131	898931	0220390	quartz-muscovite-hornblende schist	040	70	E	cleavage	S1											
131	898931	0220390	quartz-muscovite-hornblende schist		40	140	lineation	mineral											
131	898931	0220390	quartz-muscovite-hornblende schist	036	50	W	cleavage	S1											
131	898931	0220390	quartz-muscovite-hornblende schist		30	330	lineation	mineral											
132	899130	0219497	granitoid	composed of 1 cm phenocrysts of plagioclase, k feldspar, albite and groundmass of hornblende, biotite. Outcrop disoriented, 1-2 m boulders.															
133	899442	0218694	granitoid	composed of 1 cm phenocrysts of plagioclase, k feldspar, albite and groundmass of hornblende, biotite. Intruded by quartz veins, but veins are deformed and foliated.															
134	899408	0218383	muscovite-hornblende-quartz schist	composed of muscovite, hornblende, quartz, foliated and dipping to the east.	032	66	E	cleavage	S1										
134	899408	0218383	muscovite-hornblende-quartz schist		038	70	E	cleavage	S1										
135	899758	0218222	volcanoclastic greywacke	composed of fragments of muscovite, hornblende, quartz schist with pyrite/sulphides. Lineation defined by hornblende.	040	80	W	cleavage	S1										
135	899758	0218222	volcanoclastic greywacke		054	88	E	cleavage	S1										
135	899758	0218222	volcanoclastic greywacke		040	90		cleavage	S1										
135	899758	0218222	volcanoclastic greywacke		30	040	lineation	(hornblende) mineral	sinistral	EBU									
136	902181	0212309	granodiorite	composed of plagioclase, quartz, hornblende, muscovite, biotite. 1-5 cm quartz veins. Dextral shear bends.	042	70	E	cleavage	S1										
136	902181	0212309	granodiorite		108	90	trend												
136	902181	0212309	granodiorite		112	90	fracture	shear	dextral										
137	904862	0193515	phenocrystic granodiorite	plagioclase phenocrystic, quartz, matrix hornblende, biotite, muscovite, k feldspar alteration. Cropping out as boulders														cidf-137	
138	905311	0184433	phenocrystic granodiorite	plagioclase phenocrystic, quartz, matrix hornblende, biotite, muscovite, k feldspar alteration.	022	66	E	cleavage	S1									cidf-138	
138	905311	0184433	phenocrystic granodiorite		020	68	E	cleavage	S1										
139	905196	0184243	phenocrystic granodiorite	composed of (0.5-3 cm) phenocrystic plagioclase, quartz, hornblende, biotite, plagioclase phenocrysts are zoned. Weak foliation & crosscut by conjugate shear fractures. Ductile shears.	160	90		fracture	F1	dextral									
139	905196	0184243	phenocrystic granodiorite		060	90		fracture	F2	sinistral									
139	905196	0184243	phenocrystic granodiorite		356	90		fracture	F1	sinistral									
139	905196	0184243	phenocrystic granodiorite		356	82	E	fracture	F1	sinistral									
139	905196	0184243	phenocrystic granodiorite		060	90		fracture	F2	dextral									
139	905196	0184243	phenocrystic granodiorite		050	90		fracture	F1	dextral									
139	905196	0184243	phenocrystic granodiorite		136	90		fracture	F2	sinistral									
139	905196	0184243	phenocrystic granodiorite		022	90		fracture	F1	dextral									
139	905196	0184243	phenocrystic granodiorite		150	90		fracture	F2	sinistral									

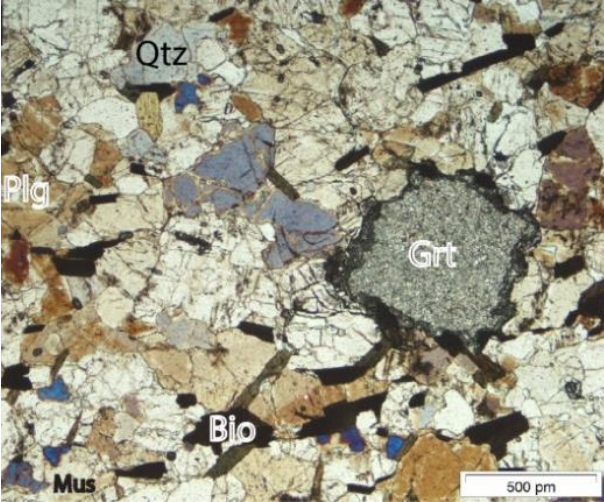
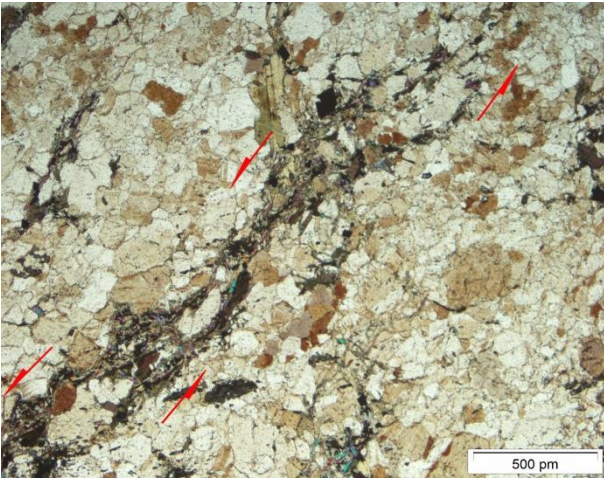
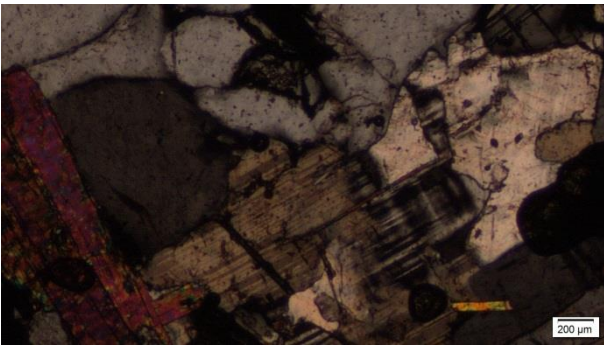
Appendix B

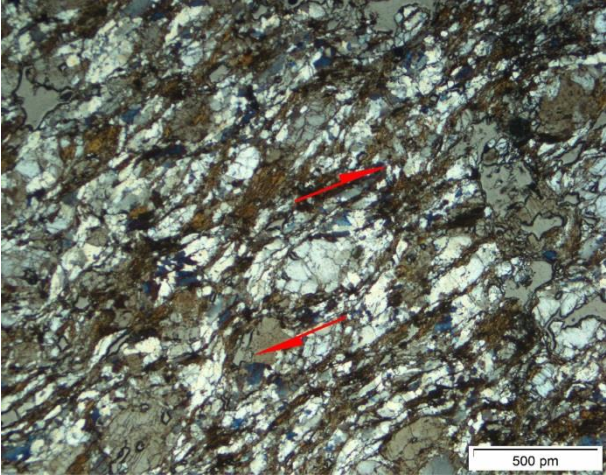
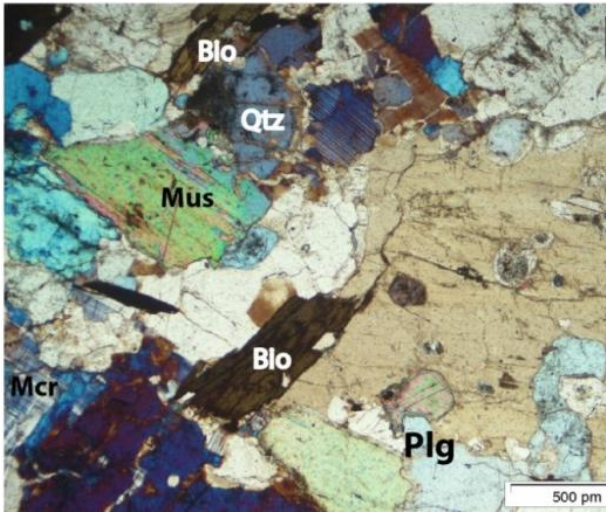
Petrography and mineralogy data

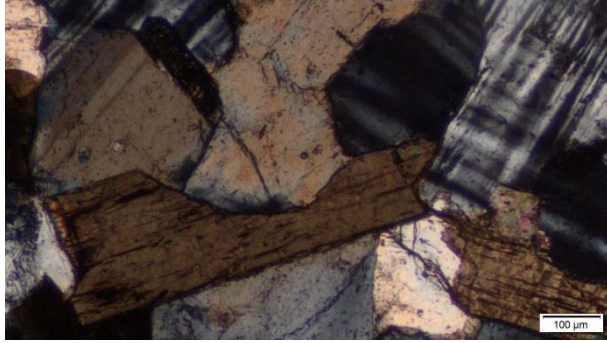
Introduction

The study area consists of the Ferké Batholith (intrusive rocks) and the surrounding metasedimentary sequences. The intrusive rocks are not only restricted to the Ferké Batholith but also intrude the surrounding metasedimentary sequences, at least in part. Lithologies across the study area are affected by multiple deformation events resulting in metamorphism. Petrographic study aids and provides important evidences with which to draw satisfactory information regarding the deformation effects on the minerology of the rock units. Thirty selected samples have been prepared for polished thin sections for minerology and micro-tectonic studies. Mineralogy and texture of these rocks samples bear a direct relationship with deformation and metamorphism. Details of petrographically analysed data are as follows:

Sample Number and Name	Description
CdiF_100 – Two-mica Granite 	Two-mica Granite crops out northwest of the town of Niakaramandougou at UTM 30P 0230076 966097, south-central portion of the Ferké Batholith. In microscopic scale, it has seriate texture dominated by mica, plagioclase and alkali feldspar phenocrysts. Alkali feldspar is showing strings of perthite. Biotite contains pleochroic halos around inclusions of zircon, monazite and xenotime. Metamorphism is indicated by chlorite replacing biotite. Other primary minerals include altered muscovite, hornblende and recrystallised quartz that exhibit undulose extinction.

CdiF_086 – Granodiorite gneiss 	Granodiorite gneiss crops out southeast of the town of Tafiré at UTM 30P 0238706 984714, southeast part of the Ferké Batholith. In microscopic scale, it has euhedral and equigranular texture dominated by biotite. Biotite crystals are roughly aligned in the same orientation across the thin section. Other primary minerals include plagioclase, hornblende and quartz. Plagioclase feldspars, often albitised, altered, clouded and show undulose to inclined extinction. Garnet developed as large phenoclasts.
CdiF_048 – Proto-mylonite 	Proto-mylonite was observed crosscutting the eastern margin of the Ferké Batholith, defining the YNB of the Ferké Shear Zone (FSZ) at UTM 30P 0293297 1045965. It is dominated by the mylonitic texture with rotated clasts of alkali feldspar indicating sinistral sense of displacement. Chlorite appears to be replacing biotite, indicating metamorphism. Garnets can be observed both as large and small grains.
CdiF_085 – Granodiorite 	Granodiorite crops out southeast of the town of Tafiré, intruding a gneiss at UTM 30P 0238713 984648, southeast part of the Ferké Batholith. In microscopic scale, it has medium-grained with phenocrysts of feldspar and muscovite. Muscovite phenocrysts constitute the bulk volume of the rock and are roughly aligned in the same orientation. Other primary minerals include feldspars, hornblende and

	quartz. Skeletal texture is shown by early growth of quartz in microcline.
CdiF_110 – Biotite schist 	Biotite schist crops out east of the town of Tortiya at UTM 30P 0222001 969610, western margin of the Ferké Batholith along the FBB of FSZ. In microscope scale, it is fine-grained with porphyroclasts and strong foliation. These features were probably caused by intense shearing. Porphyroclasts are predominantly rotated plagioclase, quartz and garnet that indicate dextral sense of displacement.
CdiF_074 – Two-mica granodiorite 	Two-mica granodiorite crops out northeast of the town of Tafiré at UTM 30P 0276722 1011939, east portion of the Ferké Batholith. In microscopic scale, it has phaneritic texture and dominated by crystals of mica and feldspars. Pleochroic halos were observed around inclusions of zircon, monazite and xenotime in biotite. Metamorphism is indicated by sericite replacing albitised plagioclase. Microcline hosts inclusions and aggregates of quartz, plagioclase and biotite. Perthite occurs as inclusion within microcline and plagioclase, in places.
CdiF_067– Granite	Granite crops out south of the town of Ferkessédougou at UTM 30P 0253935 1048064, east-central portion of the Ferké Batholith. In microscope, it has seriate texture dominated by mica, plagioclase and alkali feldspar phenocrysts. Mica minerals (biotite



and muscovite) are aligned, defining foliation. Sericite is replacing plagioclase, microcline and muscovite, in places, showing metamorphism. Plagioclase and alkali feldspar are showing strings of perthite.