RHODES UNIVERSITY
Grahamstown • 6140 • South Africa

STRUCTURAL CONTROLS OF GOLD MINERALISATION IN SEGUELEN PIT OF SIGUIRI GOLD MINE, GUINEA

By

Massa BEAVOGUI

A dissertation submitted in fulfillment of the requirements for the degree of

MASTER OF SCIENCE

(Exploration Geology)

MSc Exploration Geology Programme

Geology Department

Rhodes University

P.O. Box 94

Grahamstown 6140

South Africa

15 October 2014

DECLARATION

I declare that this dissertation is my own work. It is being submitted for the degree of Master of Science in the University of Rhodes, Grahamstown. It has not been submitted for any examination in other University.

Signed:

____

Massa Beavogui

_____________day of__________2014

ABSTRACT

The present study provides the results of detailed mapping and analysis of structures encountered in Seguelen pit of Siguiri gold mine, Guinea, where the Siguiri mine is geo-tectonically located in the Baoulé-Mossi domain of Man Shield in West African craton. The gold deposit is hosted in low-grade metamorphic sediments of turbidites sequences which form part of the Lower Proterozoic of Birimian Super group. Three rock formations of Balato, Fatoya and Kintinian underlay the overall pits. The Siguiri gold mine is characterized by the deep weathering profile, developed over the rocks reaching 200 m below the surface in some areas and often capped by the lateritic gravel or duricrust.

The rock formations at Seguelen area are characterised by strong bedding monotonously dipping towards SW and trending NW-SE. The lithology of the host rocks has strong control on the disseminated mineralisation throughout the deposit.

Two domains of rock formations are clearly distinguished at Seguelen:

- Fatoya Formation(Ffm) domain ; and
- Kintinian Formation (Kfm) domain.

The two domains are separated by a contact zone of 1.7 m wide parallel to bedding and characterised by the presence of quartz fragments as well as thinly sheeted shale and black shale. This contact zone is identified as disconformity.

The major tectonic deformation which has affected the region is known as D2 corresponding to the Eburnean orogeny. The major D2 related structures is the regional thrust striking N-S over an area of 12 km long and 3 km wide and within which corridors all Siguiri gold Mine open pits are located. In the N-S trending structures, there is east-northeast shortening and north-northwest extension.

There is pervasive hydrothermal alteration (carbonatization and sideritization) and supergene alteration in the all pits. The hydrothermal alteration attests the intensity of hydrothermal

fluid-flow over the host rocks. The hydrothermal fluids flowed along the fractures and within the wall rocks through bedding plans to form numerous auriferous quartz veins bearing disseminated sulphides through chemical reaction between fluids and wall rocks, which are remarkable at Seguelen pit.

Three quartz vein sets are distinguished at Seguelen:

- NNE-SSW quartz vein set
- NE-SW quartz vein set
- NW-SE quartz vein set

The NE-SW and NNE-SSW quartz veins are often lenticular and associated with the bulk mineralisation.

Key words:

Birimian basin, Lower Proterozoic, Baoule-Mossi, Kenema-Man, Man shield, West Africa Craton, Eburnean Orogeny, Bedding, Faults, Folds, Fractures, Mineralization, Ore body, Gold deposit, Seguelen pit, Siguiri gold mine，Guinea .

ACKNOWLEDGEMENTS

This dissertation would not be possible without the help of people of good will who directly or indirectly contributed. I wish to acknowledge for their guidance, support, understanding and patience.

Special thanks go to Mr. Craig Duvel, Head of Geology Department at Siguiri Gold mine who for the first time told me about Rhodes University and offered all his encouragement and support. That day of our discussion in 2012 will remain engraved in my memory.

Likewise, this study could not be possible without the entire funding by Siguiri Gold mine (AngloGold Ashanti/ Siguiri gold mine). I would like to show my gratitude to the company (AGA) through the Siguiri Gold mine Managing Director, Mr. Terry Mulpeter. Furthermore, I sincerely thank the Human Resources Development through Dr. Mahdy Camara, Mr. Djby Saré Special and great thanks to Mr. Mamadou Pathé Barry for his exceptional availability, the regular monitoring of our progress and the laughs.

I sincerely thank my Supervisors Dr. Stanislav Ulrich and Mr. Maxime Viateur, without your mentoring this dissertation could not be possible.
It is a pleasure to acknowledge all SAG Exploration team through Mr. John Bell, Mr. Mamadou Traoré, Mr. Eddie Connell, Mr. Georges Steyn, and Wynand Slabert. Special thanks to Mr. Eddie for his thorough reading of my dissertation.

Thanks to Professor Yong Yao, Ms. Ashley Goddard, Prof. Steve Prevec and all Geology Department Staff for their inestimable support.

The last and not the least my mother and all family members, my special thanks go to them.

DEDICATED

In the memory of my younger brother

Joseph Valaye Béavogui

1983-2007

CONTENTS

ILLUSTRATIONS

TABLES

CHAPTER 1: INTRODUCTION

1.1. Location and Geography of Siguiri region

Siguiri Gold Mine is the largest one, and its gold mineralization is hosted in lower Proterozoic rock formations of Birimian Super group (Baoulé-Mossi domain) in Guinea. The major host rocks consist of turbidites sequences (siltstone, sandstone, and greywacke), argillite, shale and breccia-conglomerate. The mine is located in north east of Guinea near Siguiri town (coordinates: latitude-11°33'N; longitude-9°21'W and altitude about 400m above sea level). It is situated about 25 km NW of Siguiri town and 830 km NE of the Capital Conakry (*Figure 1*).

The major ethnic group is the 'Malinké' and the local dialect is the Malinké which is almost spoken by the native and allogenous. French is the official language although English is being spoken by the expatriates and some local workers. Infrastructure is typically poor and most of the secondary roads are difficult to use in wet season. The national road is well paved and connects Siguiri to Bamako. There is also a small airfield commonly used by the Mining Company (AngloGold Ashanti) for transportation of expatriate staff.

The landscape is characterised by the grassy stunted savannah. The main rivers flowing over Siguiri area are the Niger and Tinkisso flowing from northwest to east. The fauna is characterized by numerous monkeys, wild pigs, springboks, chimpanzees, antelopes, various range of snakes (black, green mamba, viper) and rare lions.

The climate is tropical and characterized by wet and dry seasons. The raining is restricted to the wet season starting from June to October with sometimes the rainfall reaching up to 1200mm per year. The dry season is characterized by the hot temperature reaching sometimes the peak of 50°C and Harmattan (dry and warm wind) blowing off Sahara desert from north to south.

The main economic activity is the orpaillage (traditional mining) and informal trading. The traditional mining in Siguiri area has continued many years, and many local people dig holes to find the gold.

The use of mercury for gold separation from the gangue and the destruction of vegetation became real and serious environmental concerns.

Figure 1.Map of Guinea showing the location of Siguiri Gold mine in north eastern part. The Guinea country itself is situated in western part of Africa (after Peter Winkler, 2009).

The mine consists of cluster of opened pits located along N-S trend, from the south to the north: Sintroko, Sokunu, Kosise, Kami, Toubani, Bidini, Kalamagna, Kozan and Seguelen. The latter is the main active pit and most of the others have reached the bedrock and the mining operations are stopped. The future of Siguiri mine is based on the development of sulfide ores below current pit shells. All these pits are almost aligned along the N-S structural corridors with 12km-strike long and 3km wide (Wulf,K., 2013,unpubl.). The actual mining production of Gold-bearing ore reached 32,000 tons per day.

1.2. Aims of this Study

The main reason for this study is to address aspects of Seguelen geology and structures which were not defined in details, although the previous gold deposit discovery showed strong structural controls within the overall pits. The identification of different rock units and their spatial relationships will help to establish a model whether the deposit has a lithological control or not.

The inventory of structural patterns (faults, folds, foliations) and the definition of their geometrical characteristics will explain mineralization styles of the deposit. A clear understanding of vein orientations and other structures are critical for setting up an exploration drilling Programme.

An understanding of structures related to the gold mineralization will elucidate the ore body continuation downwards.

Finally, there is need to understand the hydrothermal gold mineralization within the Eburnean orogenic system in a more broad sense.

CHAPTER 2: METHODOLOGY

2.1. Field work

This study is based on field mapping and core logging for two months from May to June 2014, during which the work was undertaken by the author. A detailed pit mapping was completed, and the structural data gathered by pit mapping team were validated and incorporated in the entire data. The quartz veins, lithological contacts and a variety of structures were measured and mapped. Due to the intense weathering, the linear structures are difficult to distinguish in field.

A total of 58 grab samples were collected from the wall rock and quartz veins, the samples were analyzed at SGS Lab in Guinea.

The GPS Garmin 62st was used to read the coordinates of observation points. The Freiberg compass was used to measure the dip and dip directions of structures. The tape and geologist’s hammer were used to measure the true width of veins and rock units.

The core logging at core yard was based on the delineation of rock units, alpha, beta and true width measurements of veins, linear structures. The Kenometer revealed great importance during the core logging as it is easy and precise to operate. The photographic camera was used in overall tasks to illustrate features of rocks, veins and structures.

The interpretation of pit mapping and core data was done using the GIS software for 2D map digitalization; the stereo net 32 and georient for plotting structures, leapfrog software to model the lithological bedding and ore body.

2.2. Thesis structure

This thesis includes an over view of Siguiri mine with a brief description of the location, host rocks, socio-economics, climate and environment.

The regional geology and the history of the Siguiri gold mining are described and the major orogeny events are also mentioned.

Gold mineralisation style at the mine scale is discussed .The final part of the thesis is dedicated to a detailed structural study of Seguelen pit in Siguiri mine and its controls on the gold mineralisation.

2.3. Previous study

Siguiri gold mine was the subject of several structural studies in the past and this is still on-going. The seniors project geologists in the past and recently the CET (Center for Exploration Targeting) teams have introduced a lot of new knowledge about the structural complex of Siguiri gold mine.

Rod Holcombe undertook a study of structural framework of Siguiri gold mine in 2007. He concluded that Siguiri Gold Mine is hosted by a west verging fold-and-thrust stack based on the exposed fold structures at the time of pit exposure level. He also made a critical recommendation that mine geologists must look the deposit not only on grade controlled point of view but geological view by gathering structural and stratigraphic data. The data will be the first order structural information for exploration geologists. He addressed that all pits must be well mapped and documented as they are the only windows for local geology due to the thick saprolite cover in the area.

Paranhos Jr (2008) suggested a mineralisation model of the overall transpression structure.

Mark Watts (2010), senior geologist, distinguished and described for the first time three lithological units, namely Fatoya, Kintinian and Balato Formations.

Steyn and Kisters (2012) from the University of Stellenbosch broadly carried out a structural study through the existing and accessible open pits. They concluded that there is veining increase in the competent lithology and in the areas of ENE-trending axial depression or culminations or cross-folds.

Katharina Wulf (2013), senior geologist, undertook a geological and structural interpretation of Silakoro prospect and general characteristics of the "Kintinian Formation" in the west of Siguiri Gold Mine. She established a space correlation within N-S-trending direction between Siguri open pit trend and the major thrust zone.

Maxime Viateur (2013), senior geologist, ran several diamond drilling projects mainly in Sanutintin, Seguelen and Kami, he came out with some relevant observations which have reconsidered the first lithostratigraphic column .He suggested that Balato Formation is the oldest, Kintinian the youngest and Fatoya in the middle in age.

CET (Center for Exploration Targeting, 2013 and 2014) established a detailed structural map of Siguiri Gold Mine Blok1 and conducted U-Pb dating on detrital zircons. The results of dating are summarized below:

- 2122±8 Ma; Kintinian Formation (from Sanutintin conglomerate)
- 2119±5 Ma; Kintinian Formation (from Sanutintin greywacke).
- 2120±6 Ma; Fatoya Formation (from Kami).
- 2113±10 Ma; Balato Formation (from Sintroko Push back1).
- 2108±8 Ma; Marble hill (NW of the Siguiri Mine).

CHAPTER 3: GEOLOGICAL SETTING AND REGIONAL GEOLOGY

3.1. Introduction

Siguiri region is situated in the north of the Man Shield or Leo Rise of West African craton (*Figure 2*). The Man/Leo Rise is composed essentially of two large units: the Archaean Kenema-Man domain and the Paleoproterozoic Baoule-Mossi domain (lower Proterozoic) or Birimian (Bessoles, 1977); (Cahen, 1984);(*Figure 2*).

The term “Birimian” was coined for the first time in the Birim River Valley (south of Ghana) by Kitson (1919, 1928).

Several countries in West Africa are underlain by the Birimian rock formations: Senegal, Mali, Guinea, Ivory Coast, Burkina Faso, Niger and Ghana. Guinea remains the big unknown amongst the countries with Birimian geology; only very broad studies were carried out by the French geologists from 1940 to earlier 2008.

The Birimian of Guinea occupies a vast area, comprising a major part of the Siguiri basin located in the northern part of eastern Guinea. The Siguiri Basin is bordered to the south-west by the volcanic rocks of the Niandan-Banié Range and the Kiniéro volcanic belt. Elsewhere, the basin is bounded by intrusive granitic rocks belonging to the plutonic belt. The total surface area is somewhat 26000km^2.

Siguiri basin is dominantly composed of “Lower Birimian” terrigenous clastic sediments (argillite, finely bedded silstone, feldspathic sandstone, and limestone), with minor volcanic intercalations of lava, pyroclastic and black schist, which form the B1 (Bessoles, 1977; Junner, 1940a). Tuff intercalations, abundant in places are also found in the sediments, indicating that pyroclastic activity was synchronous with basin filling (Emmanuel,E., 2002).

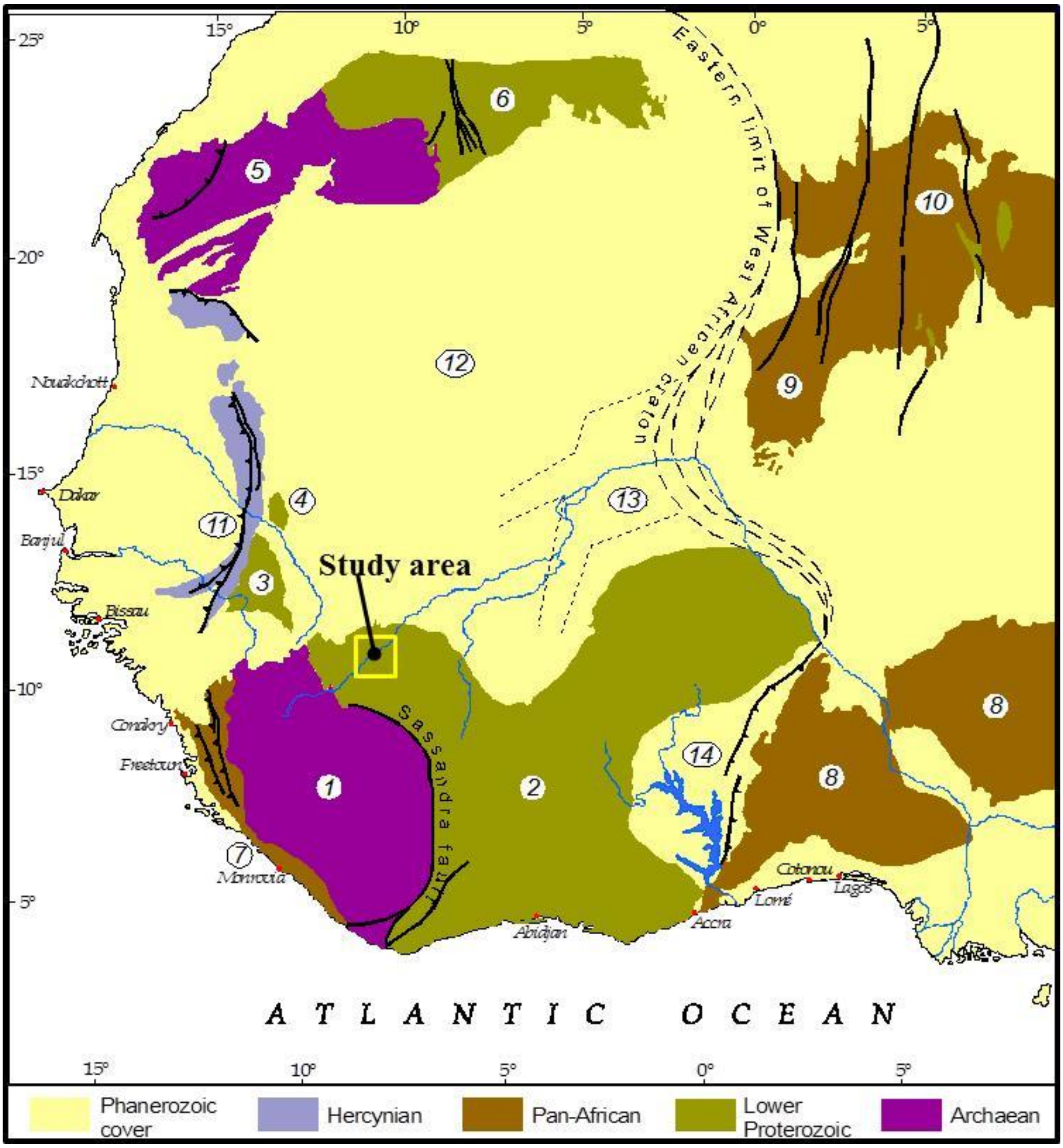


Figure 2.Geological sketched map of the West African Craton showing the main domains and location of the studied area (adapted from Boher et al., 1992).

3.2. Tectonic setting

Siguiri region is composed of two domains: the Archean domain and lower Proterozoic (Birimian) domain.

The Archean domain shows the superposition of three major tectono- magmatic cycles:

(1)A pre-Liberian (older than 2.8-2.9 Ga) with high grade metamorphic succession (amphibolite to granulite facies); (2)Two batholiths of Liberian age(~2800-2900 Ma) ; (Bering,D., 1998; Goujou,J., 1999; Thiéblemont., 2002) occupy the western and southeastern of forest Guinea.(3) Two BIF units, the Nimba and Simandou successions (Lamotte,M.Routhier., 1943).

The Paleoproterozoic or Birimian domain was established and structured during a single cycle, the Eburnean (~2200–2000Ma). The term "Eburnean" refers to all tectonic, metamorphic and plutonic events affecting the Birimian rocks during the Paleoproterozoic at ~2200-2000 Ma (Bonhomme, 1962).

The boundary between the Archean and Paleoproterozoic domains is traditionally identified as the Sassandra Fault in the southern part of the craton. The nature of this Archean/Paleproterozoic transition zone is still under debated (Miléssi, 1994). Nevertheless the boundary has been described as a diachronous unconformity that spanned a period of ~2.7-2.3 Ga (Windley, 1984), and marked the initiation of a major cycle of crustal accretion. Lithologic, sedimentologic, tectonic and geochronologic studies provided a model of progressive D1 deformation and thickening reflecting progressive tectonic accretion of Proterozoic rocks onto the Archaean nucleus. In particular, the sediments of part of the lower Birimian (B 1) were being deposited while the earlier lithotectonic pile was being progressively built up through thrusting (early D1). The Birimian B1 flysch-type sediments, derived from erosion of the domain undergoing thickening, were themselves later accreted through thrusting and folding (late D1), which implies progressive burial of the earlier terrane by continued tectonic stacking. On the basis of geochronologic arguments, it is suggested that the Sassandra strike-slip fault (*Figure 2*) was the trace of a suture separating an Archaean domain to the west from a Paleoproterozoic domain to the east (Emmanuel,E., 2002). Abouchami (Abouchami, 1990) considered that there has been no contamination of the Birimian rocks by Archaean basement, which would mean that they were deposited away from any continental influence and, consequently, their contact with the Archaean is tectonic.

Ledru et al. (1991b) proposed a four-stage evolutionary model:

(1) Early Birimian extension, with the deposition of B1 sediments in an intracratonic basin (first accretionary stage);

(2) Compression and tangential tectonism (D1);

(3) Extension with emission of voluminous B2 volcanic rocks (second accretionary stage); and (4) the major Eburnean sinistral (D2) and then dextral (D3) dislocations and granite emplacement (Ledru., 1989b;1981b; Feybesse., 1990a,b).

The D4 event is linked to NW-SE shortening and on-going magmatism. It is also associated with a major phase of mineralisation commonly associated with quartz veining and arsenopyrite (e.g. Kalana, Tellem and Tabakoroni deposits). Some low grade gold is inferred to be associated with this event at the Syama deposit, late-stage gold at Morila is also linked to syn-D4 magmatism.

During the post D4 event, there is a phase of NNW-SSE extension, and at the Banfora west, Kalana and Siguiri deposits this event produced a series of gold-bearing, steep-dipping, ENE-trending to E-trending quartz veins. This phase of deformation is inferred to be related to the relaxation or orogenic collapse immediately after D4 (Allibone., 2002) .

3.3. Stratigraphy

The presence of older Archean basement under Birimian units has been negated by several studies (Abouchami, 1990; Doumbia,S., 1998).The Birimian sedimentary basins occur abundantly across the whole Baoulé-Mossi domain (*Figure 3*).

The lithostratigraphic succession of the Birimian consists, from the bottom to the top, of:

(1) A dominantly sedimentary sequence (B 1), with tholeiitic basalt preserved locally near the base, and with common intercalations of tholeiitic volcano-sedimentary deposits and carbonates near the top; and

(2) an essentially volcanic sequence (B2) in separate areas and being composed of basic or bimodal tholeiitic rocks with rare interbedded komatiites (Milési,J., 1989) and late calc-alkaline volcanic rocks (Deschamps,M. , 1986) with fluvio-deltaic sedimentary rocks locally near the top of the volcanic sequence. The diachronism of sequences B1 and B2 established through geological observations is confirmed in certain areas by geochronologic data (Lemoine,S., 1988; Milési,J., 1989); (Figure 4).

The Siguiri basin of Paleoproterozoic domain is essentially composed of marine detrital sedimentary rocks (argillite to sandstones) and to a lesser extent, volcanic rocks (lava and pyroclastic) intercalated within sediments and sub-volcanic dykes.

The Birimian volcano-sedimentary successions were first regarded as filling geosynclinals basins (Bassot, 1966; Tagini,B., 1971; Bessoles, 1977) or intracratonic basins (i.e. aulocogens, rifts (Junner, 1940a; Kesse,G.O., 1985), in particular as a cover resting unconformably upon an Archaean basement (Milési,J., 1989).

Ledru et al., 1989 has defined a major unconformity between a metasedimentary Lower Birimian (B1) and a metavolcanic Upper Birimian (B2), on the basis of:

(a) The observation of dykes cutting the metasediments,

(b) The presence of pebbles of foliated metasedimentary rocks (previously mentioned by Bard (Bard,J.P., 1974), in conglomerate intercalated with the metavolcanic, and

(c) The identification, in the B1 assemblage, of an additional phase of tangential tectonism (Ledru., 1989b;1981b).

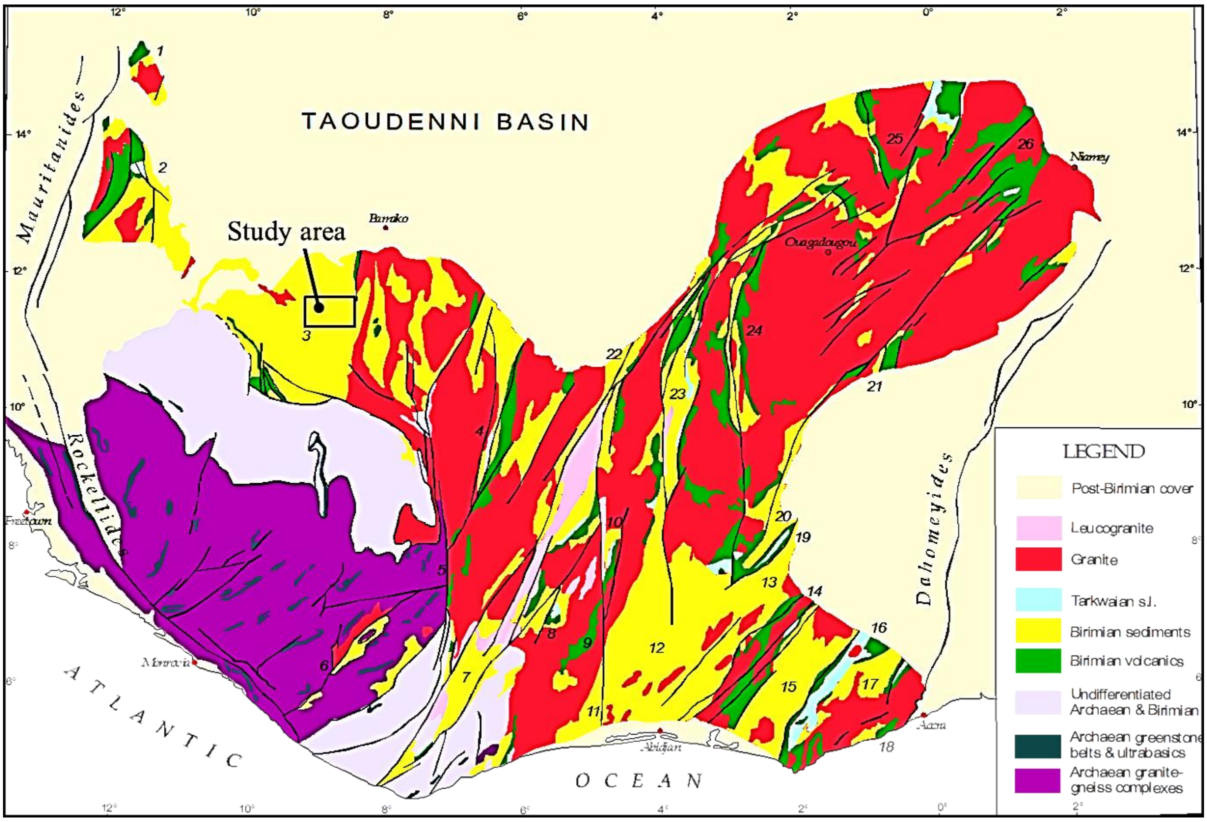
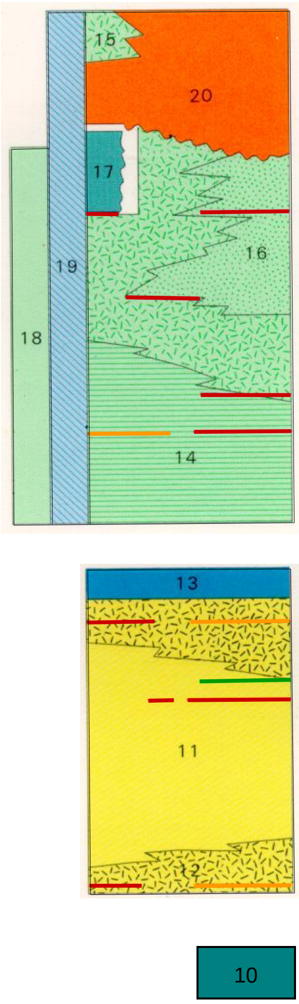


Figure 3.Simplified geological map of the Man shield (after Milesi, et al., 1989). 1. Kayes inlier-2. Kedougou-Kenieba inlier-3. Siguiri basin-4. Boundiali belt-5. Sassandra fault-6. Toulepleu-Ity area-7. Hana Lobo belt-8. Yaouré region-9. Toumodi belt-10. Fetekro belt-11. Brobo fault-12. Comoé basin-13. Sunyani basin-14. Sefwi belt-15. Kumasi basin-16. Ashanti belt-17. Cape Coast basin-18. Kibi-Winneba belt-19. Bui belt-20. Maluwe basin-21. Bole-Navrongo belt-22. Banfora belt-23. Houndé belt-24. Boromo-Goren belt-25. Bouroum-Yalogo belt-26. Liptako region.



B2. Volcanic and fluvio deltaic formations: lithostructural assemblages affected by the D2 and D3 deformation phases

20. Fluviodeltaic formations: sandstone, conglomerate, argillite (Tarkwaian in Ghana)
19. Plutonic-volcanic assemblage with minor volcanic rocks (Ghana)
18. Undifferentiated volcanic and volcano sedimentary rocks
17. Komatiitic to tholeiitic basalts
16. Rhyodacitic to rhyolitic volcanic rocks, chert and graphitic horizons
15. Andesitic volcanic rocks, chert and graphitic horizons
14. Basic volcanic rocks, chert and Mn levels.

Marker horizons: red: chert and quartzite levels
green: tourmaline-bearing sandstone and conglomerate
orange: Mn-rich levels

B1. Flysch-type formations with minor volcanic rocks: lithostructural assemblage affected by the D1 to D3 deformation phases

13. Carbonates and felsic volcanic rocks
12. Felsic volcanoclastic rocks and dykes, chert and Mn-levels
11. Flysch-type rocks: sandstone to argillite with graphitic and conglomeratic levels
10. Basic volcanic and plutonic rocks, ironstones (presumed lowermost B1)

Figure 4. Lower Proterozoic stratigraphy, compiled for the whole West Africa (Milesi, et al., 1989).

The lithological pile is more restricted to the south of Kankan in the Siguiri-Kankan basin (Gouloubinow, 1950; Milési,J., 1989).

3.4. Deformations and Structures

The structure of the plutonic belt in eastern Guinea is essentially characterised by the general geometry of this belt (plutons and their internal fabric) oriented around the Archean Kenema–Man core, and by the presence of major WNW–ESE to NW–SE-trending sinistral strike–slip faults affecting the central and northern parts of the belt (Lompo, 1991). The granitic rocks constitute a belt parallel to the margin of the Archean core WNW–ESE in the northwest, W–

E along the southern edge of the Siguiri basin, and then NW–SE and NNE–SSW towards the south. The central part of the plutonic belt is extensively affected by major sinistral ductile strike–slip faults generally trending WNW–ESE (locally W–E or NW–SE). They are generally easily identified on aeromagnetic maps, occurring in a close succession over large distances and constituting a variably anastomosing network.

In the south of the Siguiri basin, the continuation of strike–slip shear zones takes the form of local thrust planes showing southward or, more rarely, northward vergence. Feybesse, et al. (1999) considered that this thrusting is associated with early regional thickening prior to sinistral tectonism.

The strike–slip deformation does not affect all the granitic rock types of the belt. It is particularly well marked in the granodiorite, whereas the monzogranite locally cuts the shear zones, indicating that the shear zones were formed before intrusion of the monzogranite, but after crystallization of the granodiorite.

The global orientation of the foliation in both Archean and Paleoproterozoic rocks is almost orthogonal (NNE–SSW) to that of the strike–slip faults. Thus, it seems that the margin of the Archean craton remained ‘inert’ and stable during most of the Birimian cycle (c. 2200–2090 Ma), and only became active during a late stage of the cycle (Thiéblemont., 2002) .

The location and dominant WNW–ESE orientation of the sinistral strike–slip faults make it possible to propose a late Eburnean deformation resulting from regional shortening towards the WSW direction, mainly accommodated by sinistral strike–slip faults along the northwestern margin of the Archean domain. Consequently, this northwestern margin can be considered as a major sinistral strike–slip zone of a regional scale (Thiéblemont., 2002) .

The earliest recognized Eburnean deformation (D1) does not affect the B2 sequence. The structures formed at this stage were:

(1) SL foliation transposing the lithologic contacts (So) and L1 stretching lineation trending N-S, NE-SW to E-W, or NW-SE directions in different areas; their degree of penetrative development varies according to the intensity of deformation and metamorphism;

(2) Rare isoclinal, syn-foliation F1 folds which, because of later folding, have (like L1) variable axial trends of NW-SE to N-S directions; and

(3) Thrust planes contemporaneous with the first lithotectonic edifice (B1-D1) for which they were responsible (Miléssi, 1994).

The second deformation (D2) affects both B 1 and B2. It is represented by folding and sinistral strike-slip faults trending N-S to NW-SE direction (Feybesse., 1990a,b), contemporaneous with an important episode of granitization (Ledru,P., 1991b).

D 3 deformation takes the form of NE-SW strike-slip faults with associated folding. It is well developed in Burkina Faso (Ouedraogo, M., 1986; Feybesse., 1990a,b)
and in the Comoé basin, (Ledru,P.,Milési,J., 1988). The only other regions in which D3 can be clearly observed are those of Simandou and Boundiali.
(Allibone., 2002)
The intensity of deformation in the allochthonous Proterozoic increases downwards towards the base. Deformation towards the base of the pile becomes strongly penetrative and rotational. The dominant foliation in the West Africa Craton trends NE–SW direction and is sub-vertical in dip. The photo geology shows a dominant regional N-S fabric, defined by a set of ubiquitous, discrete, short lineaments which may be interpreted as the effects of cleavage (Miléssi, 1994) .

3.5. Magmatism

Several volcanic units of cartographic scale are distinguished. The Niani complex, composed of a variety of volcanic rocks comprising porphyritic lavas, pyroclastic and pyroclastic breccia, crops out in the eastern part of the basin near the border with Mali. Its emplacement is dated at 2211±3 Ma (Emmanuel,E., 2002) .

The volcanic range of Kiniéro crops out at the south-western limit of the Siguiri basin (Beckinsale ., 1980); (Camil,J., 1983). It is also made up of a group of various volcanic rocks, but it is clearly younger than that of the Niani complex (Feybesse,J.L., 1999).
(Wulf,K., 2013,unpubl.)

The plutonic belt forms a large batholith composed of various granitic rocks and extends along the edge of the Archean craton, separating it from the Siguiri basin further to the northwest. The belt, with average width of 50–100 km, globally strikes SE–NW direction in the north, becoming E–W direction around 10 °N and N–S direction to the south of 9°30_N, before pinched out at 8°N (Kisters,A.Steyn,J., 2013). Some isolated plutons crop out within the Siguiri basin and the Archean domain. The characteristics of the plutonic belt are granodiorite, which constitutes a vast batholith cutting the small granite plutons and veins (Emmanuel,E., 2002) .

In the northwest and along the south (Kouamelan.)ern edge of the Siguiri basin, these plutons are essentially composed of biotite granite, occurring within the actual basin, the eastern limit of which is marked by a huge pluton of two-mica granite (Emmanuel,E., 2002).

Towards the south and also within the Siguiri basin, the granodioritic batholith is cut by small plutons and veins of leucocratic monzogranite rich in potassic feldspar. Granodiorite and monzogranite coexist all along the eastern margin of the Archean craton southwards down to 8°N. The biotite granite cuts the granodiorite, but both are sheared by regional major strike–slip faults (Thiéblemont., 2002).

The granodiorite was intruded between c. 2090 and 2070 Ma and, despite local evidence indicating its posteriority (veins, granodiorite enclaves), the monzogranite yields a similar geochronological age (2074 Ma), (Thiéblemont., 2002) .

The late Eburnean plutonic belt was emplaced and moulded in a sub solidus state around the edge of the Kenema–Man craton. The belt was then affected by major sinistral strike–slip mylonitic shear zones formed under conditions of sub solidus to clearly post-magmatic in many areas. However, the shear zones were active during the formation of the granitic belt, after granodiorite emplacement but before monzogranite intrusion (Thiéblemont., 2002).

The tectonic evolution of the late Eburnean belt is thus contemporaneous with its magmatic history, which further highlights (ROBB,L., 2005; Lamotte,M.Routhier., 1943) the rapidity of events in this area.

The major volcanism is limited to the rocks of Niandan-Banié range (Ledru., 1989b;1981b) and Kiniéro belt. However, a small number of post-Birimian dolerite sills form large hills standing out in strong relief; i.e. Didi mountain reaching 807m altitude (Ledru,P., 1991b)

3.6. Metamorphism

In the lower Proterozoic terrane, all the rocks are affected by the low-grade metamorphism of greenschist-facies, (Amira, 2013), the Sericite is ubiquitous. Locally, the sediments are transformed into mica schist, at least partially due to ‘thermal’ metamorphism at the contact of the neighboring plutons. Along the southern edge of the basin, mica schist containing staurolite, sillimanite and garnet is fairly well developed (Thiéblemont., 2002).

All the rocks show irregular foliation and generally weak metamorphism (abundance of chlorite). The temperature conditions were thus relatively low (100–400 °C) and low pressures (1-3 kbar) during mylonitization, as confirmed by the crystallization of phyllitic minerals of relatively low temperature and the absence of recrystallized amphibole in the shear zones (Thiéblemont., 2002) .

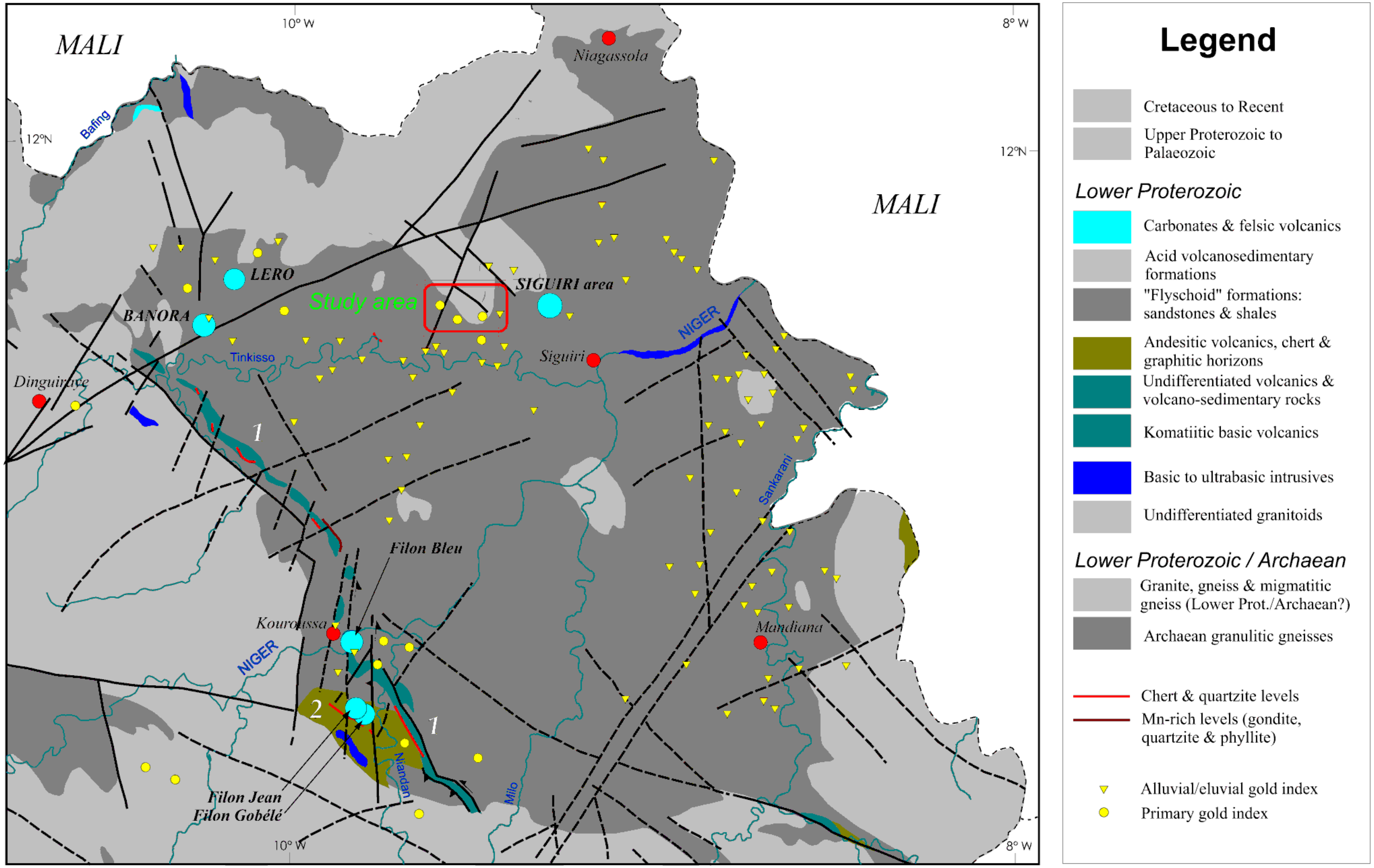


Figure 5.Geological map of Siguiri region (from Milesi, J., 1989)

3.7. Mineral resources

3.7.1 Gold

The gold mineralisation results from the chemical interaction of hydrothermal fluids transporting Au possibly as Au $(HS)_2$ complex with host rocks enriched in carbonates. The percolation of CO_2-rich fluids in the sedimentary host rock was a positive factor in term of mineralizing potential. Many ore bodies formed in preferential drainage zones that channeled mineralizing fluids along permeability pathways related to abundant structural traps developed during the brittle and brittle-ductile stages of Eburnean tectonic events (fault, shear zone, brecciation, stockworks, jog, fold hinge cleavages. The fluids flow within the low-grade metamorphic rock of lower Proterozoic Birimian super group resulted in various alteration. The most common alteration types encountered are sulfide alteration (arsenopyrite, pyrite), ubiquitous sideritization and albitisation. The origin of fluid is assumed to be derived either from dewatering of Birimian sediments at depth (Hammond,N.Q;Shimazaki,H., 1994; Mumin,A.H., 1995) or possibly from magmatic or mantle sources, in which case they would have required substantial subsequent equilibration with the Birimian host rocks (Allibone., 2002). The gold mineralisation within Siguiri can be classified as either 'quartz-bearing' veins type or 'quartz-and sulfide-bearing' vein type. From morphology point of view the isolated veins (steeply dipping to subvertical lenses) and networks of sub-parallel veins and veinlets are often encountered. In Siguiri mine vicinity, two types of gold mineralisation are distinguished:

The quartz vein-type (QVT) is always structurally controlled and characterized by the presence of visible free gold.

The disseminated sulfide-type (DST) which is either structurally controlled mesothermal type (vein selvages) or lithofacies-controlled type. The latter is well observed in Seguelen pit.

The primary mineralisation host rocks are weathered at surface, and the weathering profile is deep in some areas like Sintroko (~200m). The gold mineralisation can be encountered at different level of weathering zones such as laterite, saprolite.

The quartz veins type (QVT) of gold mineralisation is related to the brittle deformation characterised by channeled fluid flow while the disseminated sulfide type (DST) is considered as resulting from the country rock sulfidation.

In the Siguiri mine area, carbonate is pervasive in quartz veins type of gold mineralisation. The graphite is associated to shale lithology. Carbonate and gold are sometimes negatively correlated whereas graphite overall shows positive correlation with gold, suggesting that it may have acted as gold precipitant. The country rock-iron rich is considered to be favorable for gold precipitation, the iron (Fe) associated with sulfide form the various Fe-sulfide minerals while the gold is precipitated from fluid complex (Kozan old pit). Pyrite, arsenopyrite, chalcopyrite, pyrrhotite and galena are the common sulfide mineral assemblage encountered.

Siguiri mesothermal gold mineralisation is structurally controlled by the N-S structures as well as NE-SW and E-W trending quartz veins (Watts,M., 2010,unpubl.). The first mineralisation set is known as kossie-type and is associated with N-S-trending structures. The N-S trend is the dominant thrust zone in the mine area. It is assumed to be the first phase of mineralisation associated with intensive albitisation and silicification adjacent to the faults (Watts,M., 2010,unpubl.).

The mineralisation set is associated with NE-SW to E-W –trending milky quartz veins. These veins known as Kami-type are assumed to be the major gold carriers at Siguiri mine and are extensively mineralized (Watts,M., 2010,unpubl.). This Kami-type is also the main structures controlling the mineralisation at Seguelen mine although there is lithofacies control on the mineralisation beside.

The Siguiri basin further stands out amongst other Birimian terrains by its potential of alluvial gold deposits which reportedly represents over 90% of Guinea’s gold production (official).

3.7.2 Iron

The Archaean iron ore deposits of the Simandou belt, a 110 km-long and a few kilometers wide area, N-trending unit, is identical to the formations of the Nimba Mountains which straddle the Guinean-Liberian border.

Observed lithology include:

(1) Chlorite-Sericite-schist (locally graphitic),

(2) Magnetite-bearing quartzites (magnetite is typically altered to martite),

(3) Amphibolites grading into amphibole- and mica-bearing quartzites, with Sericite-schist intercalations, and

(4) Gneiss, amphibolite and migmatite representing the so-called basement. The “belt” is interpreted as a series of very tight synclinal folds. The potential of the Simandou iron ore mineralisation is high, with resources estimated at several billions of tons (Blanchot A.,Carrive J.P.& Lajoinie P., 1975).

3.7.3 Aluminium

Bauxite indices in the Siguiri basin are associated with laterites developed on top of the post-Birimian dolerite sills, which typically culminate over 800 m elevation. None of them are of any major importance (Tahon,A., 1997).

CHAPTER 4: Local Geology

4.1. Introduction

Siguiri Gold mine consists of several open pits within Blok1 hosted in lower Birimian rock units of Balato, Fatoya and Kintinian Formations. However in the far western area from Maleah to Foulata, the rocks mainly belong to the upper Birimian (B2). The predominant rock formations are sedimentary low grade metamorphic (greenschist facies) characterised by a deep weathering profile. Dolerite and granodiorite intrusions are encountered in the far western and northeastern part of Siguiri area. The major structures trending NE-SW direction are dolerite dykes and sills. The main deformation is the thrust N-S trending along which most of the open pits is aligned.

4.2. Stratigraphy

The sedimentary rock formation around Siguiri area can be grouped into three distinctive units from the oldest to the youngest: Balato, Fatoya and Kintinian Formations. This classification is widely accepted by the geologists but the dating is still subject to controversy. The most plausible dating considers Balato as the oldest formation in the area overlain by Fatoya and Kintinian is the youngest formation.

4.2.1. Balato Formation:

The Balato Formation is not well known, and the only exposures are observed in Sintroko and Sokunu open pits in the southern area (Figure 6). It extends to the east of the mine where scarce drilled holes have intersected the rocks. The Balato Formation consists of cent metric to metric predominantly black shale often graphite-rich, fine-grained greywacke and siltstone beds. The rocks are very fine-grained (0.03-0.05mm), ductile and strongly porous.

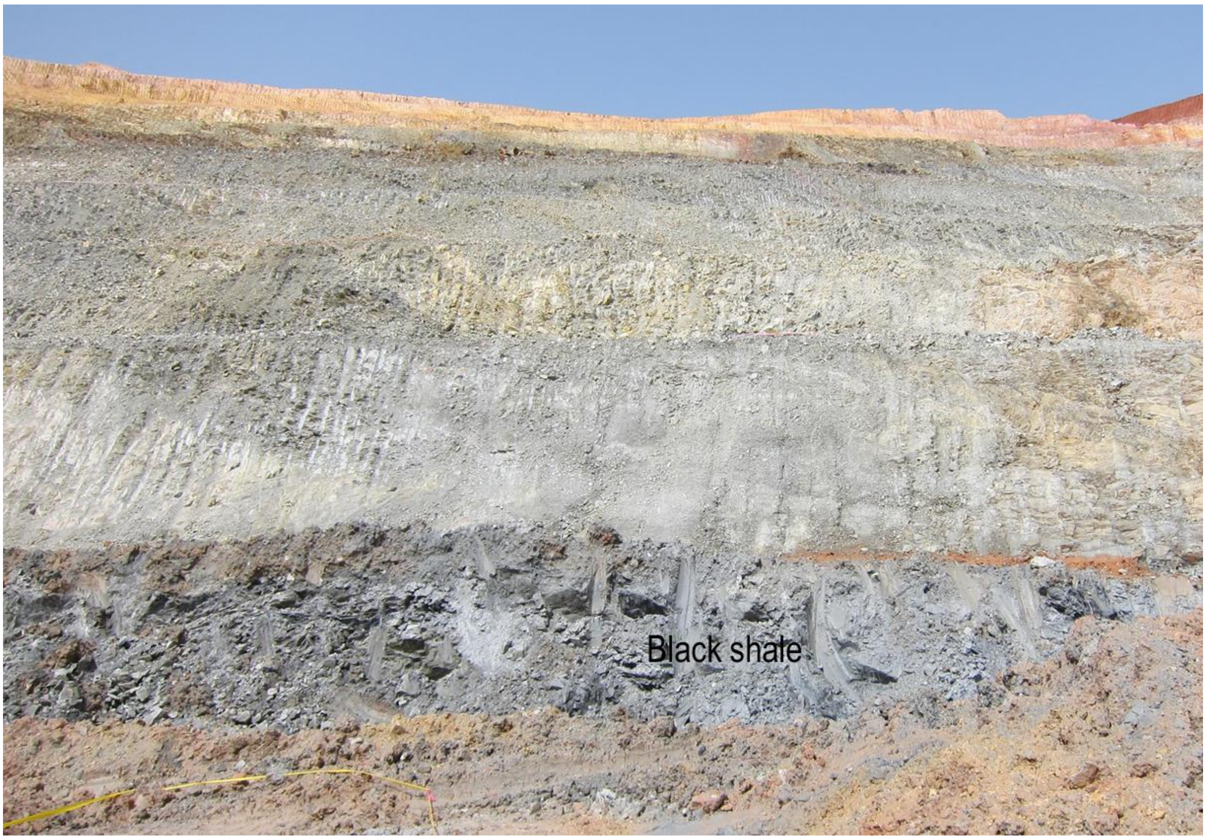


Figure 6. Balato Formation with predominance of thick black shale unit (dark grey to black rocks).

4.2.2. Fatoya Formation

The Fatoya Formation consists of turbidites sequences comprising greywackes, sandstones, fine-grained silstone, mudstones or clay, shales which contain in some particular areas minor graphite. Alkose associated with greywackes are rarely found.

The greywackes are massive units intercalated with shales in centimeter- to meter-thick. The colour is grey in fresh rock and overprinted by the weathering in altered zone.The band of graded bedding with fining upward cycles characterised the greywackes beds. The grain size of greywacke unit is 0.5-1.5mm and consists of albite and quartz grain well sorted. The overall thickness of Fatoya Formation estimated from core logging is ~400m.

The sandstone unit is composed of >90% of sand grains (0.06-0.5mm), and the unit is greywackes and silstones interbedded to each other. The colour is light grey depending on depositional environment.

The silstones are well-bedded with finer grained meta-pelite unit interbedded. The siderite (FeCO3) alteration is pervasive within the silstone and shale units.

The mudstone and shale units are very fine-grained (0.00012-0.003mm) and consist of thin intercalation with greywackes. The green shales are deposited in marine environment where the Eh potential was high enough to oxidize organic matter. The black shales are often graphite-rich and typically abundant in Balato formation. It is clayey, friable and porous materials and contains highly disseminated sulfides (e.g. Sokunu pit). The origin of the black shale is possible to form in shallow water such as lagoon, (Wulf,K., 2013,unpubl.). The rock units of Fatoya Formation show both gradational and sharp contacts, and the formation is underlain by the oldest Balato Formation.

4.2.3. Kinitinian Formation:

The Kintinian Formation overlays both Fatoya and Balato Formations, and it consists of breccia-conglomerate, quartzite, limestone, tuffs, fine-grained green schist, a thick shale unit and mudstone (0.00006-0.003mm). The Kintinian shales are distinguished from the other shales by their dark grey to greenish colour, extremely thick, veining and sulfide contents. The carbonate alteration is commonly found and the pressure-shadow is infilled by chlorite and carbonate. The sulfides are predominantly pervasive cubic pyrite.

The bedding-parallel carbonate-rich veins form up to 10% of the rock in volume. A small amount of tiny magnetite grains of 0.5mm size is encountered in some green shale.

Two breccia zones are identified within the Kintinian Formation in Sanutintin pit and Silakoro area. The Sanutintin breccia is associated with the thrust fault. The clasts are volcanic-dominated whereas the Silakoro breccia is interpreted as marine debris flow sediments, and the matrix is dominantly terrigenous.

A variety of quartzite occurs within the Kintinian Formation, comprising coarse, fine-grained, black to grey quartzite, chert-quartzite. They often occur intercalated to each other.

The dolomitic and calcitic-limestone were first encountered at Silakoro. The marble was found in the marble hill at Kourouni locality. The bulk rock units of Kintinian Formation are dominated by the shale and fine grained materials. The contact between Kintinian and Fatoya Formations is sharp.

A lithostratigraphic column of the three formations in the Siguiri mine area has been drawn recently by the CET team, and it is currently used for all geological interpretation.

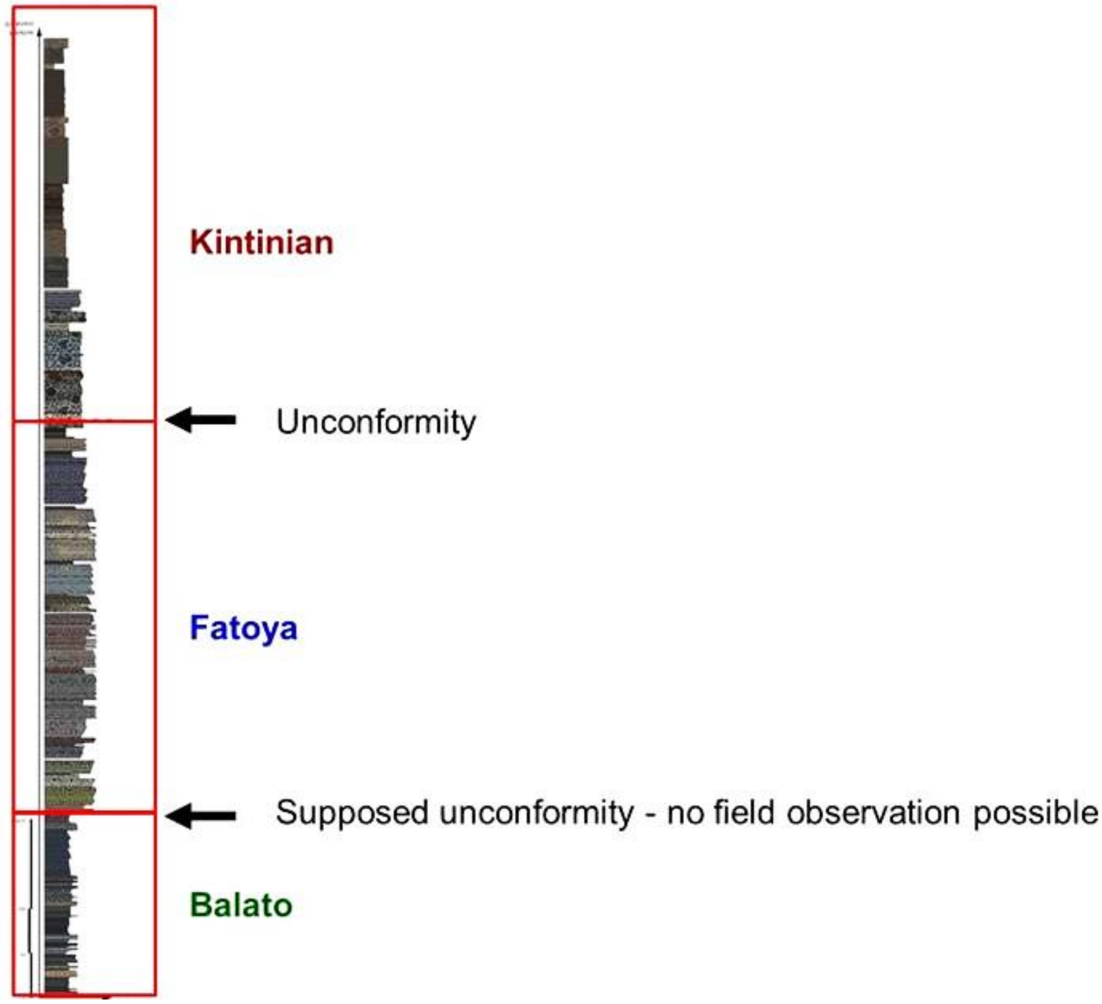


Figure 7. Lithostratigraphic column Siguiri Gold Mine area (after CET, 2014).

The Overall rocks underlying Siguiri Gold Mine are remarkably characterised by the strong and deep weathering profile typical to tropical region. The following zones below are broadly distinguished from the top to bottom:

a) Alluvial

The alluvial sediments are found typically along the drainage or form the old terraces. The alluvial sediments abound enormous gold resources in the region. The first large scale gold mining operation was focused on the alluvial materials in the channels and rivers banks. The most important drainages in the area are Tinkisso and Koba rivers. The alluvial deposit in some area (Kossisse pit) is channels filled with clay and basal conglomeratic unit (paleo placers).

b) Laterite

The laterite is very common in the area and forms the flat plateaus which are often capped by the hard duricrust. The lateritic duricrust form constitutes the final weathering product. The in-situ nature of laterite is still under debate. The rock fabric in laterite is totally undistinguishable.

c) Mottled zone

The mottled zone is composed of mottled (different coloured patches) materials generally red/brown within grey/white matrix. The rock fabric is completely altered. In Siguiri area the mottled zone appears as thin layer of <0.5m.

d) Clay zone

The clay zone is made of clay/kaolinite >80% and patchy laterite particles (<0.5m-thick). It is not easily distinguished from the mottled zone and also not encountered everywhere.

e) Saprolite zone

Saprolite zone is the thickest weathered horizon reaching 100m-thick in some areas (e.g. Sintroko pit). The saprolite is highly to moderate weathered rocks, easily broken but retains rock fabric.

f) Saprock/Transition zone

The Saprock is slightly weathered rocks which can’t be broken in the hand and retains rock fabric. It is also known as transition zone as it contains weathered and unweathered rock fragments.

g) Bedrock/Fresh rock zone

The fresh rock has no any sign of weathering and remains intact.

4.3. Structure

Siguiri area underwent several tectonic events through the time about 2.2 Ga ago.

The earlier D1 deformation affected only the lower Birimian (B1), penetrative S1 bedding parallel foliation (N-S to NNW) appears in some pits such as in Kami.

The D2 is basin scale deformation with N-S trending steep fold-shear zones (F1). The D2 affected both lower (B1) and upper (B2) Birimian sediments. Upright near vertical bedding is characteristic of the zones. Also, steep folding and weak shearing are associated with these zones. The folds plunge shallowly to the south and north.

Strongly deformed albite-dolomite-sulfide-quartz veins associated with intense silicification appear to be also associated with the D2 event.

D3 is a broad NE-SW trending mine scale fold (F2) associated with the gold bearing quartz veins. This fold F2 has re-folded the F1 folding which resulted in dome forming at the central pits such as in Kami.

The NE-SW oriented veins are usually undeformed milky quartz veins related to arsenopyrite and gold (Seguelen quartz veins type).

D4 is dextral strike slip fault to which some echelon quartz veins are associated with.

D5 is associated with the development of S2 flat foliation (NW-SE) parallel to sub-parallel to bedding and unaffected by folding.

D6 is the late deformation stage characterised by NE-SW striking faults with normal and reverse movement. The regional scale dykes strike also NE-SW direction and they post-date the mineralisation (Allibone., 2002; Bard,J.P., 1974) ; (Milési,J., 1989); (Ledru,P., 1991b); (Feybesse J.L, 2006).

Base on the structural data interpretation (bedding, foliation, folding) as well as geophysics and satellite image interpretation, three main structural mineralized corridors are recognized in the mine area (Figure 8):

a) Sintroko-Kozan corridor;

b) Eureka North-Seguelen corridor; and

c) Toubani-Bidini corridor.

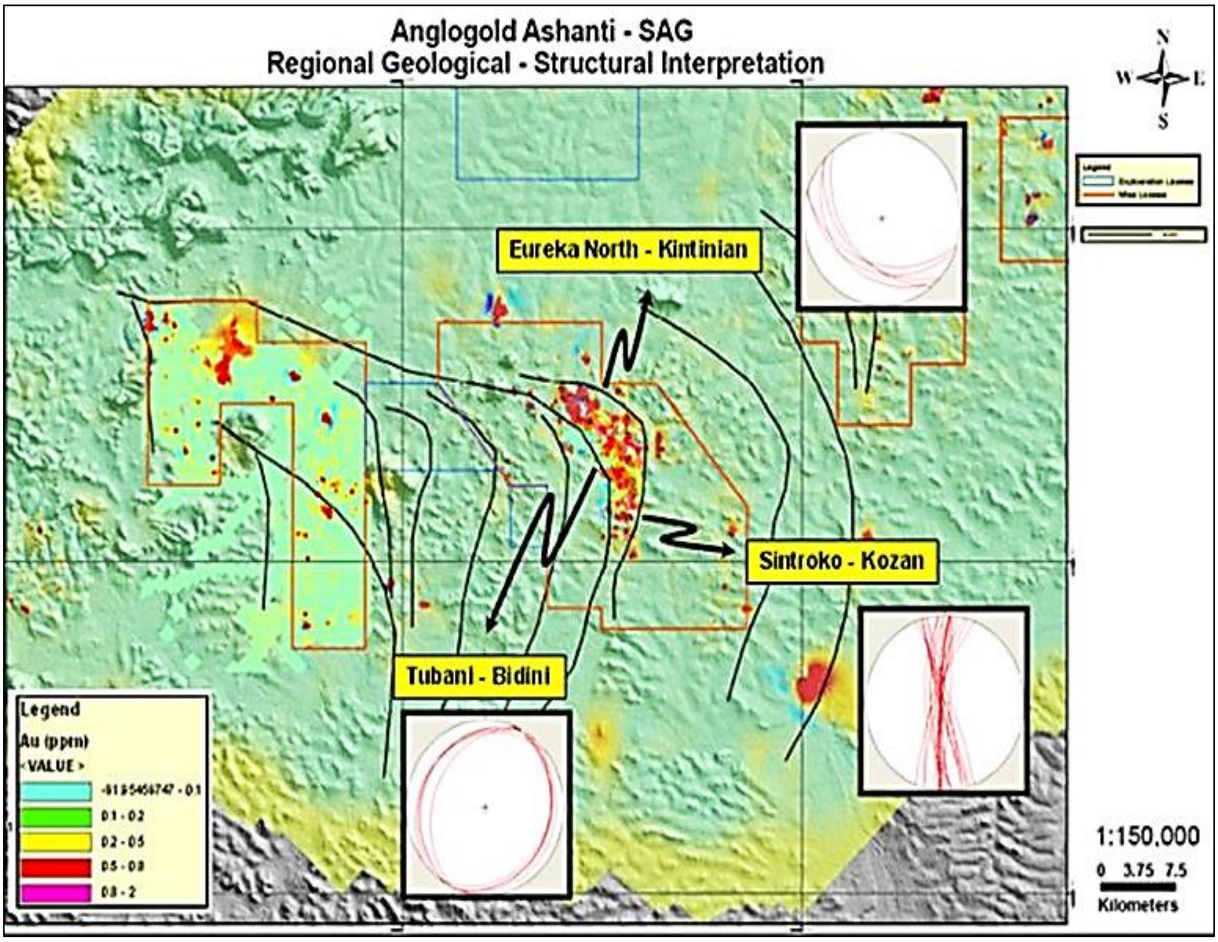


Figure 8 .Structural interpretation of Siguiri Gold Mine deposit highlighting main mineralized corridors (after Carlos Parahnos, 2008).

4.4. Magmatism

The magmatism in the area is shown by a number of regional scale mafic sills, dolerite dykes and granitoids.

The mafic intrusive dominantly represented by sills and dolerite dykes, all strike NE-SW direction, and sub-vertical at Didi, Bougouroun and Mansala area (Figure 9).

In the east of Franwalia the granite batholith containing sedimentary xenolith is well preserved. In the south of Bougouroun the rock is strongly deformed granite and pegmatite containing abundant biotite and muscovite (Exploration geologists field visit, 2012).

4.5. Metamorphism

The metamorphism in the mining area is low-grade with abundance of chlorite and muscovite, which indicates greenschist facies (Kisters,A.Steyn,J., 2013). The intensity of metamorphism increases away from the mining area and may reach amphibolite facies in some places like limestone hills at Kourouni.

4.6. Mineralisation

Base on the genesis of deposition, three type of gold deposit are distinguished in Siguiri Gold mine area:

a) Alluvial deposit

This type of deposit is encountered along the streams and in the paleo placers. It has been subject to extensive mining by the local miners as well the mining company namely Auriferous in the past.

b) Laterite deposit

The laterite deposit is very shallow and considered as transported in origin. It is also subject to mining by the local miners and by the present mining company AngloGold Ashanti.

c) Primary deposit

The primary deposit contains the bulk of gold mineralisation in Siguiri region. In the primary deposit, two types of mineralisation are recognized:

Type1: Gold hosted in the sedimentary wall rock with dissemination of pyrite and arsenopyrite.

Type2: Gold hosted in quartz veins, with local occurrences of visible gold (quartz-carbonate veins striking ENE-WSW).

These two types of the gold mineralisation coexist in some pits such as in Seguelen.

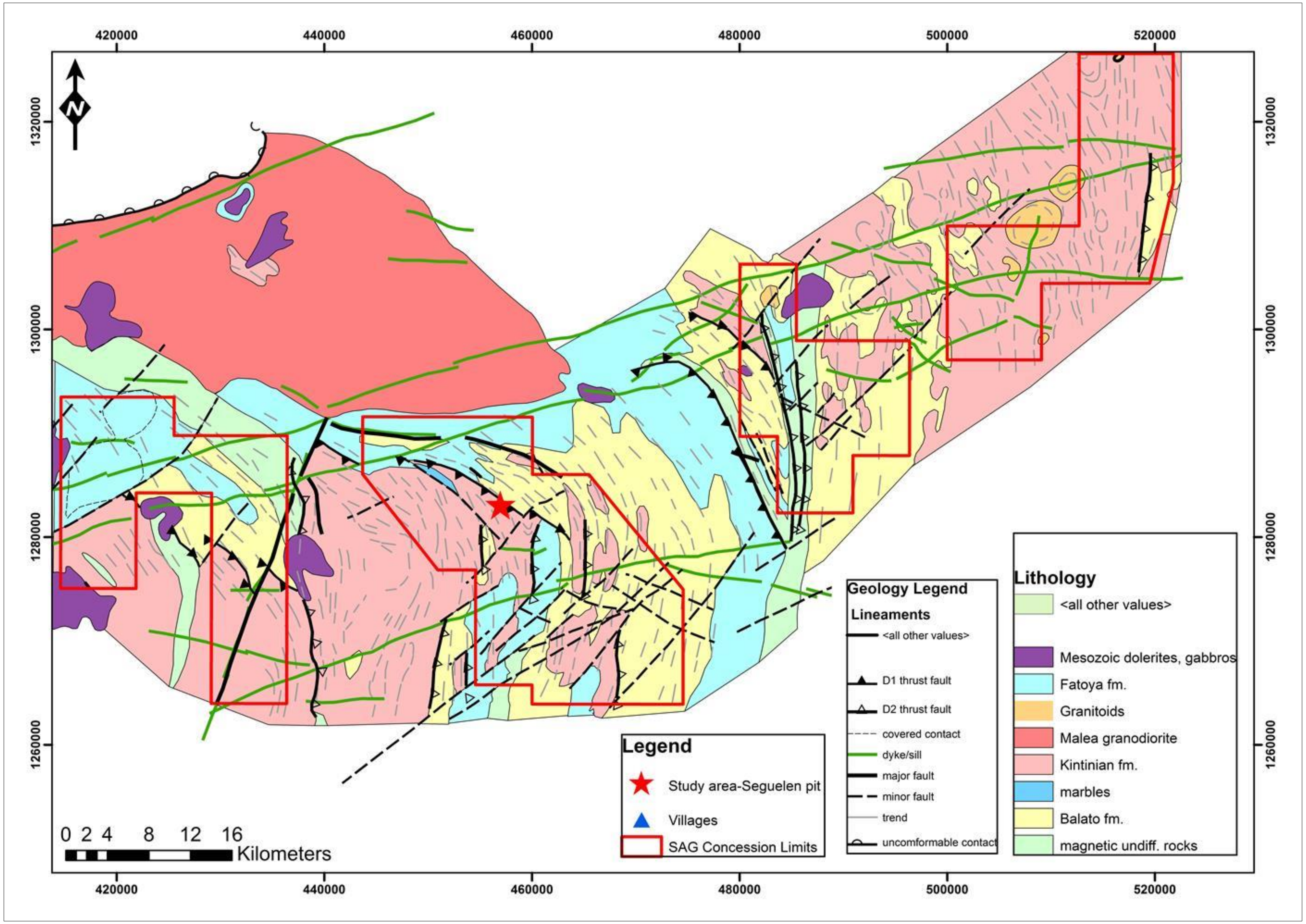


Figure 9.Simplified geological map of Siguiri Gold mine showing the main rock formations, the Balato Formation, Fatoya Formation and Kintinian Formation (CET, 2013).

CHAPTER 5: SEGUELEN ORE DEPOSIT

5.1 Introduction

Seguelen pit is one of the several open pits in Siguiri gold mining concession. It is the northernmost pit of Siguiri Mine situated near Kintinian Village about 4.5km from the plant (*Figure 10*).

The deposit consists of two separate ore body forming the two pits namely Push back 1 and Push back 2; the latter is not being mined yet while Push back1 is currently being mined. Push back1 pit extends about 800m long, striking NW-SE, and 400m wide. The host rocks mainly consist of low-grade metamorphic sediments of turbidites sequences, shale of Kintinian and Fatoya Formations, which are strongly weathered. The weathering profile sometimes reaches 150m depth (core logging data, 2013).

The bulk of gold mineralisation is structurally controlled and associated to quartz-carbonate veins and lithology units. The quartz-carbonate mineralized veins set strike to NE-SW; NNE-SSW and NW-SE.

The quartz-carbonate veins host high grade of gold and sometimes visible gold is encountered (*Figure 34*).

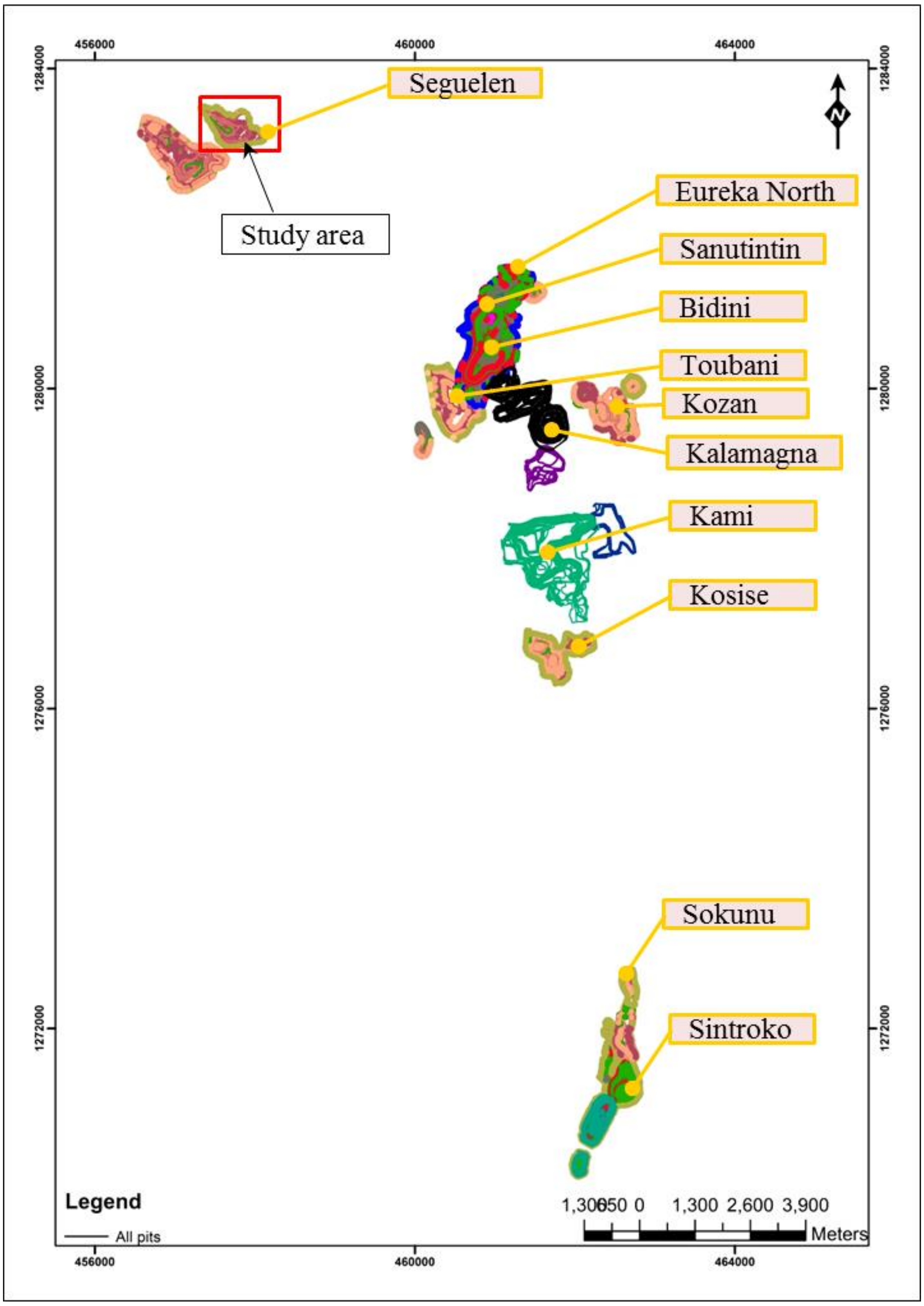


Figure 10.Map of Siguiri Gold mine showing the location of open pits, some of them are already closed.

5.2 History of Siguiri Mine

The gold mining activity in the so-called “orpaillage” has been started since the 3rd century BC in the Sarakolle Kingdom known as Empire Ghana, the first great empire in West Africa.

It was situated between Senegal and Niger. The emperor Kaya Maghan Cisse was so rich in gold that they commonly called him the king of gold.

According to the famous legend, the sacred snake called Ouagadougou Bida with seven heads was killed by young boy during the ritual of his wife to the snake. The seven heads flown over and fell down at different places known today as auriferous province such as Bouré and Sèkè, localities both in Siguiri region.

The gold operation continued over centuries with the numerous empire successions. The last was the Mali Empire with Kankou Moussa to the throne, and his pilgrination to Mecca with inestimable amount of gold was reported (Afrique Occidentale Française, 1951). The Early Carthaginian and Phoenician gold trading in West Africa have also been reported. During the 17th century the Mali kingdom was placed under Moroccan guardianship and in the year 1691, 1500kg of gold was paid to the tribute. An estimated amount of 2000t gold was reportedly produced (Afrique Occidentale Française, 1951).

The pre-independence gold production was reported by Geosurvey International (

Table 1).

Table 1.Summary of Gold production from Siguiri region reported by Geo Survey International (1983)

Year	Production (kg)
1929	79
1930	339
1931	922
1932	1241
1933	1421
1934	1863
1935	2592
1936	3000
1937	3004
1938	2426
1939	-
1940	3261 (total Guinea)
1941-1945	No data
1946	132
1947	222
1948	2641

In the late 1951 the French reported that the amount of gold annually produced has been various between 1 and 3.8 tonnes since 1931 (Afrique Occidentale Française, 1951).

During the late 19th and early 20th centuries the French involved in gold exploration with the first reconnaissance mapping completed for the Banoro, Fatoya and Kato-Kiniero areas. The dredging of Tinkisso River commenced in 1900 and continued to the 1940's. The French exploration activities also covered Kintinian, Didi, Doko and Niono (Geosurvey International, 1983).

The second phase of foreign exploration commenced with the Russian after the French left the country in the post-independence between 1960 and 1963. The Russian work was focused on the placers although some sparse rotary drilling was undertaken. A large number of placers such as Diatifèrè (Dinguiraye) and Tinkisso (Siguiri) were discovered. The first geological map was produced at a scale of 1:200 000, and it covered the whole country (Ministry of mine and geology, 2010).

In Kouroussa vicinity the stream sediment sampling was undertaken by an American joint-venture company which ended-up with failure.

The first airborne aeromagnetic-radiometric survey was conducted by the Geosurvey International between 1981 and 1983.

In 1980 SOMIQ (Société Minière Internationale du Quebec) undertook exploration activities in Siguiri and Mandiana. The institution conducted some reconnaissance mapping, and stream sediment sampling in Koron and Didi areas.

The Chevaning Mining Company Ltd. was created to undertake a detailed economic evaluation of the prospect. During 1981 and 1986 the work was focused on Didi and Koba placers and the primary gold mineralisation at Didi, Fatoya and Doko. A systematic regional exploration programme started in 1989 and continued to 1990, and its main activities included the review of available data, airphoto interpretation, geological traverses and geochemical study.

AuG (Aurifère de Guinée) continued the exploration work from its predecessor on the placers of Koba and other places such as Nankoba. The production of Koron placer (Koba) reached a peak in 1992 with 1.1t gold produced. The mine was shut down later that year due to many difficulties.

Golden Shamrock started with a pre-feasibility study in 1995 and then later Ashanti Goldfields was interested in and took over the Siguiri deposit. The production started in 1998 with SAG (Société Ashanti Goldfields de Guinée).

In 2004 the giant AngloGold was merged with Ashanti to form AngloGold Ashanti (AGA). After the Siguiri gold mine was run by AGA, its gold production increased from 7.86t in 2003 to 12t in 2008. The present gold production of Siguiri Gold mine is 11,000,000 tonnes of ore per year with an average grade of 0.9g/t of gold (Mining and Mining geology).

CHAPTER6: Lithology and structure

6.1. Introduction

The gold mineralisation at Seguelen is hydrothermal type in origin (field mapping, 2014). The hydrothermal deposit is characterised by fluid flow within host rocks, during what the fluids are responsible for gold transportation and deposition to form a wide range of economic mineralisation over the world. The formation of hydrothermal gold deposit requires four main components (Miller J.,Fougerouse,D., 2012) .

a) Fluids;
b) Pressure head (gradient);
c) Pathways;
d) Traps

The source of mineralized fluids is thought to be related to one of the major waters: sea, meteoric, metamorphic and connate (formational) waters (ROBB,L., 2005). The fluids considered as gold carrier need to interact with large volumes of rocks in order to dissolve and transport the metals required forming hydrothermal deposits.

The movement of large volume of fluids within the Earth’s crust is typical the response of pressure gradient which is often related to the deformation, which in hydrothermal process is regarded as major player in controlling fluid flow throughout the crust (Sibson,R.H, 1975; Oliver,N.H.S, 1996). The nature of the fluid flow can be either pervasive or channel flow. The latter is the response to the orogenic compression which squeezes the fluid out of rock package into channel-way (thrusts, faults).

This chapter describes in details the deformations or structures which have played a major role in the formation of Seguelen gold deposit. In the particular area of Seguelen pit, many of secondary structural features are obliterated by the weathering process. Nevertheless some prominent structures remain (bedding, faults, foliations and veins).

Seguelen pit is underlain by two lithological domains separated by a disconformity of 1.7m of thickness. The domains are known as Kintinian Formation (Kfm) and Fatoya Formation (Ffm); (Figure 11).

Kintinian Formation is located to the Southwest of the pit and it is characterized by the bedding-parallel and cross-cutting quartz-carbonate veins. It is made up of shale-dominated interbedded with sandstone layers. Some centimetric intercalation of polymicitic clasts is observable within the Kintinian Formation, which is the youngest formation in the mine area with >400m-thick (core data). The shale is made up of thin layers of clay rich in kaolinite (Brown Field Exploration Report, 2013).Kintinian shales are generally greenish color.

Fatoya Formation is situated to the northeast of the pit and it's characterized by a thick unit of greywacke intercalated by the thin layers of shale and siltstone with overall thickness of ~400m (core data). A large number of quartz veins steeply dipping to the east and cross-cutting the bedding are omnipresent within the formation. Bedding-parallel quartz veins are also abundant in the pit and are characterised by the selvage on its edge.

The hydrothermal halos of the fluid reaction with wall rocks are pervasive on the eastern wall of the pit in Fatoya domain. This attests the intensity of the hydrothermal fluid flow and its alteration. The fluid flowed either through bedding plans or fractures. The latter cross-cut the bedding with limited extends.

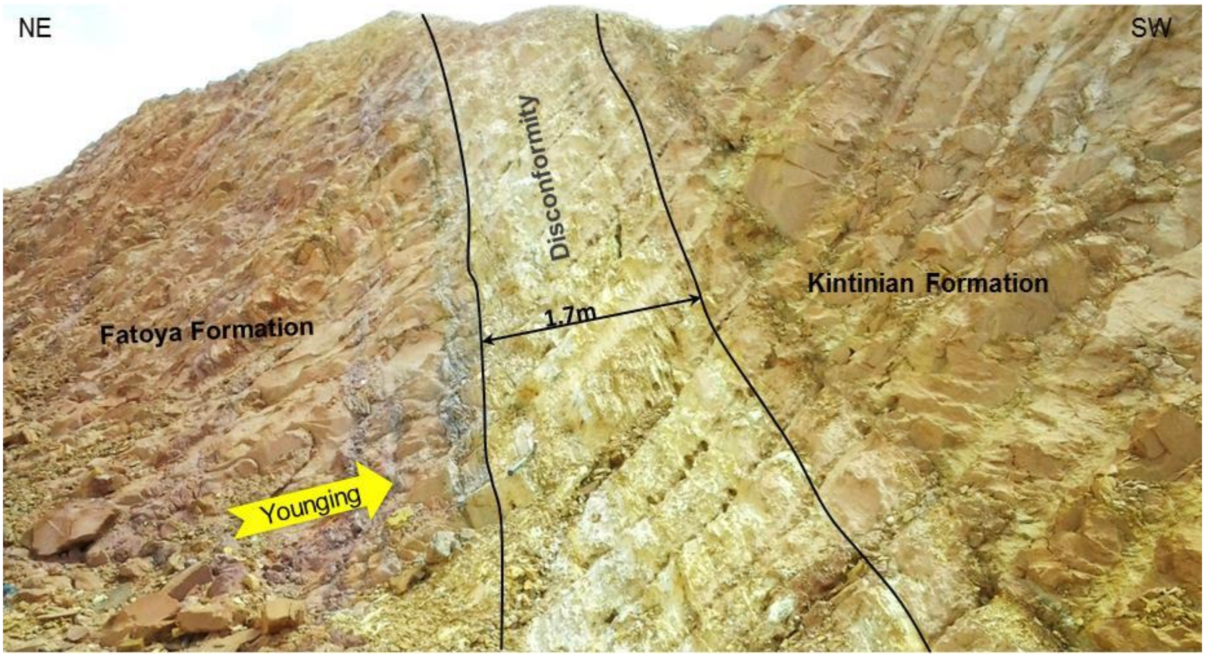


Figure 11.Disconformity between Fatoya Formation and Kintinian Formation with an average thickness of 1.7m, both formations underlay Seguelen open pit.

6.2. Lithology

Seguelen pit and the overall Siguiri open pits are underlain by a thick sedimentary rock package weakly metamorphosed and consist mainly of greywacke, sandstone, silstone, claystone (shale and mudstone) and green schists. The overall rocks underwent strong weathering processes which have altered them deeply reaching ~150m in some pits. The lithology is remarkably characterised by strong bedding in some areas and an upward grading where the lithology is not disturbed.

6.2.1. Shale unit

Shale is a fine-grained sedimentary mud rock that is a mix of flakes of clay minerals and tiny fragments (silt-sized particles) of other minerals with grain size<1/256mm. Shale is characterized by breaks along thin laminae or bedding less than one centimeter in thickness. This characteristic is called fissility. Shale is also recognized by the soapy touch and constitutes the predominant rock unit in Kintinian Formation. It is distributed throughout Siguiri pits and generally shows greenish to grey, reddish, yellow or black colors. The greenish, grey or red to reddish colors are indicative of ferric oxide (hematite for red; chlorite for green) and iron hydroxide (goethite for brown; limonite for yellow) ;(pit mapping data, 2014).

The black shale shows high content of unoxidized carbon greater than 1% which was deposited in anoxic, reducing environment (e.g. stagnant water columns). It often contents high sulfide dissemination and less quartz veins (*Figure 12*).

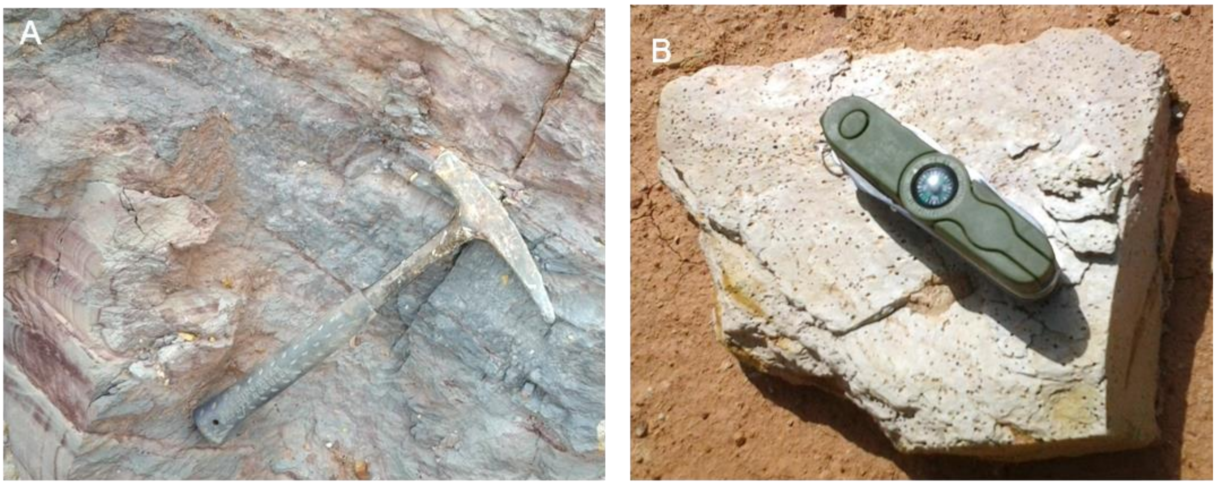


Figure 12. A .Fine grained black shale rich in carbon, photo taken on the SE wall within Kintinian Formation. B. Kintinian shale with pervasive siderite spots, photo taken in west of the pit.

6.2.2. Claystone

Claystone is the hardened clay composed primarily of clay-sized particles (<1/256mm), and it often shows a cleavage almost parallel to the bedding plane. The massive and blocky claystone is mudstone.

6.2.3. Silstone

Silstone is sedimentary mud rock containing silt sized particles greater than 2/3 (1/256-1/32mm). It lacks fissility and lamination which is typical for shale. The silstones are differentiated by the amount of silt particles. Silstone shows generally light grey color in fresh condition and change significantly in weathering environment where it is red to reddish (iron oxide, hematite), yellow (limonite, goethite) in colour. Silstone layers interbed with greywacke unit and are predominant in Fatoya Formation. Sulfide dissemination and quartz veining within silstone unit are limited. Silstone is common rock in all the pits, and in Seguelen pit this unit is found in both Fatoya and Kintinian domains (*Figure 13*).

Figure 13.Photographs of siltstone. A. Fine grained silstone unit with weak liesegang banding. B: Silstone unit with moderate limonite and kaolinite, abundance of steep conjugate quartz veins.

6.2.4. Sandstone

Sandstone is a sedimentary rock composed of sand-sized grains of mineral, rock or organic material (1/16-1mm). It also contains a matrix of silt- or clay-size particles that binds the sand grains together. Some Sandstone layers show high content of quartz greater than 90% in volume (arenites) whereas in other sandstone unit the content is more lithic with quartz less than 90% in volume (wackes). The sandstone rock is one of the common rocks encountered in all pits. Sulfides are often highly disseminated within sandstone unit; and quartz veining is well developed due to relative high porosity and brittle property of sandstones (*Figure 14*). This unit is interbedded with greywackes in Fatoya domain.

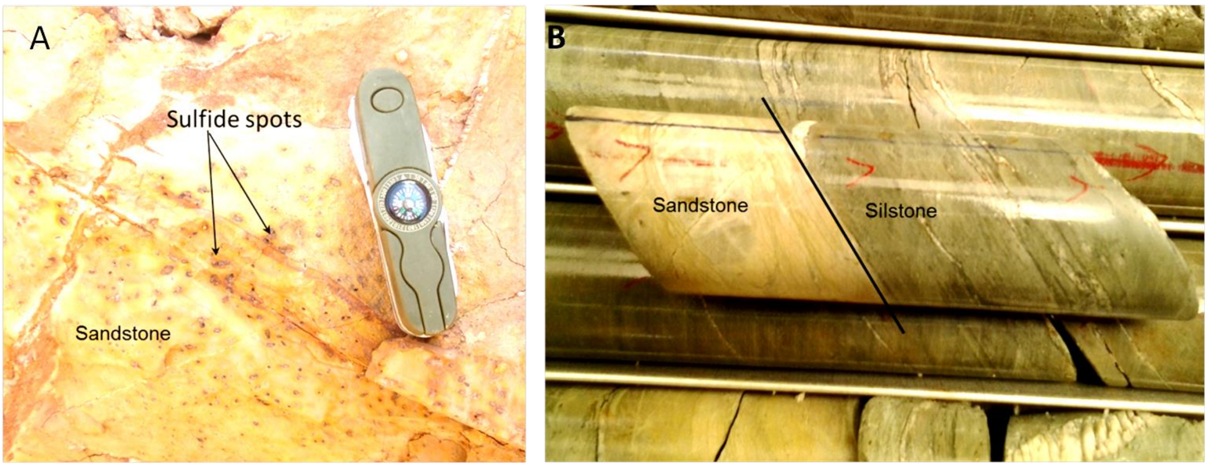


Figure 14 .Photographs of sandstone. A. Wackes sandstone unit with abundant oxidized sulfides. B. Arenites (sandstone) unit in gradational contact with silstone unit.

6.2.5. Greywacke

Greywacke is a variety of very coarse-grained sandstone (1-2mm) generally characterized by its hardness, dark colour and poorly sorted angular grains of quartz, feldspar, and lithic fragments cemented by a clay-fine matrix. Greywackes show mostly grey to brown colour (*Figure 15*).

In Seguelen pit greywacke occurs as thick beds of 5m mostly in Fatoya Formation. The greywacke is derived from turbidity current on the edge of continental shelves, and it is distributed throughout all Siguiri pits.

Figure 15.Photographs of greywacke. A. Medium to coarse-grained greywacke. B. Very coarse- grained greywacke, both photo taken in NW wall of the pit.

6.3. Structures

Seguelen pit as well as the wall Birimian basin underwent several tectonic deformations. In the mine scale the overall deformation shows generally northern trending. The most impressive features are the disconformity zone and the abundant smoked and milky quartz-carbonate veins. Another feature sticking out is the hydrothermal fluid footprint through the wall rocks. Contrary to the deformational structures, bedding generally strikes northwest and dips to the southwest direction. The bedding is characterised by the various rock units alternating (shale, silstone, sandstone, greywacke etc.).The weathering processes have obliterated most of the secondary features such as graded bedding, ripples, flute casts, tool mark, ball and pillow structures and flame structure which are no longer observed in this deep weathered environment.

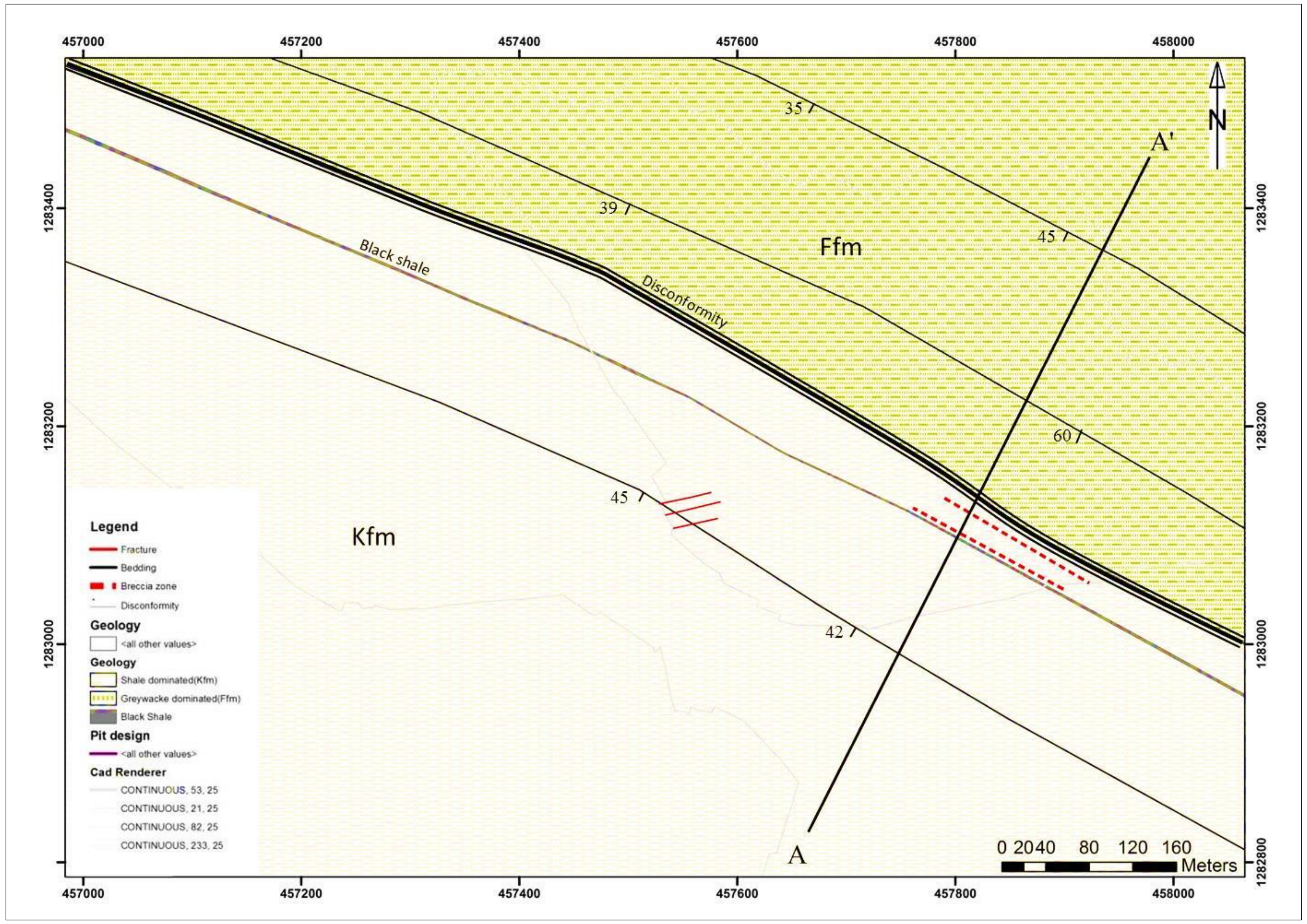


Figure 17. Geological sketch map of Seguelen deposit underlain by Fatoya and Kintinian Formation. The line A-A' is the draw

Cross-section.

Figure 16. South West view of Seguelen pit, breccia zone of ~1.50m thick sub-parallel to bedding and black shale layer (~5m) thick parallel to the bedding set, over cross the entire pit (push back1).

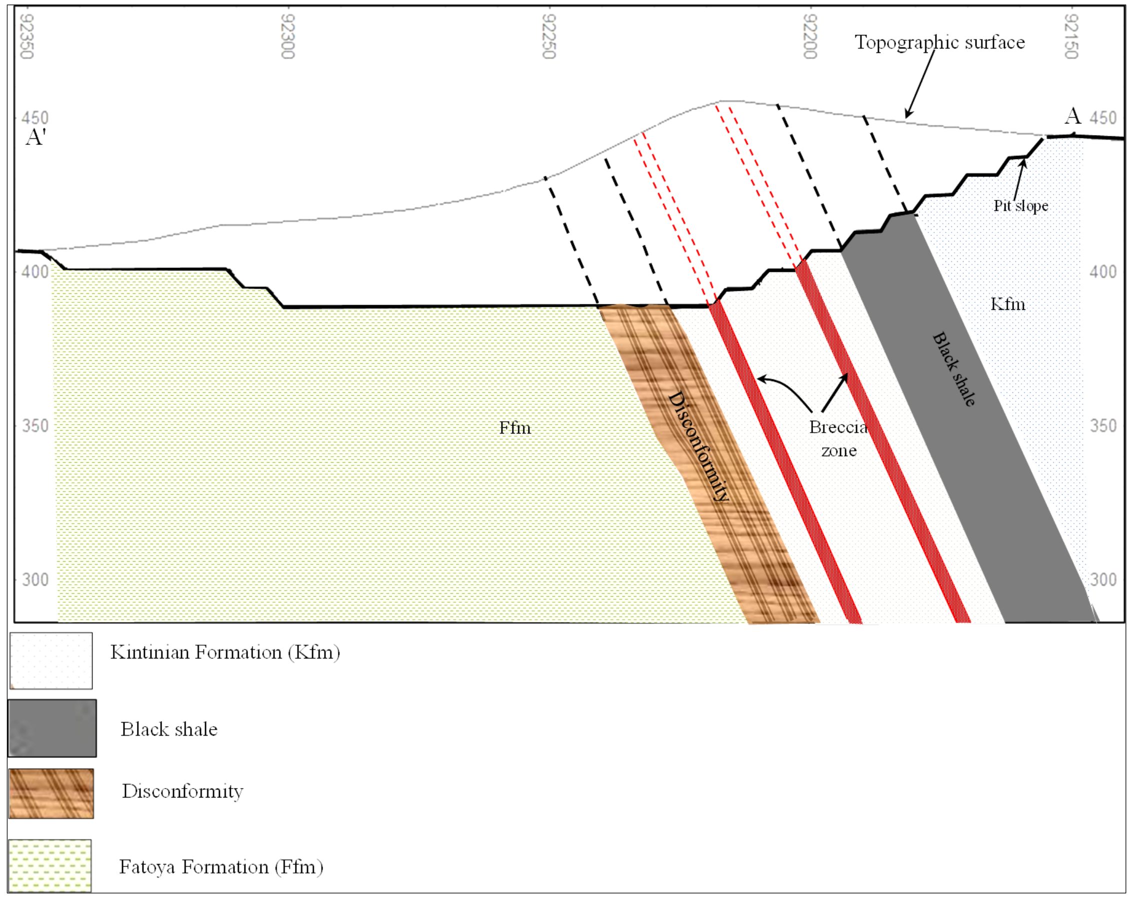


Figure 18. Cross-section A-A' looking towards south east.

6.3.1. Bedding (S0)

Bedding (S0) is very common planar feature well preserved in Seguelen pit. The bedding is characterized by the alternation between greywacke and siltstone beds as well as shale. The layers are generally thin and parallel. The Fatoya thick greywacke beds underlay the Kintinian Formation (*Figure 19*). Fatoya greywackes are intercalated by thin shale beds. The Kintinian Formation shows the alternation between sandstone, siltstone, greenschist and shale. The overall bedding shows a parallel interbedding relationship and an upward grading (normal grading). Different bed units are distinguished by the variation of grain-size and composition. Other remarkable feature particular to Seguelen deposit is the pervasive hydrothermal fluid flow through the bedding plans, along which alteration is well observed. Within the mud rock beds overprinting structures appear and are known as liesegang bands.

Figure 19. Photographs of bedding (S0). A. Bedding within Fatoya and Kintinian Formations, photo taken on the Southern wall of the pit. B. Strong bedding in the greywacke unit within Fatoya Formation.

Stereographic projection of bedding indicates that the layers (beds) generally strike northwest-southeast (116˚ in average) and dip gently to the southwest (43˚ in average); (*Figure 20*).

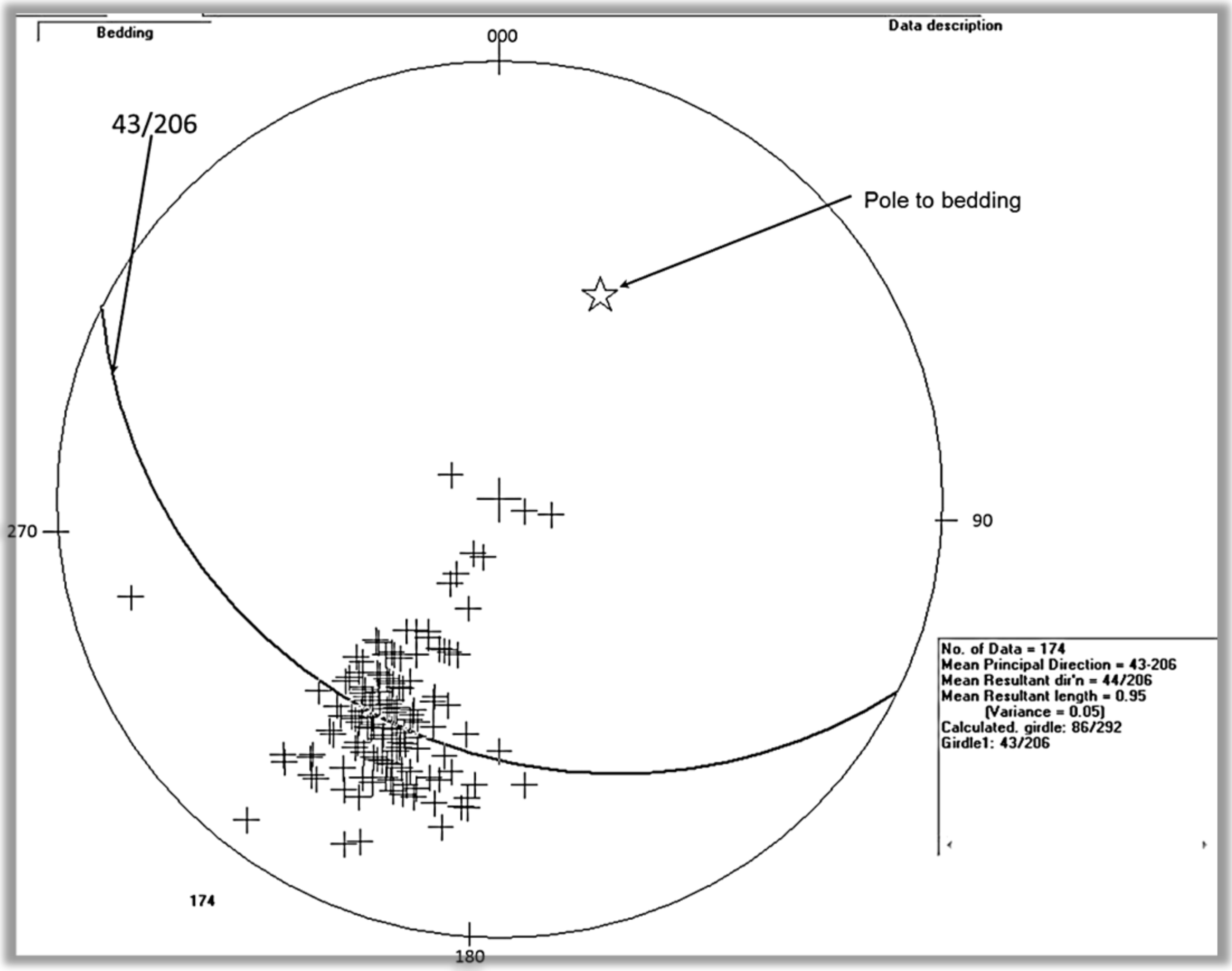


Figure 20. All bedding dominantly trend northwest-southeast direction and dip gently to the south west.

6.3.2. Disconformity

Disconformity is generally a surface between parallel rocks strata, indicating the interruption of sedimentation, and it is a type of unconformity.

Kintinian domain in southwest and Fatoya domain in north east are separated by a large disconformity of 1.7m wide parallel to bedding set. It gently dips 42-46° SW and strikes 115-126° SE .The disconformity layer marks either the break in sedimentation or significant change of the environment. It is significantly characterized by the thin sheet of clay layers of ~1cm thick, shale and other very fine particles are laminated parallel to the main strike.

This contact zone between both Kintinian and Fatoya Formations was early outlined during geophysical survey (IP) and later mapping in the open pit during the mining operations (*Figure 21*); (Brown Field Exploration Report, 2014).

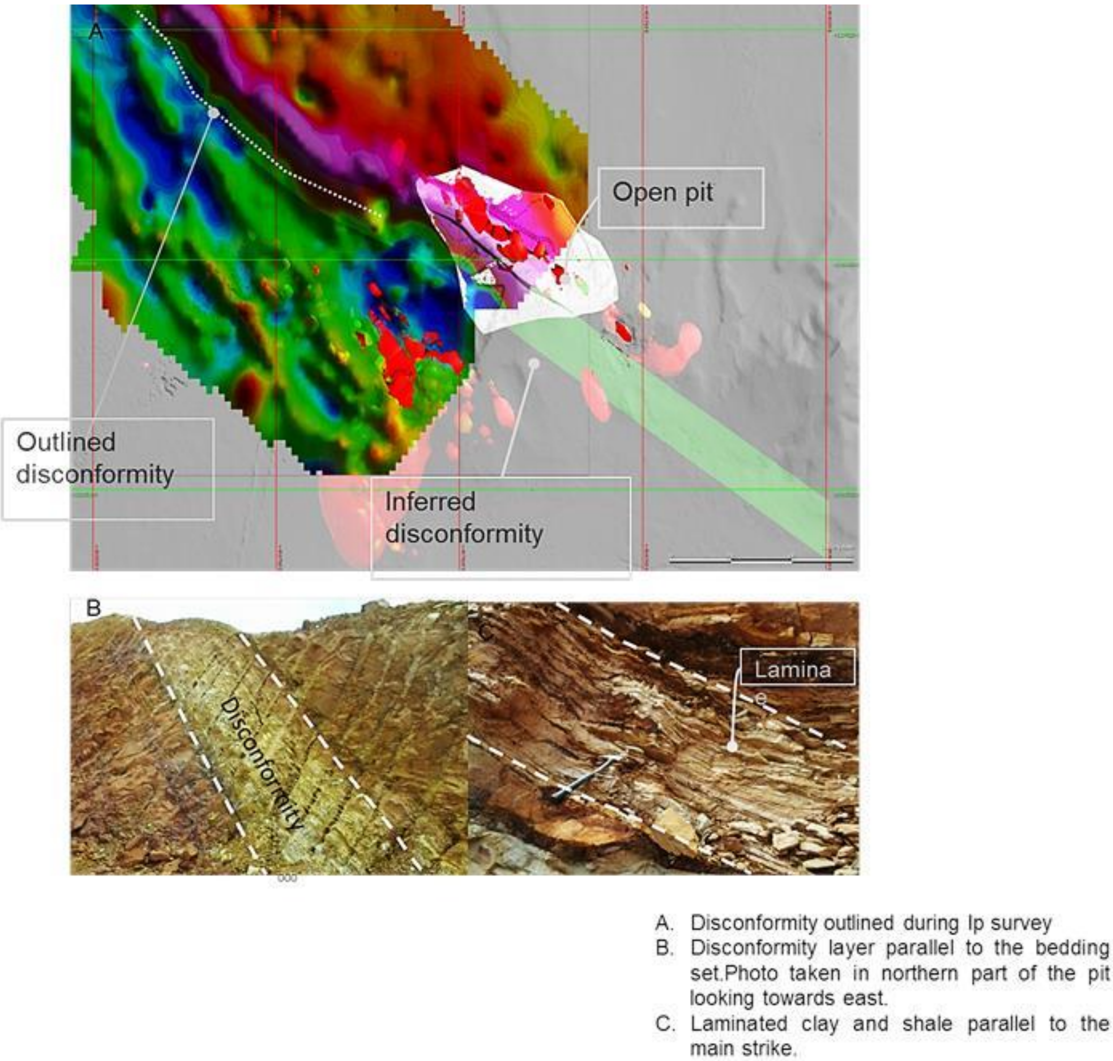


Figure 21. Perfect interpolation between disconformity identified by geophysical IP survey and open pit mapping.

Stereographic projection of disconformity shows northwest-southeast striking parallel to bedding plane (*Figure 22*).

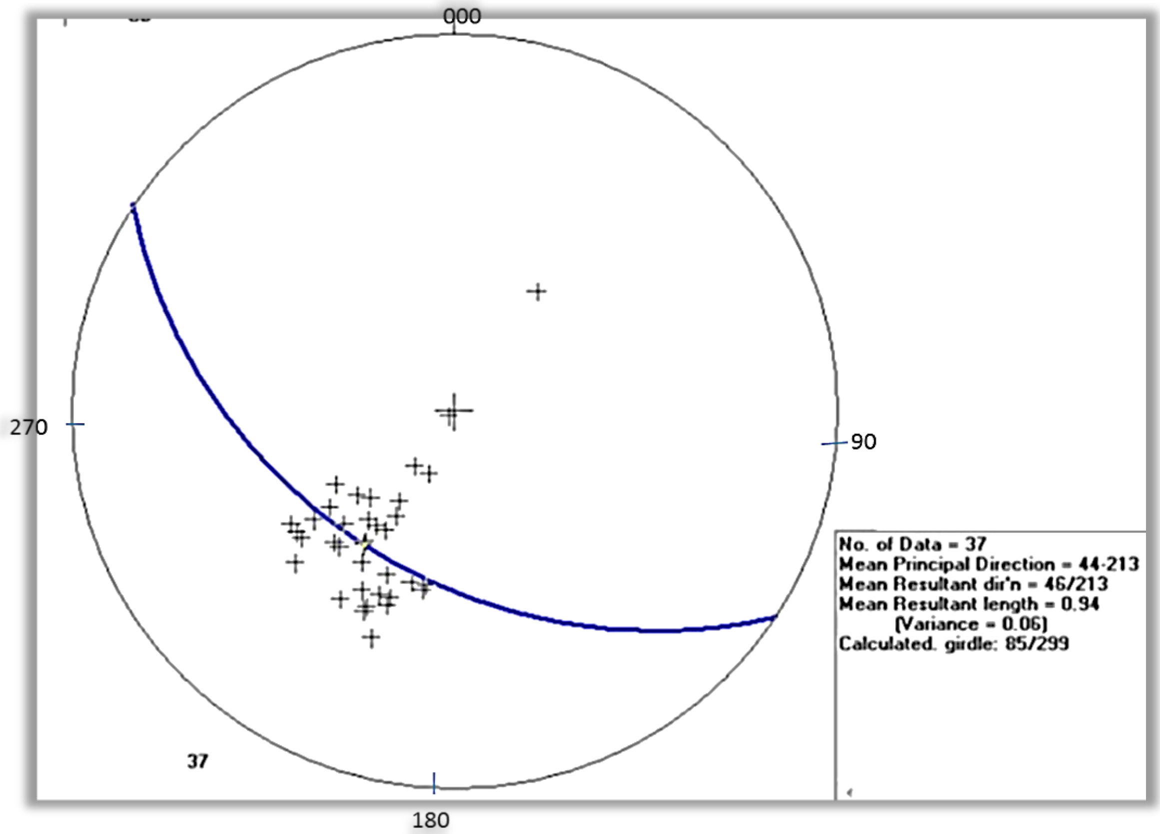


Figure 22. Stereographic plot of disconformity striking northwest-southeast and dipping southwest.

6.3.3. Folding

At Seguelen pit, no mine scale folding was observed. The most important folding encountered consists of small folding of quartz- carbonate veins. This small folding (vein scale) is frequently and clearly observed on core (*Figure 23*).

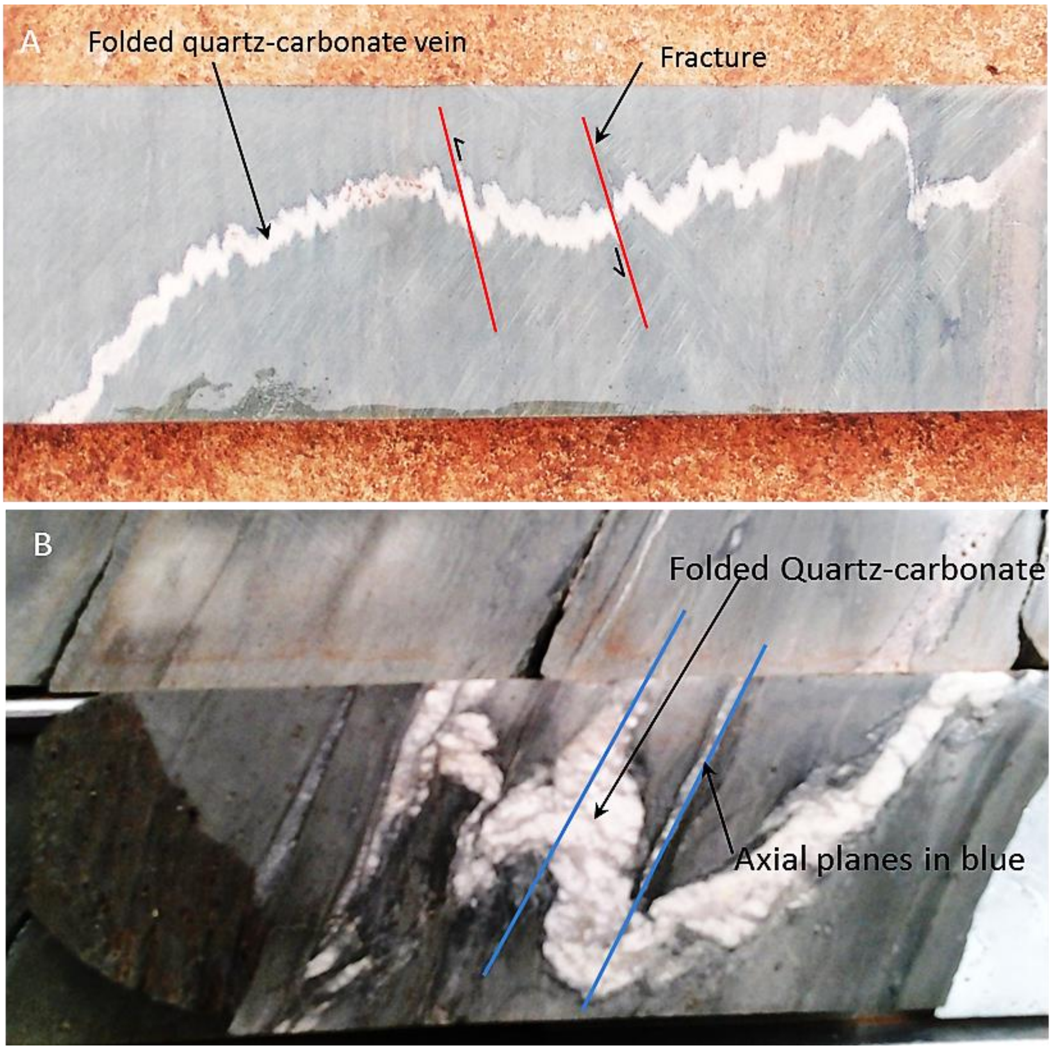


Figure 23. Photographs of micro folding. A. Small folding of quartz-carbonate vein hosted in shale rock. Two fractures cut the vein with minor displacement. B. Quartz-carbonate vein folded with axial planes shown in blue lines.

6.3.4. Faults

During the pit mapping, no mine scale fault was encountered within the deposit. Microfaults with minor displacement are observed within quartz veins (*Figure 23*.A).

6.3.5. Breccia zone

Two large breccia zones are observed on south wall of the pit. These breccia zones are characterized by the fine particles and angular quartz fragments weakly folded. There is little folding within the damaged zone and both breccia zones have width of ~2.2m and ~1.5m, respectively. An important characteristic of these zones is the intensity of hydrothermal fluid flow through the brecciated zones showing the hydrothermal metamorphic halo, which is a very important component of mineralization processes in Seguelen (*Figure 24*).

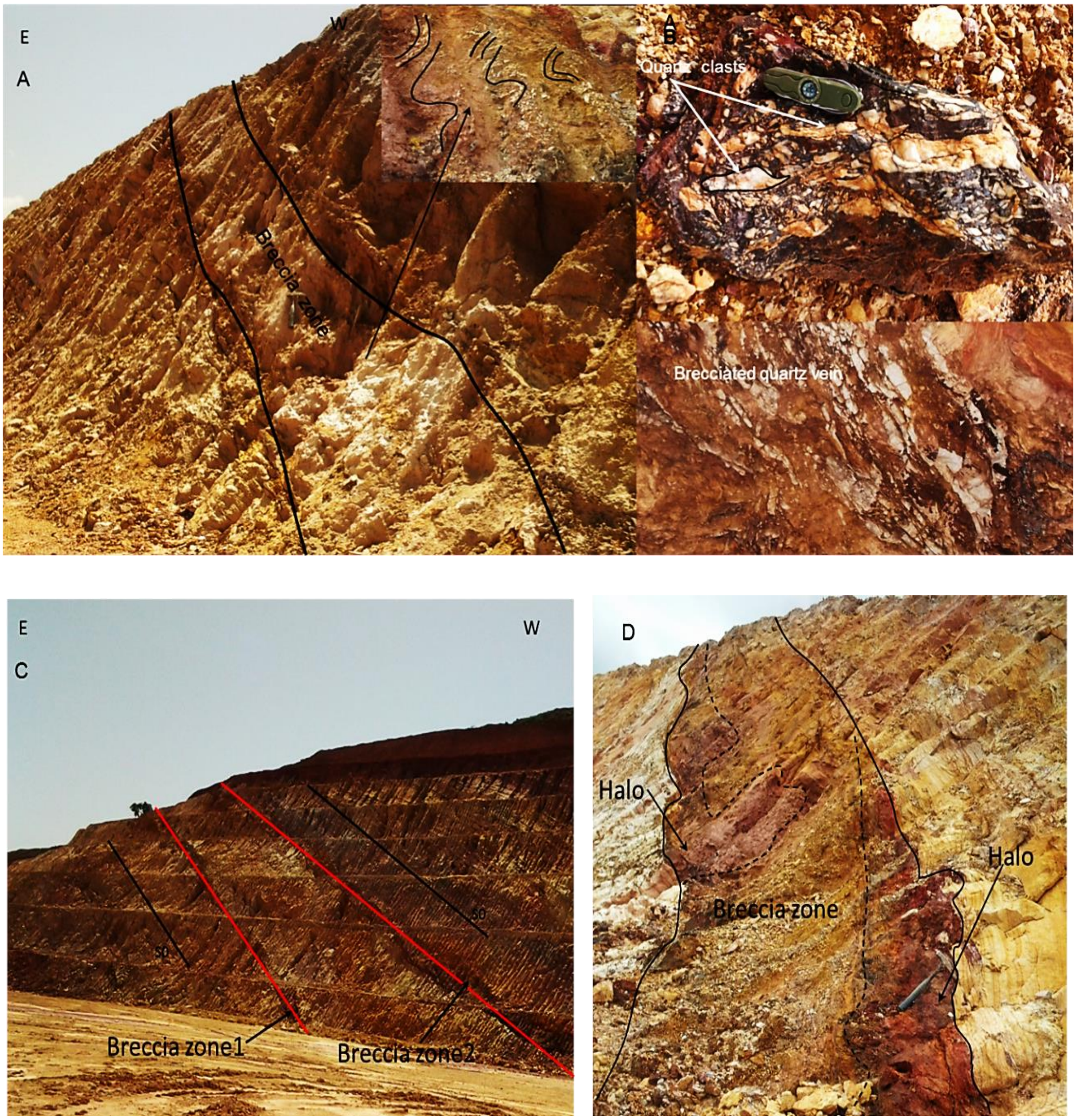


Figure 24. Photographs of breccia zones. A. Sedimentary breccia zone with fragmented and folded quartz veins~1.5m thick. B. Quartz clasts within schist matrix. C. Sub-parallel main breccia zones inferred in the south west part of the pit. D. Hydrothermal halo with the breccia zone indicating the intensity of the fluid flow. The hydrothermal alteration occurs in the contact between the fluid and host rock.

6.3.6. Quartz veins

The quartz veins at Seguelen and in most of Siguiri gold pits constitute the major gold bearing features. The bulk of the gold mineralisation is hosted in the milky quartz veins, with thickness often varying from 0.3cm to 5cm. The mineralized quartz veins at Seguelen are remarkably characterized by their lenticular geometry cross cutting the bedding plane and sub-vertically dipping. The quartz veins are often folded and can be easily observed on core. Two generations of quartz veins are distinguished in Seguelen are:

The first generation consists of quartz veins cross-cutting bedding. These quartz veins are related to D2 deformation event and form the important part of gold mineralized in Seguelen area and strike NE-SW; NNE-SSW (see below a, b) and are related to D2 (*Figure 26* & *Figure 27*).

The second generation consists of bedding-parallel quartz-carbonate veins and is related to D3 deformation event. They are less mineralized than the first one.

Three quartz veins sets are observed at Seguelen (*Figure 26* &*Figure 27*):

a) NNE-SSW trending quartz veins (mineralized and sub-vertically dipping);
b) NEE-SWW trending quartz veins (mineralized and sub-vertically dipping); and
c) NW-SE trending quartz veins (barren and moderately dipping to the south west).

Quartz veins at Seguelen underwent D2 deformation in extensional regime. Pinch and swell structures and micro folding of quartz veins are frequently seen (*Figure 25*).

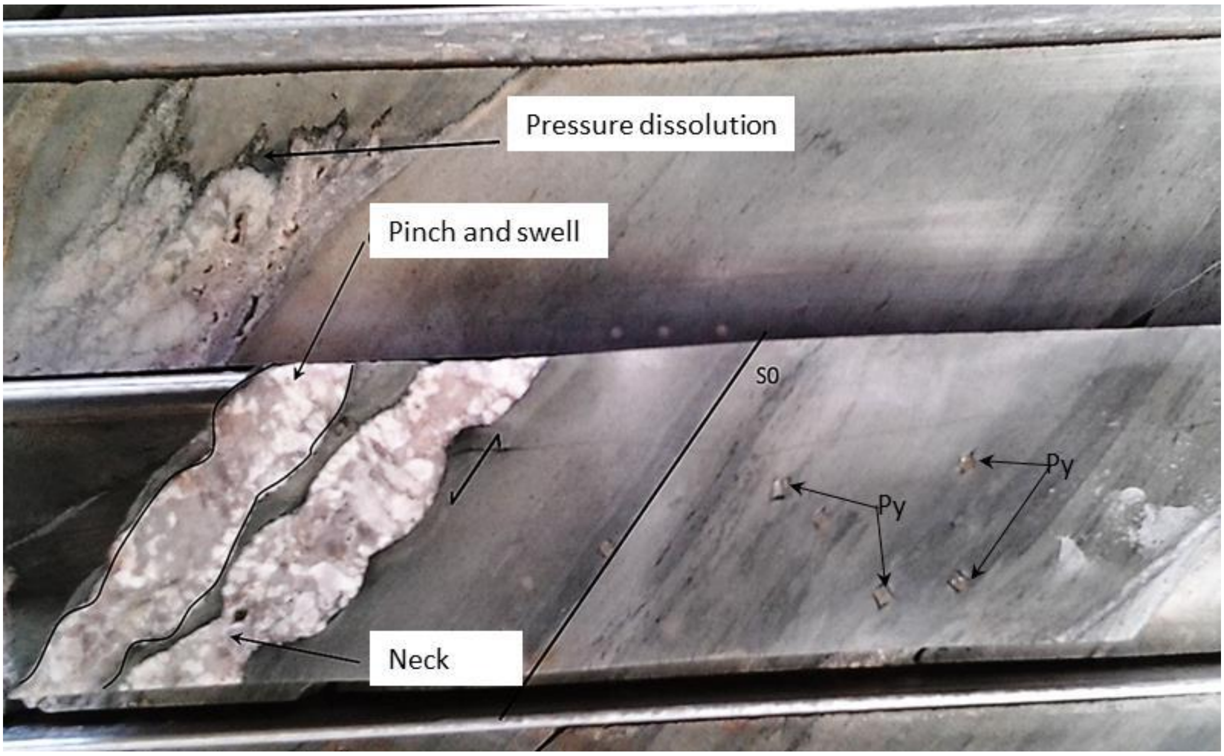


Figure 25. NE-SW striking quartz-carbonate veins showing pinch and swell structure indicating the sense of stretching parallel to the bedding set. The approximate stretching length is 0.5cm.Disseminated pyrite within the host rock (Py).

Veins selvage is mainly related to the first generation of quartz-carbonate veins in Seguelen deposit. It is the result of chemical interaction between the hydrothermal fluid and wall rocks (*Figure 32*).

The physical properties and chemistry of the fluid responsible is beyond of the scope of this present thesis.

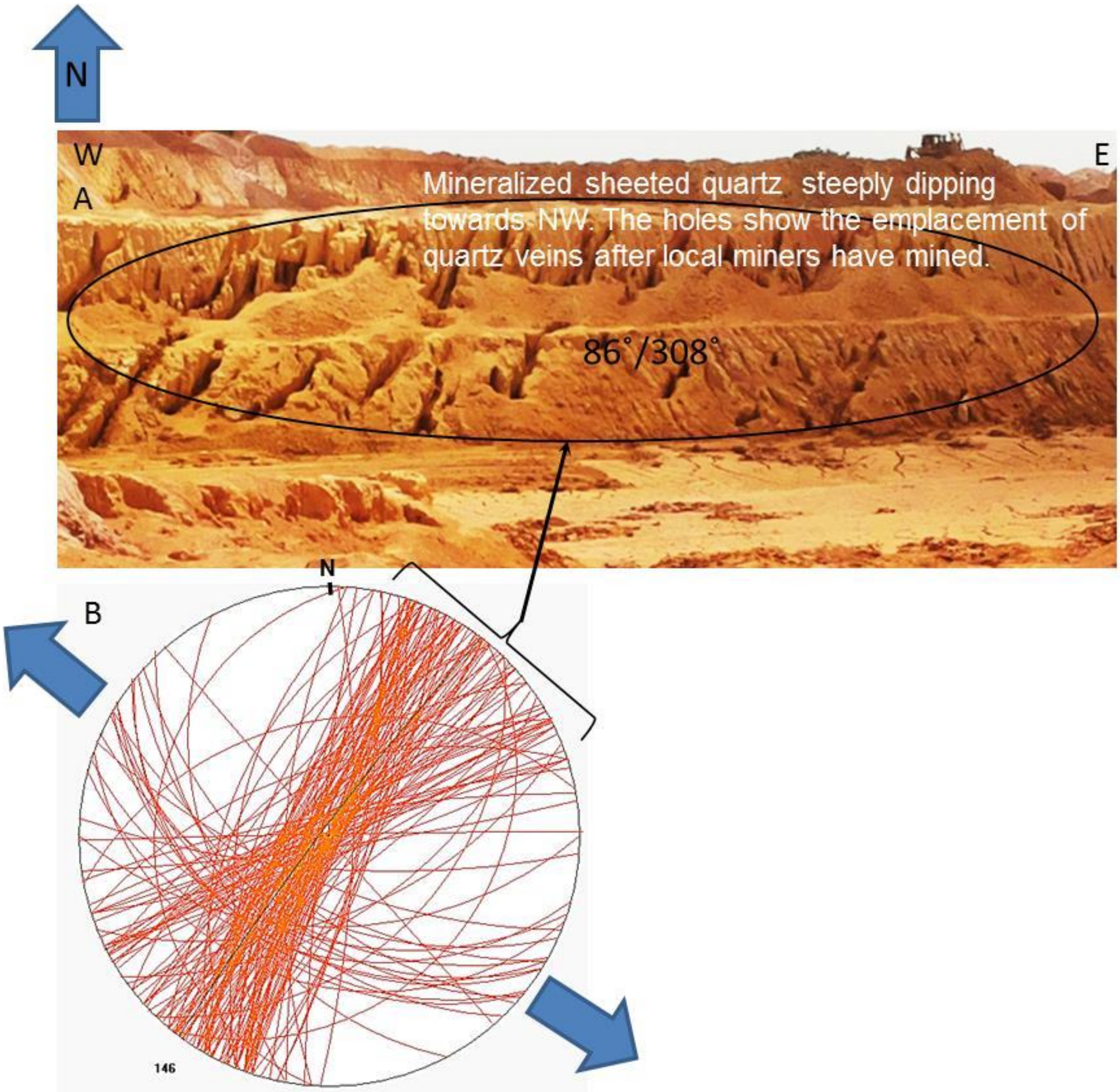
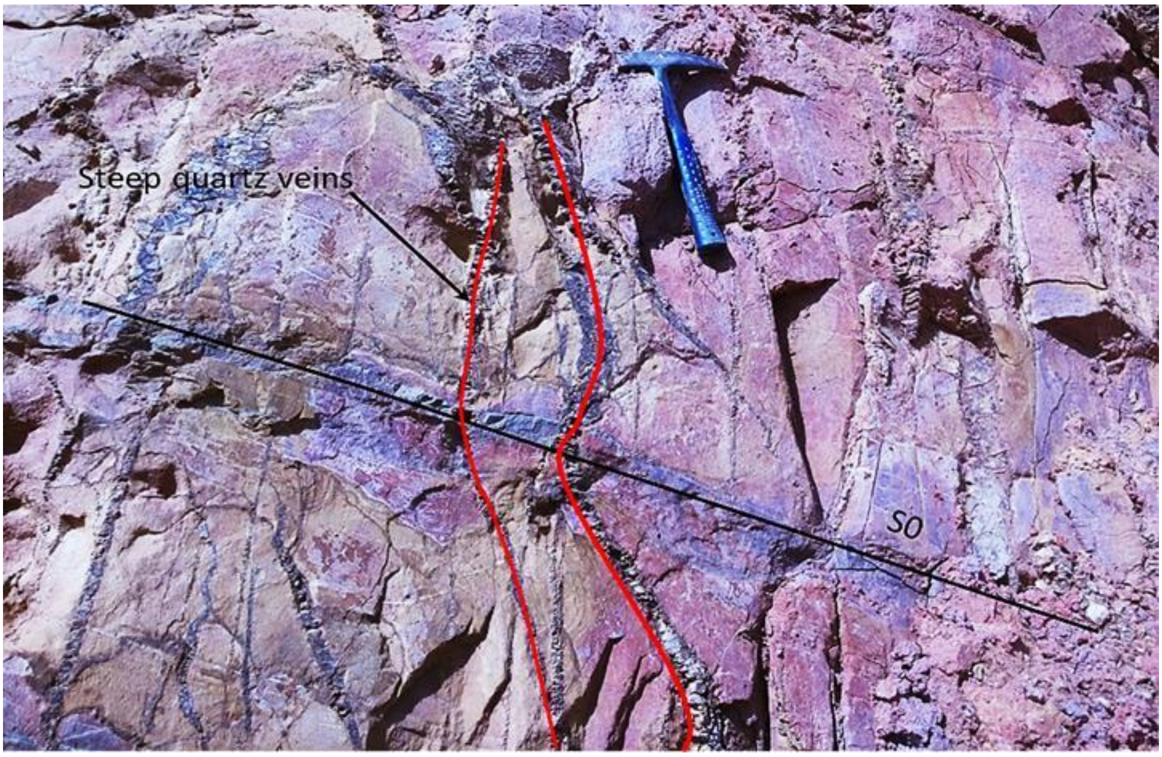


Figure 26 .A.The holes in the photo above indicate the emplacement of quartz veins which have been removed by the local miners. These quartz veins strike 308˚ NE-SW and dip sub-vertically 86˚. Conjugate quartz veins in extensional regime, sub-vertically dipping towards NW. This quartz vein set hosts the bulk of gold mineralisation in Seguelen deposit.

Figure 27. Photographs of quartz veins. A. Mineralised lenticular quartz veins sub-vertically dipping and striking N-S, photo taken on the south east wall of the pit. B. Typical mineralised milky quartz vein of Seguelen deposit, photo taken on core (borehole KTRCDD008).The Au grade within this quartz vein is ~2.81g/t.

6.3.6.1. Quartz veins and Bedding relationship



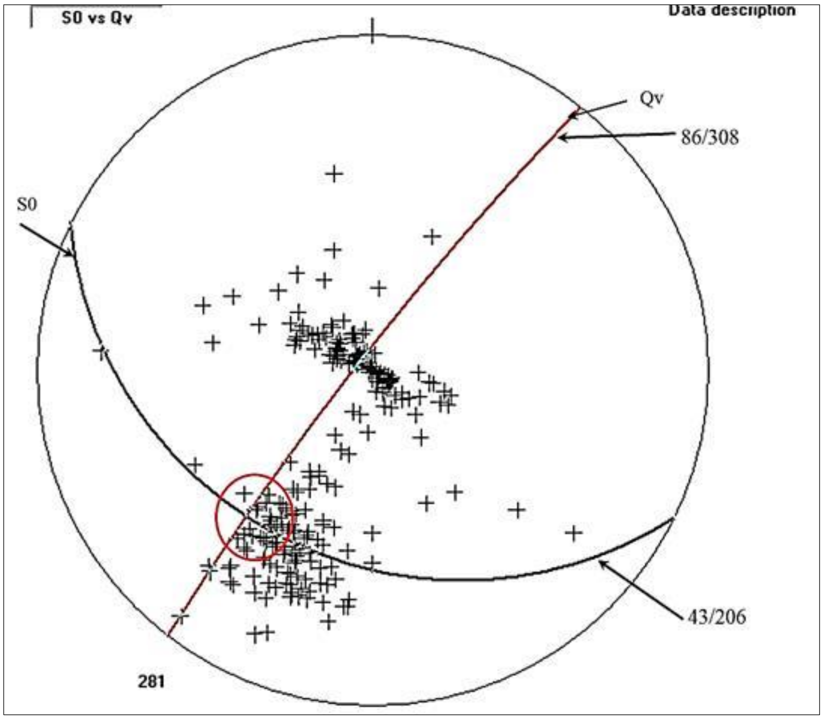


Figure 28. Stereographic projection of quartz veins (red circle) and bedding (black circle). Notice the red circle indicates the intersection between the two settings. The majority of quartz veins cross cut the bedding set at steep angle (almost perpendicular).

6.4. Secondary structures

6.4.1. Foliation and mineral lineation

Foliated fabrics are almost absent at Seguelen due to the low grade of metamorphism. The apparent foliations observed on the core are in fact the mineral lineation often oblique to bedding planes (*Figure 29*).

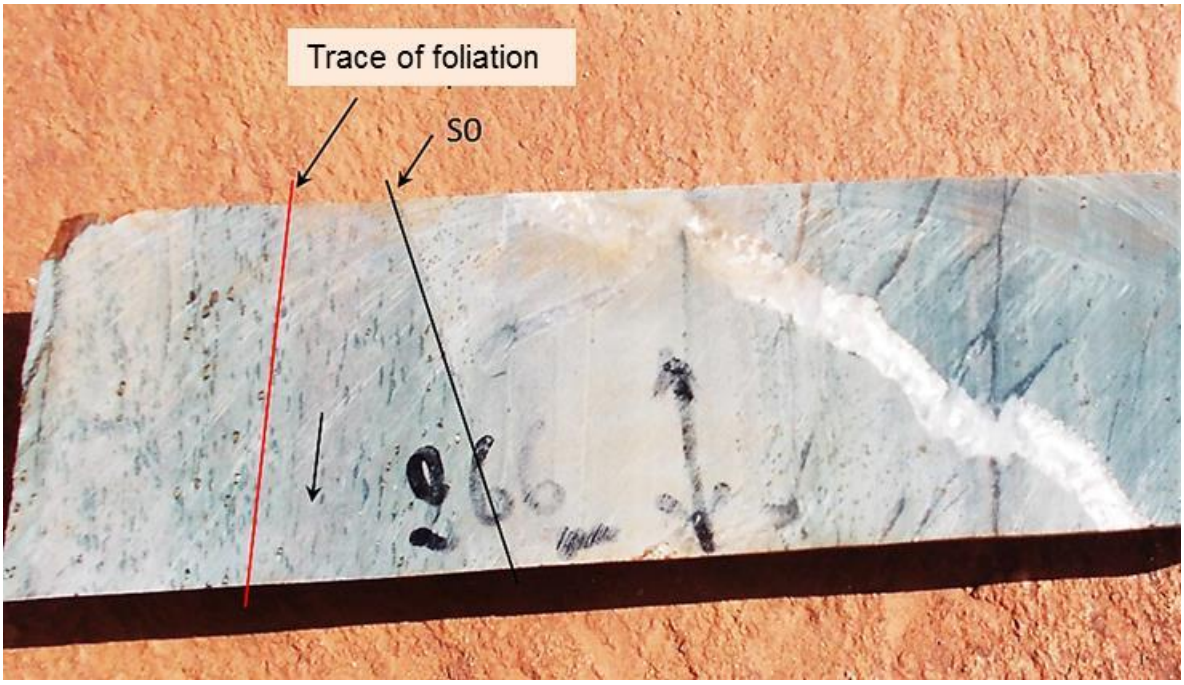


Figure 29.Trace of foliation (red line) oblique to the bedding plan (back line).

6.4.2. Fractures and cleavages

The fractures and cleavages occur in the western part of the pit within the claystone unit. The fractures cross-cut the bedding planes at high angle.

The low-grade metamorphism in claystone shows slaty cleavage and fissility fabrics parallel to the bedding plan (*Figure 30*).

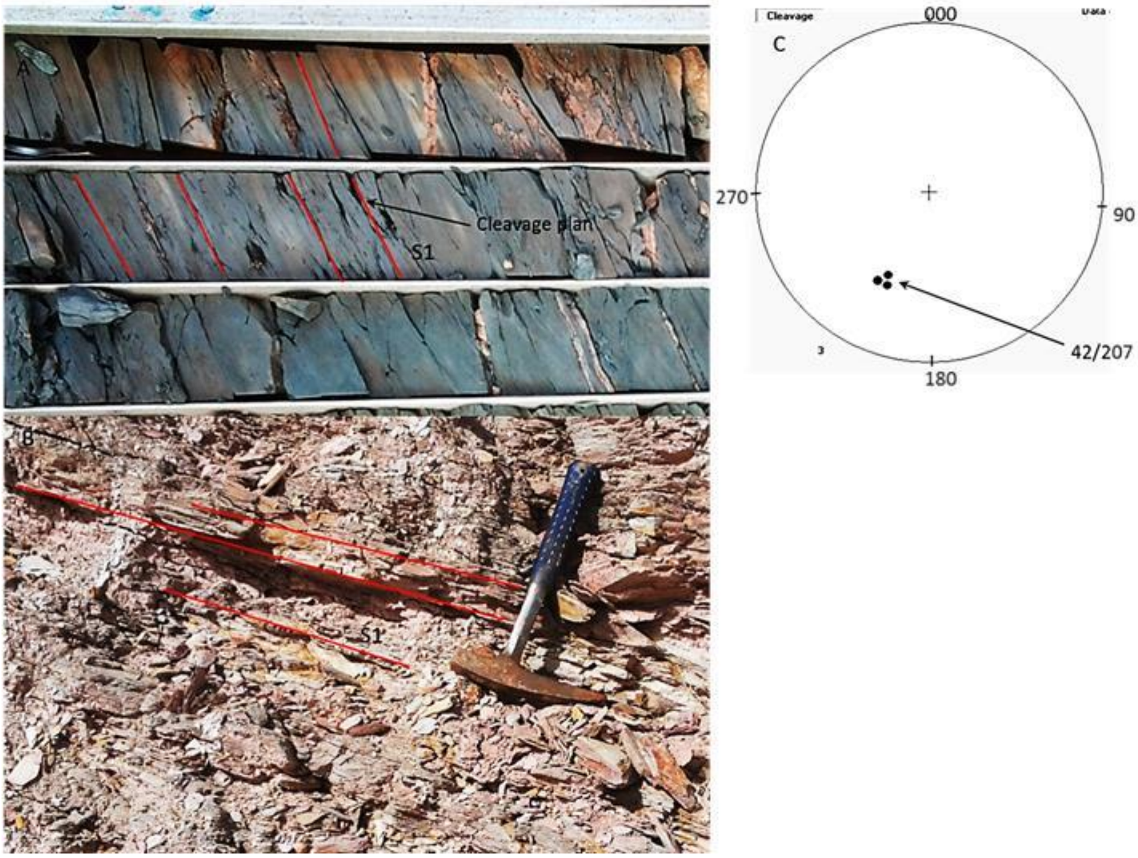


Figure 30. Photographs of cleavages. A. cleavages in shale unit parallel to the bedding plane, photo taken on core. B. cleavages in claystone unit parallel to the bedding plane, photo taken on the south west wall of the pit. Red lines show cleavage planes which coincide with fissility planes.

6.5. Structural control to the mineralisation

The Seguelen gold deposit is one of the largest gold mineralisation within Siguiri mine complex. It is characterized by the size of the deposit and the high grade of the mineralisation.

Four geological features have largely contributed to the deposition of the mineralization:

a) Reactivated bedding
b) Breccia zone
c) Quartz veins
d) Lithology/Wall rock

Fifty eight (58) grab samples were taken on different structures cited above and samples were sent to the lab for gold analysis. The lab result is shown in the chart below (Figure 31).

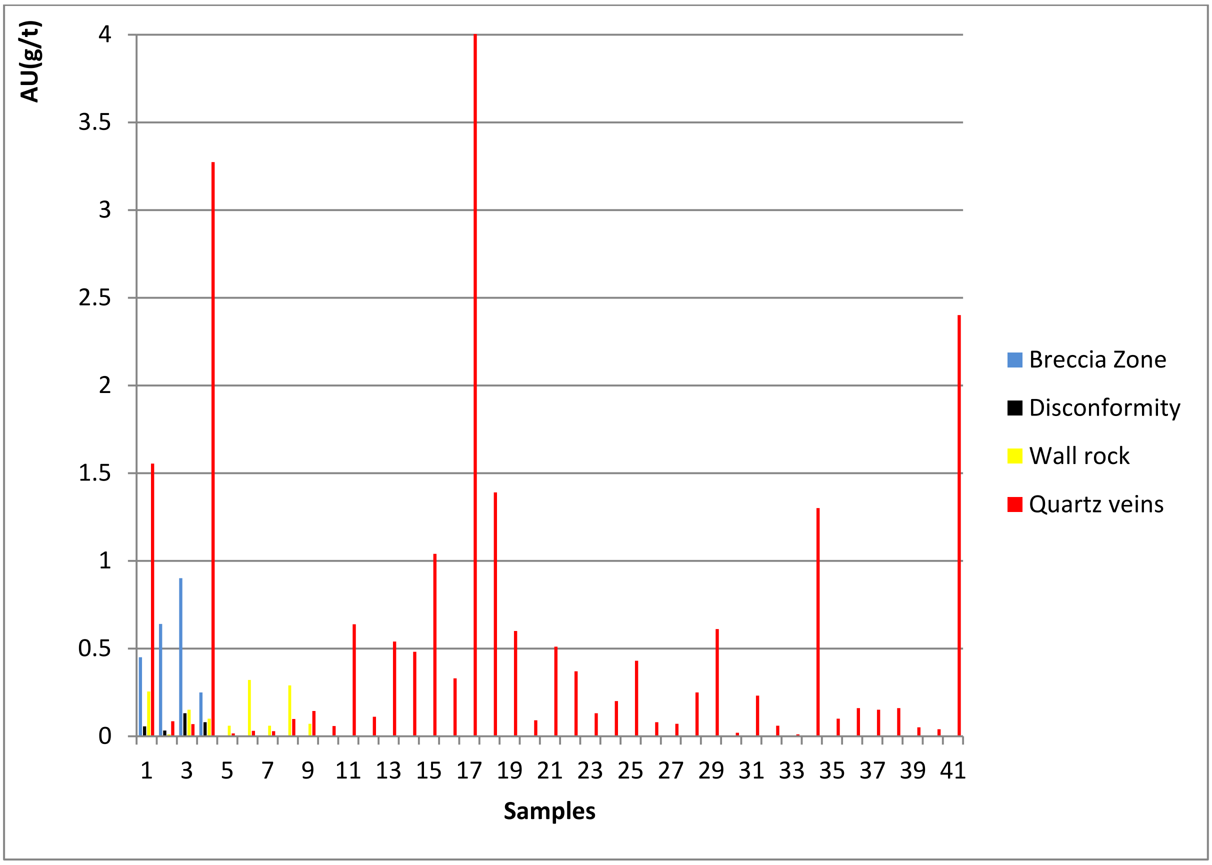


Figure 31.Graph showing the AU grade distribution within different structures. It appears on the graph that quartz veins host the bulk of gold mineralisation with the grade exceeding the cut-off (0.5g/t) in average .This is followed by the breccia zones with minor results>0.5 g/t.

The overall mineralisation can be broadly divided into two hydrothermal systems:

- Channelized, fractured open system with inert wall rocks (no chemical reaction); and
- Channelized, fractured open system with reactive wall rocks.

6.6. Channelized, fractured open system with reactive wall rocks

a) Reactivated bedding

The reactivated bedding is one of the prominent geological features observed at Seguelen. During the flow of hydrothermal fluids, the bedding was reactivated and served as important pathway and traps for the formation of gold bearing quartz veins. The hydrothermal halo is often encountered in the interbedding planes (*Figure 32*).

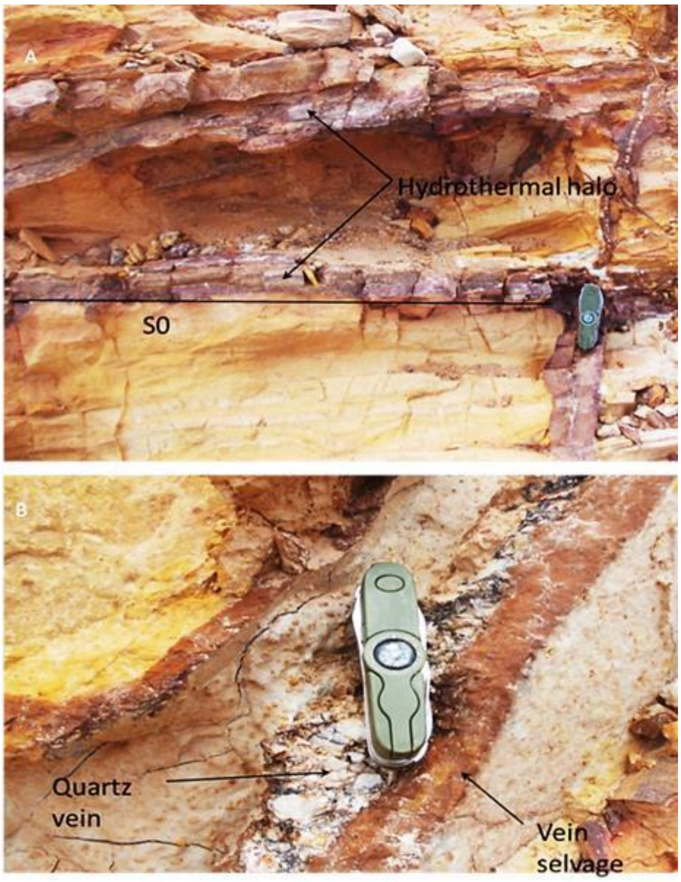


Figure 32. Photographs of halo and quartz veins. A. Hydrothermal halo resulting from the reaction between the wall rock and fluids which flowed through bedding planes. This feature is ubiquitous throughout the deposit. B. Quartz vein selvages with variable thickness, possibly indicating that the fluids flowing along the contact were hydrothermal with chemical compositions and reactive with wall rocks.

b) Breccia zone

Two breccia zones were outlined during the pit mapping, and they are characterized by the hydrothermal alteration. The thick halo on the edge of the zones appears to be an evidence for an important conduit of fluid flow (*Figure 33*).

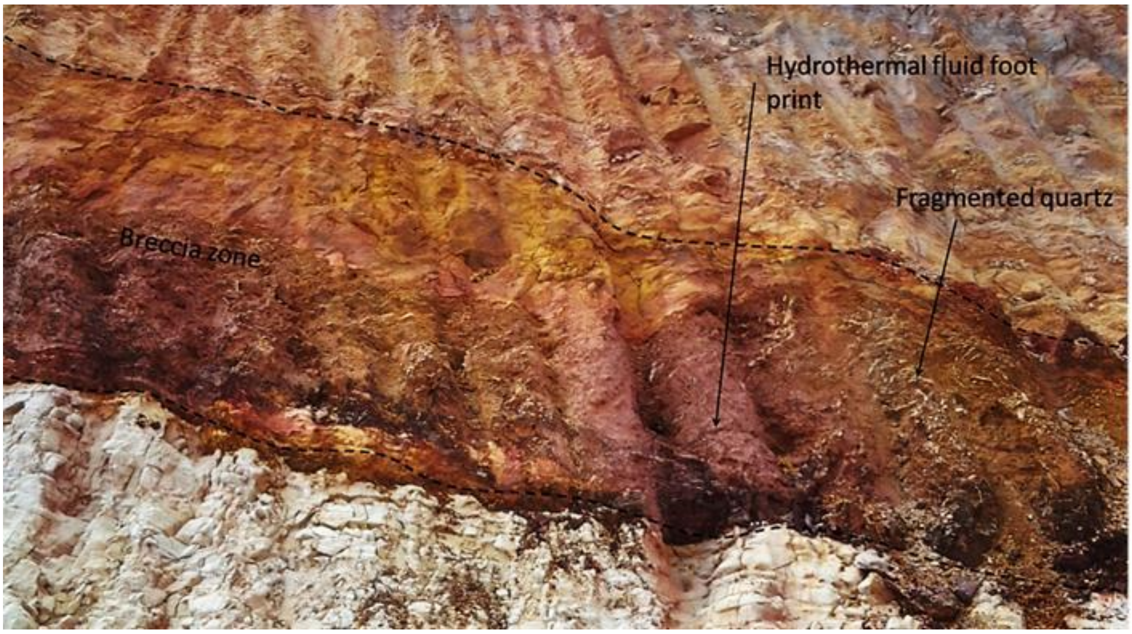


Figure 33. Hydrothermal fluid conduit along the existing breccia zone.

6.7. Channelized, fractured open system with inert wall rocks

c) Quartz veins

Quartz veins at Seguelen are typically sheet-like and lenticular .The quartz veins mainly dip steeply to NW (see section 6.3.6) and host a large part of the gold mineralisation. The quartz veins are milky and cross-cut bedding planes. The mineralisation of Seguelen deposit is largely quartz veins related. (*Figure 26*; *Figure 27* &*Figure 34*).

Figure 34. Visible gold lodged in quartz vein. The overall grade of this 1m interval of core is 2.36g/t gold (Exploration drill core).

d) Lithology

At Seguelen, sulfides are pervasively disseminated within the country rocks, typically in shale, sandstone and claystone. The shale often contains high grade of gold although it generally shows a behavior below the brittle-ductile transition. The fluids seem to migrate through shale flakes and claystone fissility. The shale also presents some porosity through which the fluids may migrate and drops its loads. The carbonaceous shale (black shale) is also favourable to gold mineralisation. The silstone and greywacke are less favourable to this kind of dissemination (*Figure 35* &*Figure 36*).

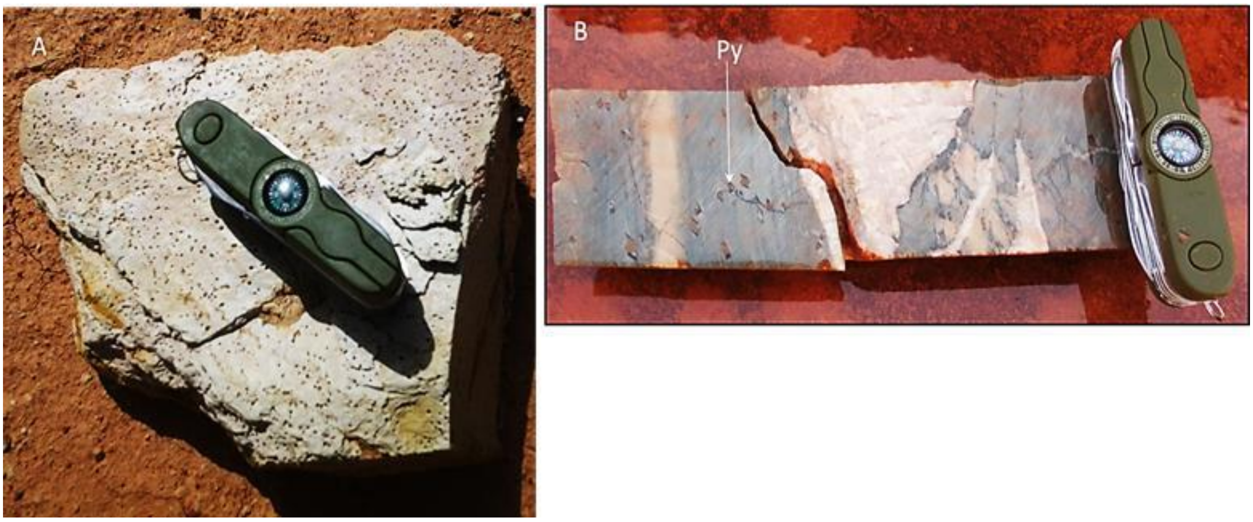


Figure 35: Photographs of disseminated sulphides. A. Strong dissemination of sulfides throughout the shale rock (spots are sulphides minerals mainly pyrite). B. Pyrite dissemination within the shale (Exploration drill core).

Table 2: Distribution of Au grade within wall rocks at Seguelen mine, Brown field drill holes data.

BHID	FROM	TO	LITHO	AU
KTDD001	44.7	45.3	SL	4.49
KTDD001	48.3	49.3	SL	4.79
KTDD001	51.3	52	SL	4.33
KTDD001	63.2	63.8	SL	6.19
KTDD001	58.3	59.8	SL	3.01
KTDD001	65.7	66.3	SL	3.02
KTDD001	71.3	71.8	SL	3.76
KTDD001	83.5	84	SL	3.29
KTDD001	87.8	88.3	SL	4.14
KTDD001	90.6	91.1	SL	3.21
KTDD001	91.1	91.7	SL	24.3
KTDD001	101.3	102.3	SL	7.13
KTDD001	103.3	103.8	SL	16.5
KTDD001	118.3	118.8	SL	4.41
KTDD001	126.3	127.3	SL	24.7
KTDD001	137.3	138	SL	15.1
KTDD001	142	143	SL	5.7
KTDD001	146	147	SL	3.54
KTDD001	151	152	SL	3.81
KTDD001	155	156	SL	3.8
KTDD001	178	179	ST	4.56
KTDD001	226	227	ST	3.15
KTDD004	71	72	SH	3.33
KTDD004	81	82	SH	3.43
KTDD004	84	85	SH	3.45
KTDD004	87	88	SH	6.21
KTDD004	136	137	SH	10.8
KTDD004	161	162	SH	3.15
KTDD004	167	168	SH	5.05
KTDD004	168	169	SH	9.25
KTDD004	169	170	SH	8.25
KTDD004	170	171	SH	3.32
KTDD004	174	175	SH	3.09
KTDD004	175	176	SH	9.6
KTDD004	176	177	SH	12.4
KTDD004	182	183	SH	3.94
KTDD004	184	185	SH	3.64
KTDD004	206	207	SH	8.23
KTDD004	249	250	SH	4.68
KTDD004	255	256	SH	4.1
KTDD004	268	269	SH	4.17
KTDD004	306	307	SH	3.2

BHID	FROM	TO	LITHO	AU
KTDD005	142.5	143.5	SS	7.25
KTDD006	83	84	SH	17.8
KTDD007	52	53	SS	11.5
KTDD007	54	55	SS	7.07
KTDD007	67	68	SS	6.34
KTDD007	70	71	SL	3.04
KTDD007	75	76	SS	3.23
KTDD007	77	78	SS	5.35
KTDD007	78	78.6	SS	8.85
KTDD007	78.6	79.6	SS	5.8
KTDD007	116.8	118	SS	3.38
KTDD007	167	168	SS	3.32
KTDD007	168	169	SS	13.1
KTDD008	186.5	187.5	SS	3.95
KTDD008	216.5	217.5	SS	3
KTDD008	234.5	235.5	SS	6.72
KTRCDD004	357.17	358	SH	5.63
KTRCDD005	66	67	SL	6.42
KTRCDD006	141	142	SW	3.54
KTRCDD007	81	82	SL	3.04
KTRCDD007	179	180	SW	3.63
KTRCDD007	187	188	SL	3.89
KTRCDD007	191	192	SW	9.27
KTRCDD007	193	194	SL	4.34
KTRCDD007	221	222	SW	3.17
KTRCDD008	138	139	SW	4.76
KTRCDD008	179	180	ST	4.83
KTRCDD008	180	181	ST	5.52
KTRCDD009	172	173	SW	3.49
KTRCDD011	129	130	ST	9.38
KTRCDD013	204	205	ST	4.27
KTRCDD014	92	93	SL	9.91
KTRCDD014	116	117	SL	5.05
KTRCDD014	186	187	SL	4.44
KTRCDD015	199	200	ST	6.25
KTRCDD015	241	242	ST	4.56
KTRCDD015	242	243	ST	6.89
KTRCDD017	88	89	SL	6.69

***SL= claystone, SH=shale, ST =silstones, SS=sandstone, SW=Greywacke.**

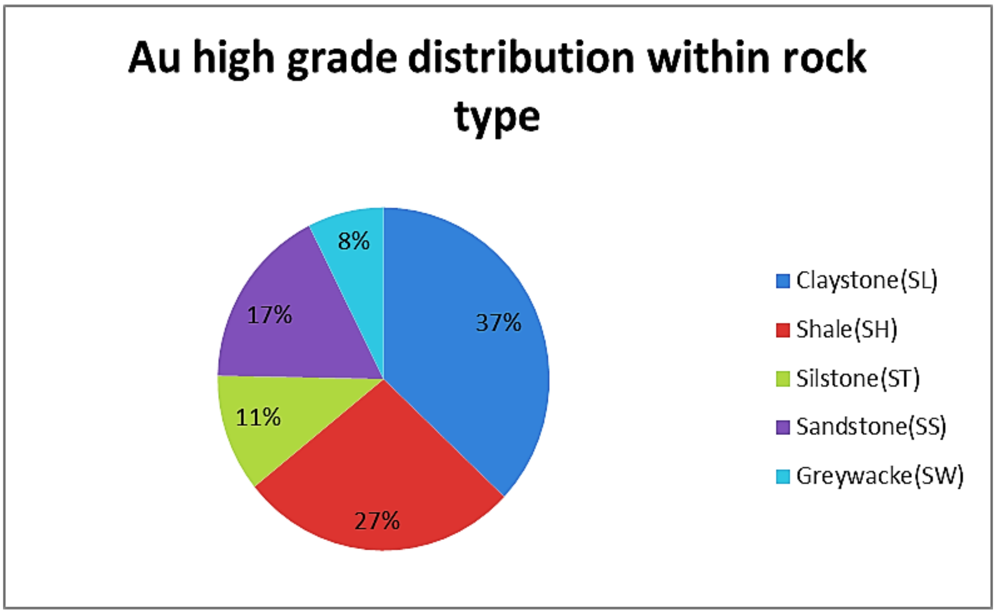


Figure 36: Au grade breakdown distribution within wall rocks. It appears that claystone and shale are the most favourable rocks within which the sulfides are disseminated (Brown field drill holes data).

6.8. Hydrothermal alteration

Hydrothermal deposits exhibit strong lateral zonation of alteration phases on scale of metres. Mineralogical assemblages within the alteration zones and the width of these zones generally vary with wall rock type and crustal level.

In general, carbonates include ankerite, dolomite or calcite; sulphides include pyrite, pyrrhotite or arsenopyrite; alkali metasomatism involves in sericitization, formation of biotite or K-feldspar and albitization; mafic minerals are highly chloritized. Sulfidation often is extreme in Fe-rich mafic host rocks as well as carbonaceous shales. Chloritisation is pervasive in Siguri mining complex (Figure 37).

Figure 37.Seguelen core photograhs.A.The green colour shows chlorite alteration.B.Pervasive siderite alteration.C.Carbonate alteration on the edge of the quartz veins.

6.9. Ore body

Two distinct ore bodies lying almost parallel to one another constitute the Seguelen gold deposit (*Figure 38*).The first one called ore body1 is the focus of this present thesis and it is currently being mined.

The ore body1 of push back1 trends towards north west and dips gently to the south west.

The ore body2 lies within push back2 in the southern part and is not mined yet.

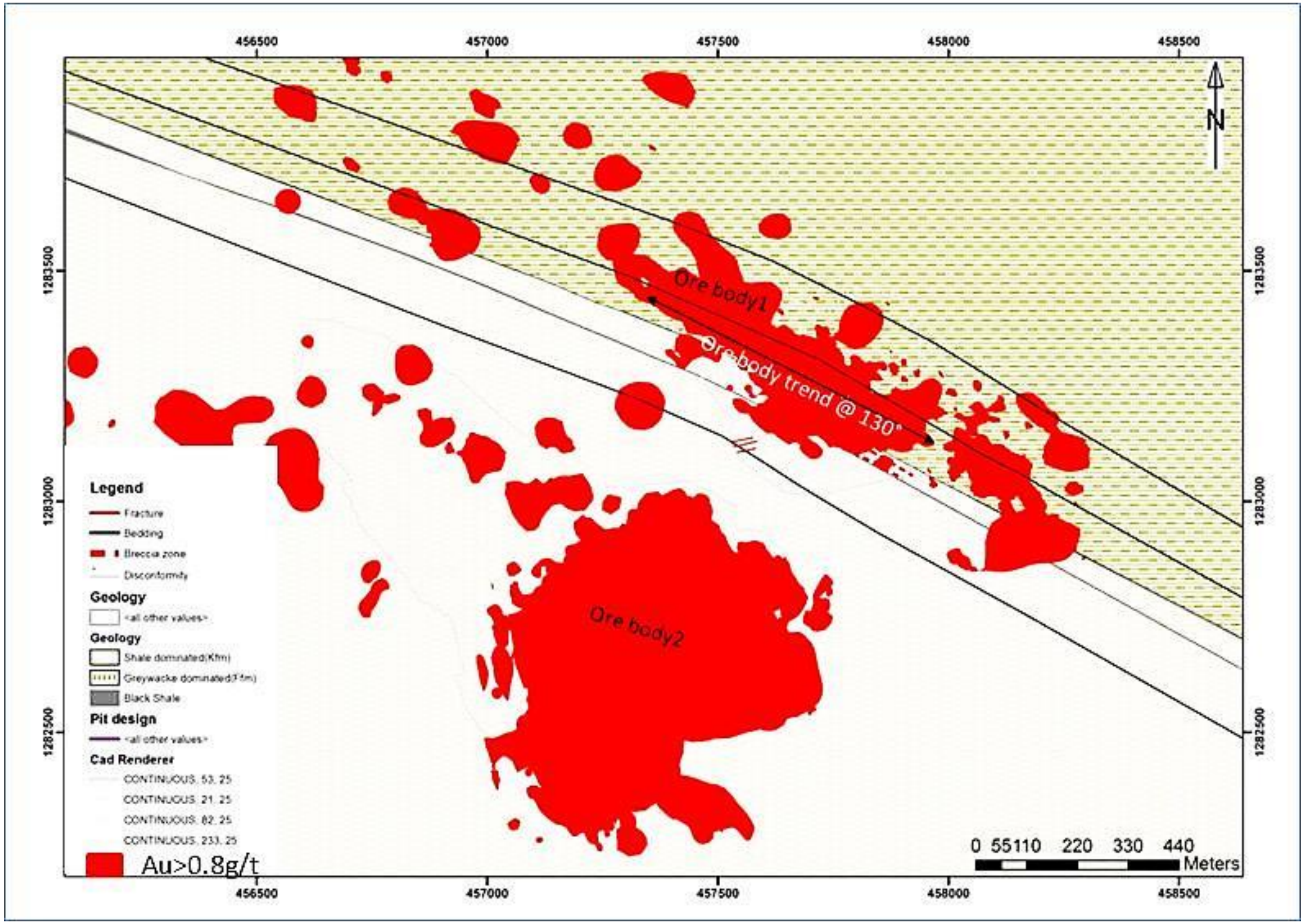


Figure 38: 2D view of Seguelen ore shoot orientation sub-parallel to the bedding plane attesting bedding reactivation controls on the mineralisation (data extracted from model after Landao, 2014).

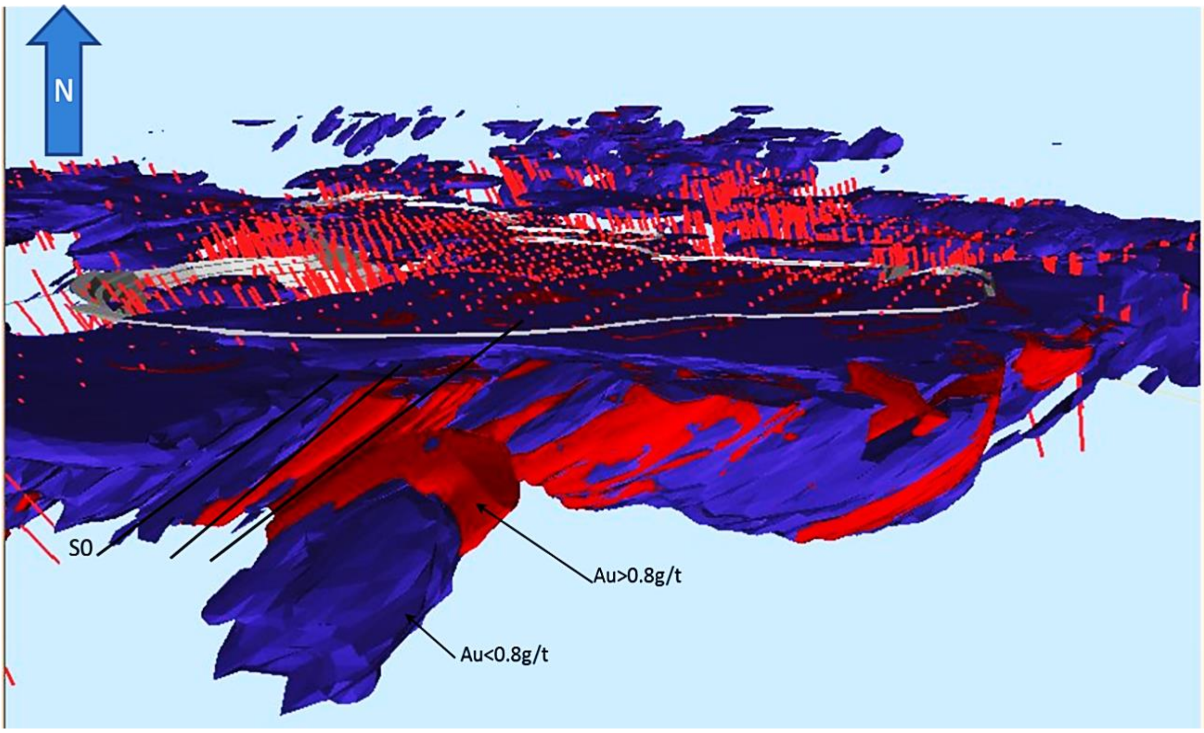


Figure 39:3D view of Seguelen deposit, the orebody dips south west almost sub-parallel to the bedding plane. The high and low grade envelopes occur as sheet-like following the bedding units. The red and blue envelopes are, respectively, high and low grades (adapted from Landao, 2014).

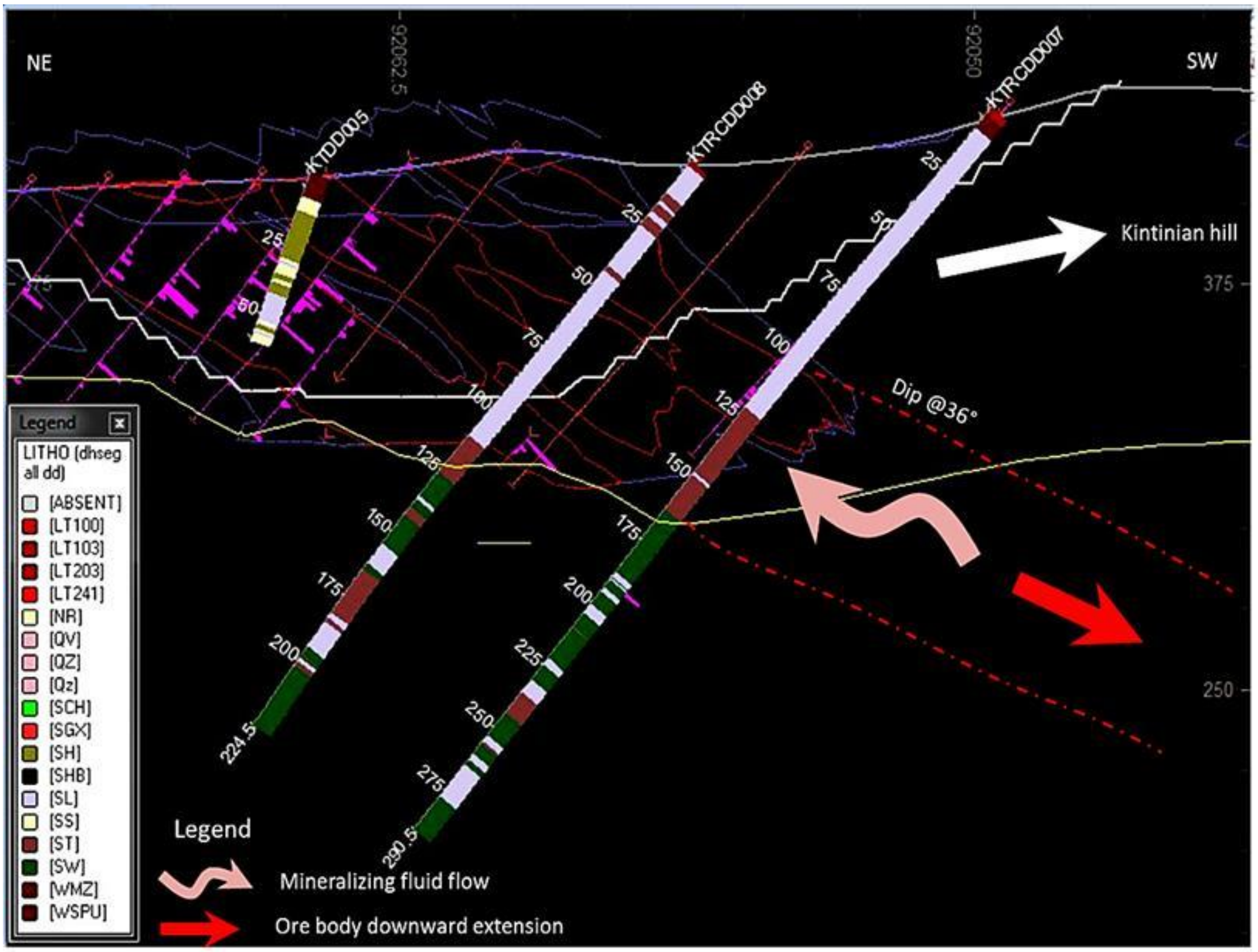


Figure 40: Cross-section of Seguelen deposit1 showing mineralising fluid pathway and possible extension of ore body downward to the south west, where the hill is between the actual pit and Kintinian village. The ore body dips gently to the south west around 36°.

6.10. Structural synthesis

The overall quartz veins of Seguelen deposit and the other pits are assigned to three deformation events: D1, D2 and D3 (*Figure 41*).

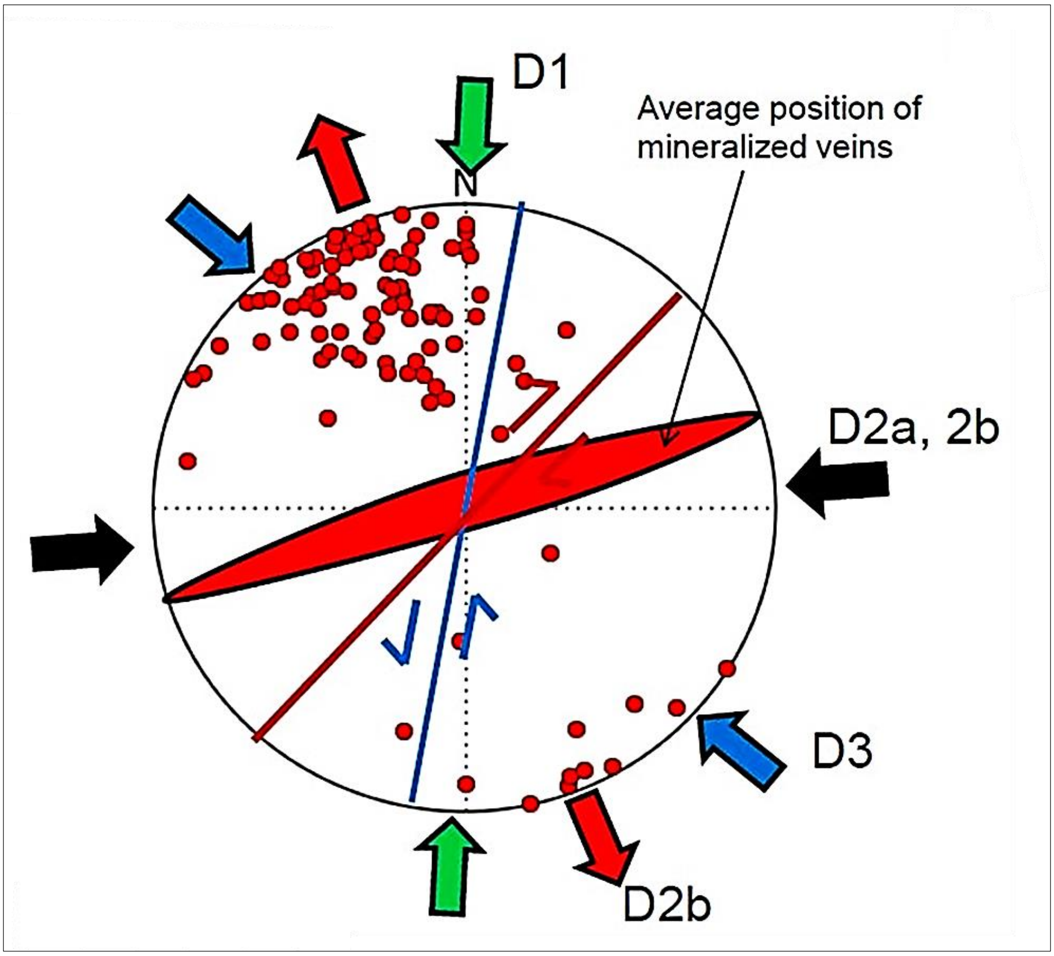


Figure 41: Diagram of all mineralized veins in relation with deformation events through time (after CET, 2011).

The major deformation events are respectively D1, D2 and D3 with the associated structures frequently encountered in the field.

D1: this event corresponds to first regional thrust striking N-S. An entire corridor of 12km long and 3km wide underwent shortening deformation, It forms a first order of structures characterized by the development of barren bedding parallel veins due to fluid pressure gradient at rocks unit boundary.D1 structures are not so favourable to gold mineralisation, although some spots of mineralisation are encountered. Quartz veins of D1events strike N-S.

D2: this deformational event controls the bulk gold mineralisation in Siguiri mine complex. The associated structures striking E-W and NE-SW correspond to the shortening and building of heterogeneous fluid pressure gradient; the sub-event D2b corresponds to the opening of mineralized tensional quartz veins as well as conjugated hybrid veins. These veins have generally lenticular form (Seguelen typical case).

D3: this event controls NW-SE shortening structures such as cleavage and sinistral sub-horizontal shearing along the cleavage. *Some mineralised structures are associated to D3.*

CHAPTER 7: DISCUSSION

Siguiri gold mine is hosted in a thick sedimentary basin of Paleoproterozoic of Birimian Super group. Nine open pits in the current mine form a valuable operational activities into a deep weathered environment. The lower Birimian B1, underlain the whole mining complex and was accreted during the Eburnean Orogeny event.

The regional thrusting structural corridor outlined by the first aeromagnetic image interpretation strikes N-S direction and hosts all the open pits. The corridor is associated with the first deformation D1 which affected the entire basin (Figure 42).

The bulk of gold mineralisation in the Birimian terrane is related to the numerous tectonic events which affected the basin. The mineralisation related to the quartz veins is associated to the shortening deformation D2 (CET, 2011). The sulfides disseminated mineralisation type is often encountered in shale (sandy shale), claystone and sandstone units and it is formed by the hydrothermal fluid, which is derived from deep source during the deposition.

The geological observation in the lower Birimian environment is almost impossible due to the lack of outcrop. The rocks on surface are completely weathered up to 100m deep with all primary structures obliterated. Due to the deep weathering, the boundary between Kintinian and Fatoya formations is unclear. An attempt has been made to describe it as disconformity.

7.1. Tectonic events

Three major deformation events have affected the whole mining complex, and they are named as D1, D2 and D3 formed during the Eburnean orogeny (2.2-2.090 Ga).

The tectonic evolution of early Proterozoic Birimian during the Eburnean orogeny is described as a polycyclic process and is summarized as follows (Milesi, 1992; Feybesse, 2006):

~ 2.35 – 2.1 Ga

Extensional tectonics and associated deposition of the upper Birimian (B2) volcano-sedimentary formations including basic volcano plutonism of tholleiitic character at the base, followed by flyschoid with volcano-sedimentary intercalations, overlain by carbonate formations at the top.

~ 2.15 - 2.1 Ga (Start of Eburnean tectonics)

D1: N(NE) – S (SW) directed shortening associated with shallow-angle thrusting and crustal thickening that caused the development of bedding parallel schistosity (S1), flat-lying isoclinal folding and high grade metamorphism (550-650 ºC and 6 kb) at lower crustal levels and the development of E-W to WNW-ESE trending fabrics.

~ 2.095 – 1.98 Ga (D2-D3 tectonic continuum)

D2: W (NW) – E (SE) directed shortening with associated upright F2 folding and development of penetrative ENE-WSW trending cleavage (S2); transcurrent tectonics in the form of NE-SW directed sinistral-ductile faulting, showing variable developed reverse component s at low to medium grade metamorphism (200-300 ºC and 2-3kb).

D3: W (NW) – E (SE) brittle shortening and major transcurrent tectonics. Folds with N-S to NNE-SSW orientated fold axis and related S3 cleavage. Brittle to brittle-ductile dextral strike-slip faults with WNW-ESE (dominant) to ENE-WSW (minor) orientation.

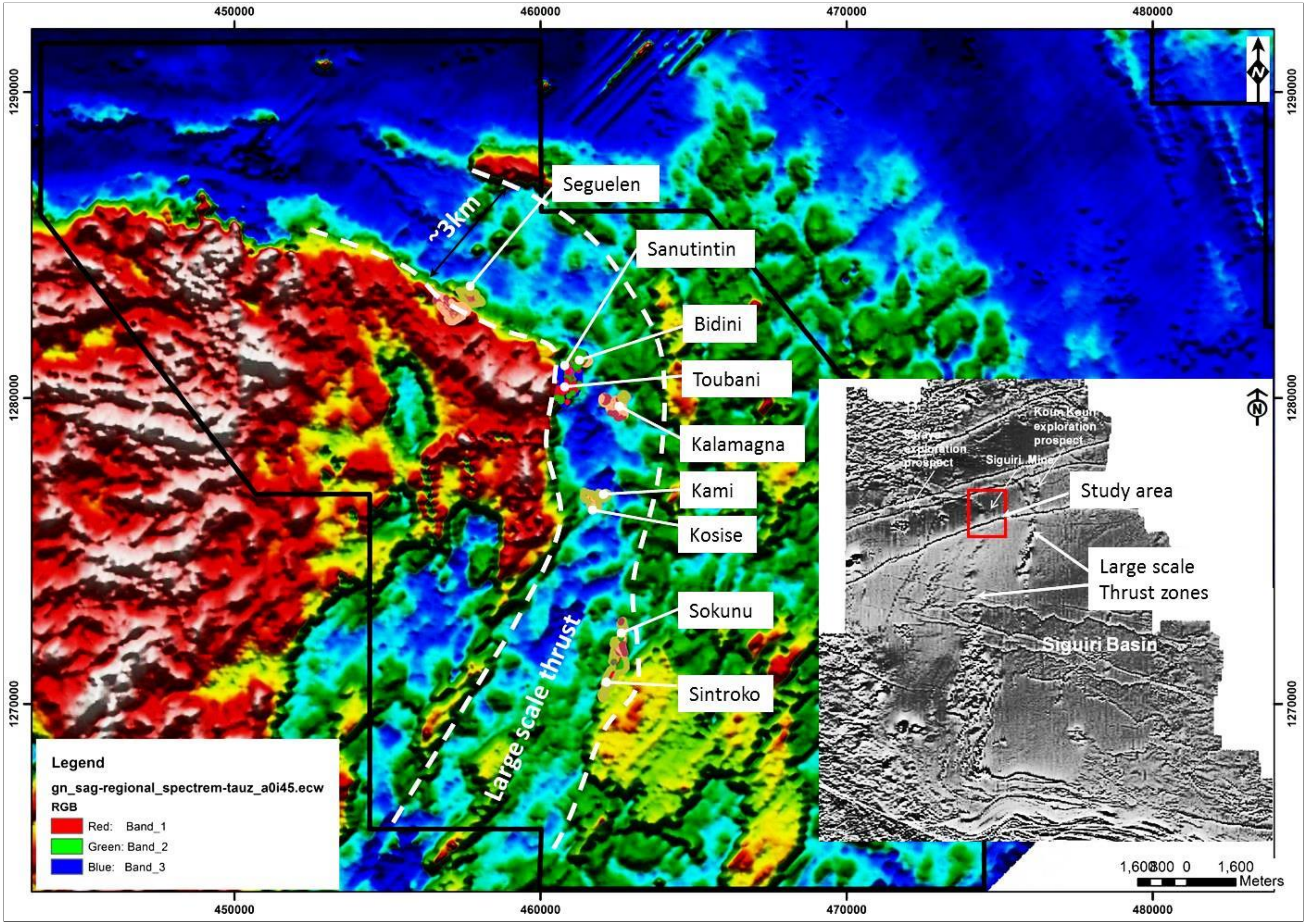


Figure 42.Electromagnetic image of Siguiri Gold Mine area. The thrust zone is outlined with white dashed line; all the open pits are almost aligned within this zone.The mine area coincides to the bending of the thrust (red square).

7.2. Quartz veins

The gold mineralisation at Seguelen is strongly **associated** to quartz veins typically to the steep dipping vein **set (dip ~80˚-86˚)**. These quartz veins are conjugated and cross-cut bedding set.

There is strong lithological control on the spatial distribution of quartz veins. In the Seguelen deposit, the Fatoya Formation, which is made up of greywacke and silstone, is more brittle and hosts a large portion of the quartz veins while the Kintinian Formation which is more shaly counts less quartz veins.

Bedding-parallel quartz vein set is barren and results from the early bedding activation deformation.

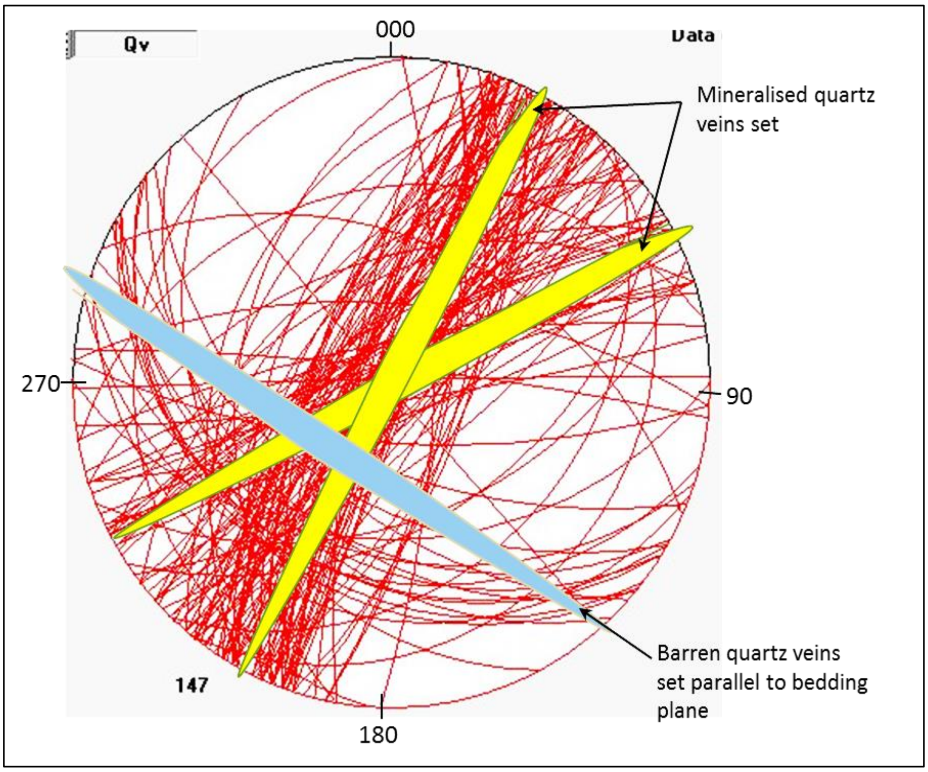


Figure 43 : Distribution of Seguelen quartz veins in distinct structural settings.

7.3. Hydrothermal alterations

Hydrothermal alterations are conspicuous throughout the mine. Some are pervasive such as chloritization, albitization, sideritization, carbonatization and potassic alterations.

The source of the mineralising hydrothermal fluid at Seguelen as well as the whole mine is unclear and needs further investigation as the mining activity is going deeper.

CHAPTER 8: CONCLUSIONS

The thick sediments of Siguiri basin form B1 package of lower Paleo Proterozoic Birimian. It is characterised by the interlayering of different rocks units, which was affected by the low-grade metamorphism and deep weathering. The succession of sediments is known as turbidites sequences. The normal grading at Seguelen is sometimes difficult to observe due to the strong alteration.

A large corridor of 12km long by 3km wide hosts the cluster of Siguiri gold mine open pits from the south to the north. This damaged zone is assigned to D1 and it is recognized as primary structures.

The D2 deformation is identified as secondary structures and hosts the bulk of disseminated auriferous mineralisation within Siguiri basin. Micro-folding of quartz veins and fractures with minor displacement in the pit are thought to be related the D2 and D3 deformations. Its structures strike NW-SE.

The alteration of hydrothermal fluids flow known as mineralized solution carrier is pervasive through the Siguiri gold mine. The extensional steep quartz veins, striking NE-SW direction and claystone, shale lithology control the entire gold mineralisation of the Seguelen gold deposit.

The model below shows both geological features controlling the mineralisation (ore shoot) at Seguelen mine (*Figure 44*).

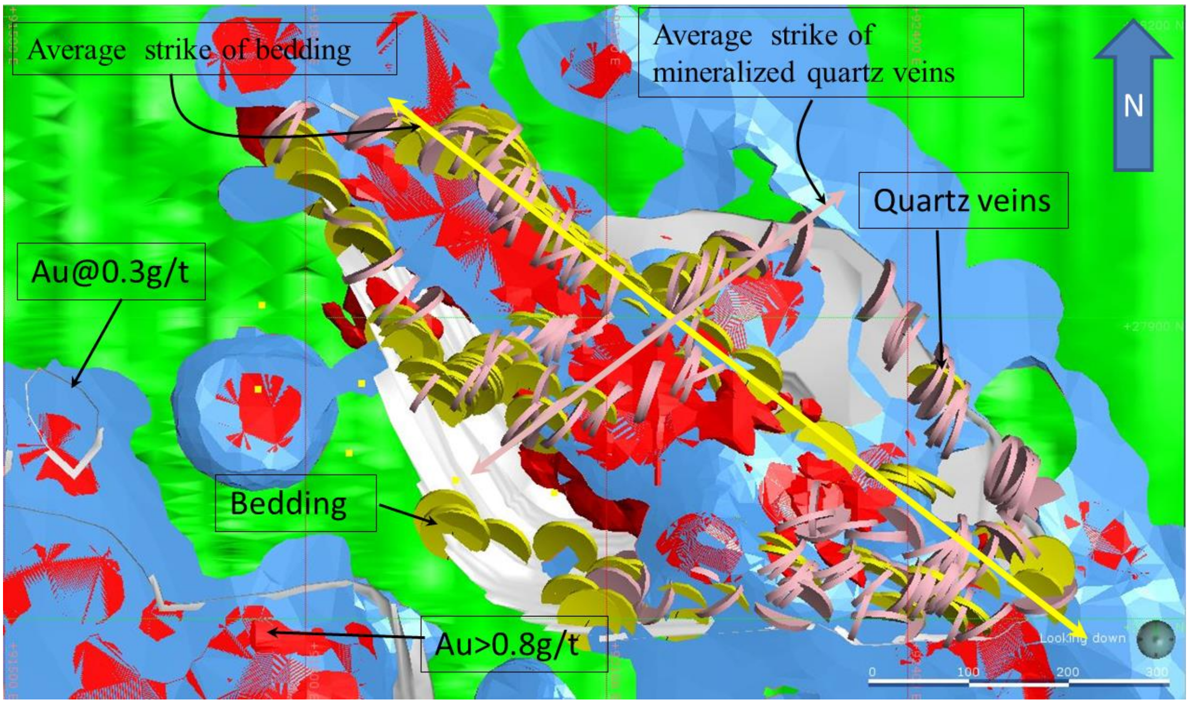


Figure 44: Seguelen mineralisation model in relation with major geological controls (adapted from Seguelen ore body model, Landao2014).

REFERENCES

Abouchami. (1990). *A major 2.1 Ga old event of mafic magmatism in West Africa: an early stage of crustal accretion. J. Geophys. Res. 95, 17605–17629.*

Allibone. (2002). *Structural controls on gold mineralization at the Ashanti gold deposit, Obuasi, Ghana.Society of Economic Geologists special Publication 9, p. 65–93.*

Amira. (2013). *West African Exploration Initiative,stage2.*

Bard,J.P. (1974). *Remarques à propos de l'érvolution géotectonique du craton ouest-africain en Cote-d'Ivoire.C.R. Acad. Sci., Sér. D, 278: 2405-2408.*

Bassot. (1966). *Etude géologique du sénégal oriental et de ses confins guinéo-maliens.Mémoires BRGM 40, 322.*

Beckinsale . (1980). *Discordant Rb–Sr and Pb–Pb whole rock isochron ages for the Archean basement of Sierra Leone.Precambrian Res.13,63-76.*

Bering,D. (1998). *Evaluation de l'Inventaire des Ressources Minérales de Guinée. Coopération Technique publique de Guinée—République Fédérale d'Allemagne. Projet 94.2025.8, BGR, Hannovre, p. 109.*

Bessoles. (1977). *Géologie de l'Afrique.Le craton Ouest Africain.Mém.BRGM.*

Blanchot A.,Carrive J.P.& Lajoinie P. (1975). *Bilan de nos connaissances sur la geologie et les ressources minieres.*

Bonhomme. (1962). *Contribution `a l'´etude géochronologique de la plate-forme de l'Ouest africain. Géologie et Minéralogie,vol. 5 thesis.* University of Clermont-Ferrand, Fr., p. 62.

Cahen. (1984). *Geochronology and Evolution of Africa.* Claredon Press,Oxford,P.512.

Camil,J. (1983). *Age libe´rien des quartzites a` magne´tite de la re´gion de Man (Coˆ te d'Ivoire) et leur place dans l'orogène libérien.* C.R. Acad. Sci. Paris 296,149–151.

Carlos Paranhos Jr. (2008,unpubl.). *State of Knowledge of the main geological controls of gold mineralisation.*

Deschamps,M. . (1986). *Diversité du magmatisme birrimien dans le craton ouest-africain (Burkina-Faso, Sénégal oriental, Mauritanie). Les Formations Birrimiennes en Afrique de l'Ouest.* CIFEG, Publication Occasionnelle, 10, 45–64.

Doumbia,S. (1998). *Petrogenesis of juvenile-type Birimian (paleoproterozoic) granitoids in Central Cote-d'Ivoire, West Africa: geochemestry and geochronology. Precambrian Res. 87, 33–63.*

Emmanuel,E. (2002). *Late Eburnean granitization and tectonics along the western and northwestern margin of the Archean Kenema-Man domain.* Orlean.

Feybesse J.L. (2006). *The Paleoproterozoic Ghanaian province:Geodynamic model and ore controls,including regional stress modeling.* Orleans,France.

Feybesse,J.L. (1999). *Tectonic controls and geometry of the hydrothermally altered and mineralized ore bodies of the Rank area E,Kenyase, Bosumkese, Yamfo trend, Teekyere west, and Subenso prospects. BRGM report 99/076, p. 18.*

Feybesse. (1990a,b). *West African gold deposits in their LowerProterozoic lithostructural setting.* Chron. Rech. Min. 497,.

Goujou,J. (1999). *Notice explicative de la Carte géologique de la Guinée à 1/200 000; Feuille no. 30, Macenta .Conakry (GIN): Ministère des Mines, de la Géologie et de l'Environnement. 22 p.*

Gouloubinow, M. (1950). *Note explicative de la carte géologique Bougouni-ouest (1/500 000). Carte grologique de I'AOF, Dakar.* Grande imprimerie Africaine, 28 pp.

Hammond,N.Q;Shimazaki,H. (1994). *Geology and geochemical aspects of ore formation at the Prestea mesothermal vein gold deposit in the Birimian system of Ghana. Int. Geol. Rev. 36,715–731.*

Junner. (1940a). *Geology of the Gold Coast and Western Togoland.Gold Coast Geol. Surv.* Accra Bull., 11, 40 pp.

Kesse,G.O. (1985). *Geotraverse of the Birimian Systems in southern Ghana. UNESCO Newslett. Bull. 4, 7–10.*

Kisters,A.Steyn,J. (2013). *Structural geology of Siguiri Mine.*

Kouamelan. (n.d.). *Geochronological evidence for reworking of Archean terrains during the Early Proterozoic (2.1 Ga) in the western Coˆ te d'Ivoire (Man Rise-West African Craton).* Precambrian Res. 86,77–199.

Lamotte,M.Routhier. (1943). *Monographie géologique du Mont Nimba.Contribution à l'étude du Birrimien d'A.O.F. Bull. Soc. géol. France 5 (XIII), 113–124.*

Ledru,P. (1991b). *Transcurrent tectonics and polycyclic evolution in the Lower Proterozoic of Senegal-MalL Precambrian Res.,50: 337-354.*

Ledru,P.,Milési,J. (1988). *Géologie et gitologie de l'or des series birrimiennes du Ghana. BRGM Rep., 88 AFO 122 GEO, 36 pp.*

Ledru. (1989b;1981b). *West African gold deposits in their LowerProterozoic lithostructural setting.* Chron. Rech. Min. 497,.

Lemoine,S. (1988). *Évolution géologique de la région de Dabakala (NE de la Côte d'Ivoire) au Protérozoïque Inférieur. Possibilité d'extension au reste de la Côte d'Ivoire et au Burkina Faso: similitudes et différences: les linéaments grenville-Ferkessédougou.* Clermont-Ferrand, France, p. 389.

Lompo, M. (1991). *Etude structurale et géologique des séries birimiennes de la régionde Kwademen, Burkina Faso, Afrique de l'Ouest.Evolution et contrôle structuraldes minéralisations sulfurées et aurifères pendant l'Eburnéen.* France, p. 200.

Milési,J. (1989). *Tectonique transcurrente et évolution polycyclique dans le Birrimien,Protérozoïque Inférieur du Sénégal-Mali. Comptes Rendus de l'Académie des Sciences, Paris 308, 117–122.*

Miléssi, J. F. (1994). *The Archaean/Proterozoic contact zone in West Africa: a mountain belt decollement thrusting and folding on a continental marging related to 2.1 Ga convergence of archean cratons.* Precambrian Research 69, 199–227.

Miller J.,Fougerouse,D. (2012). *Applied structural Geology in Mineral Exploration and Mining.*

Mumin,A.H. (1995). *Evolution of gold mineralization in the Ashanti gold belt, Ghana: evidence from carbonate mineral chemistry.*

Oliver,N.H.S. (1996). Review and classification of structurals controls on fluid flow during regional metamorphism.Journal of Metamorphic Geology.

Ouedraogo, M. (1986). *Mise en évidence des relations entre schistosités et plissements dans la ceinture volcanique birrimienne de Yako-Batié (Burkina-Faso).C.R. Acad. Sci. Paris, S6r. II, 303 (19): 1713-1718.* Paris.

ROBB,L. (2005). *Ore-Forming Processes.*

Sibson,R.H. (1975). *Seismic pumping:a hydrothermal fluid transport mechanism.Journal of Geological Society.* London.

Tagini,B. (1971). *Esquisse structurale de la Cote-d'Ivoire. Essai de géotectonique régionale.Thesis of University of Lausanne.* Lausanne.

Tahon,A. (1997). *Geology of the Birrimian, Lower Proterozoic of West Africa,Volume1.*

Thiéblemont. (2002). *Late Eburnean granitization and tectonics along the western and northwestern margin of the Archean Kénéma-Man domain (Guinea, West African Craton). Precambrian Research 117, 57–84.*

Watts,M. (2010,unpubl.). *An Introduction to the geology of Siguiri Gold Mine and the Economic potential of the fresh rock in Blok1.* Siguiri.

Windley. (1984). *The Archaean-Proterozoic boundary.Tectonophysics, 105: 43-53.*

Wulf,K. (2013,unpubl.). *Silakoro report.*