University of the Witwatersrand

School of Geosciences Geol 4000

Honours Project

Ore genesis of the Essakane, Falagountou and Sokadie Gold deposits: Oudalan-Gorouol Greenstone Belt, Burkina Faso, West African Craton

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Abstract

The gold-hosting sedimentary sequences of the Oudalan-Gorouol greenstone belt underwent four events to give rise to the gold mineralisation. The alteration that resulted during the metamorphism of the rocks is linked to the gold mineralisation. Subsequent to deposition of sediments, regional metamorphism during the Eburnean orogeny gave rise to greenschist facies metamorphic assemblages and two deformation phases. The first deformation phase resulted in development of NW-NNW trending folds (F1), NW-NNW trending foliation (S1) and extensional-conjugate vein sets (V1), interpreted as Tangaean (D1) structures. The second deformation phase resulted in development of NE-NNE trending faults, stockwork veins (V2) and NE trending foliation (S2) associated with dextral shear zones, interpreted as Eburnean (D2) structures. The sequences underwent contact metamorphism to hornblende-hornfels facies during the intrusion of granitoid plutons (syn-Eburnean). Retrograde processes from the cooling of the granitoids resulted in the remobilisation of fluids in the supracrustal rocks, which travelled via shears and fracture zones resulting in alteration of the wallrock including sericitisation, silicification, carbonatisation and chloritisation (with sulphidation). The gold mineralisation occurs in the chloritisation stage of the alteration and is associated with the mineral arsenopyrite. Precipitation of sulphides in fractures lead to quartz-carbonate stockwork vein hosted gold mineralisation. The mineralisation is interpreted to be post Tangaean (D1) and synchronous to the intrusion of granitoids during the Eburnean orogeny (D2). The mineralisation is defined as orogenic gold under the subdivision of thermal-aureole gold.

Chapter 1

1.1 Introduction

The Oudalan-Gorouol greenstone belt is located in north-eastern Burkina Faso (Fig. 1.1) in the West African craton, and extends into the neighbouring Niger. The greenstone belt is characterised by meta-volcanic and meta-sedimentary rocks, and intruded by various igneous rocks (Tshibubudze et al., 2009). It hosts various Au deposits, notably the Essakane goldfield, but smaller artisanal sites can be found throughout the belt (Tshibubudze et al., 2009).

The ore genesis of Essakane, Falagountou and Sokadie areas has not been defined. Researchers have identified that quartz-vein hosted gold in the Birimian of West African craton can be attributed to deformation in the Eburnean Orogeny (Hastings, 1982; Milési et al., 1992; Dzigbodi-Adjimah, 1993; Béziat et al., 2008). Groves et al. (1998) and Goldfarb et al. (2000) classified gold in West Africa as orogenic gold and gold in Burkina Faso has also been classified as orogenic gold (Béziat et al., 2008). Taner (2004) recognised a relationship between the gold mineralisation and intrusions in the Falagountou and Essakane deposits. The gold in these deposits can be classified as mesothermal lode gold, thermal-aureole gold or intrusion-related gold.

1.2 Overview of the Study Area

The study area is located in the Oudalan-Gorouol greenstone belt ~250km to the north-east of Ouagadougou, Burkina Faso. Burkina Faso is a landlocked country in West Africa which covers 274 300 square kilometres in area (Bierschenk, 1968), and shares its borders with Mali, Togo, Benin, Ghana, Niger and Côte d'Ivoire. The official language is French, with Mooré and Dioula. The religion dominantly practised is Islam with >50% of the population being Muslim, the remaining religions are Christianity and indigenous African religions.

Burkina Faso is defined by low hills and alluvial plains and is covered by an extensive laterite plateau located at the southern edge of the Sahara Desert, with sand dunes (desert) to the north (Bierschenk, 1968). Central Burkina Faso is a savanna plateau and 198-305 metres above sea level. The Sahelian climate characterises this area, where there is eight to nine months of dry season and a rainy season from June to September. The average daily temperature has been recorded as 32°C and the average annual rainfall is less than 25 centimetres in the north and north-east. The hot desert winds (harmattan) add to the dryness of the region.

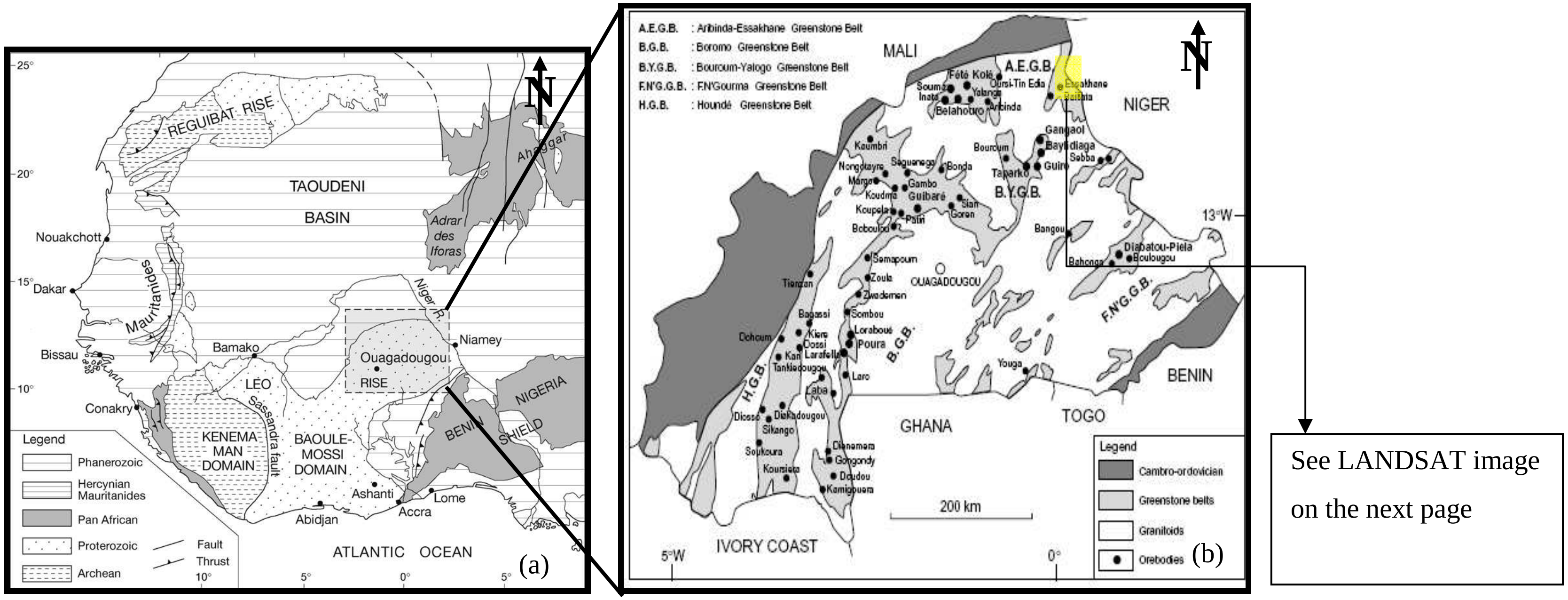


Figure 1.1: Simplified geological map of (a) the West African Craton and (b) the greenstone belts of Burkina Faso after Béziat et al. (2008)

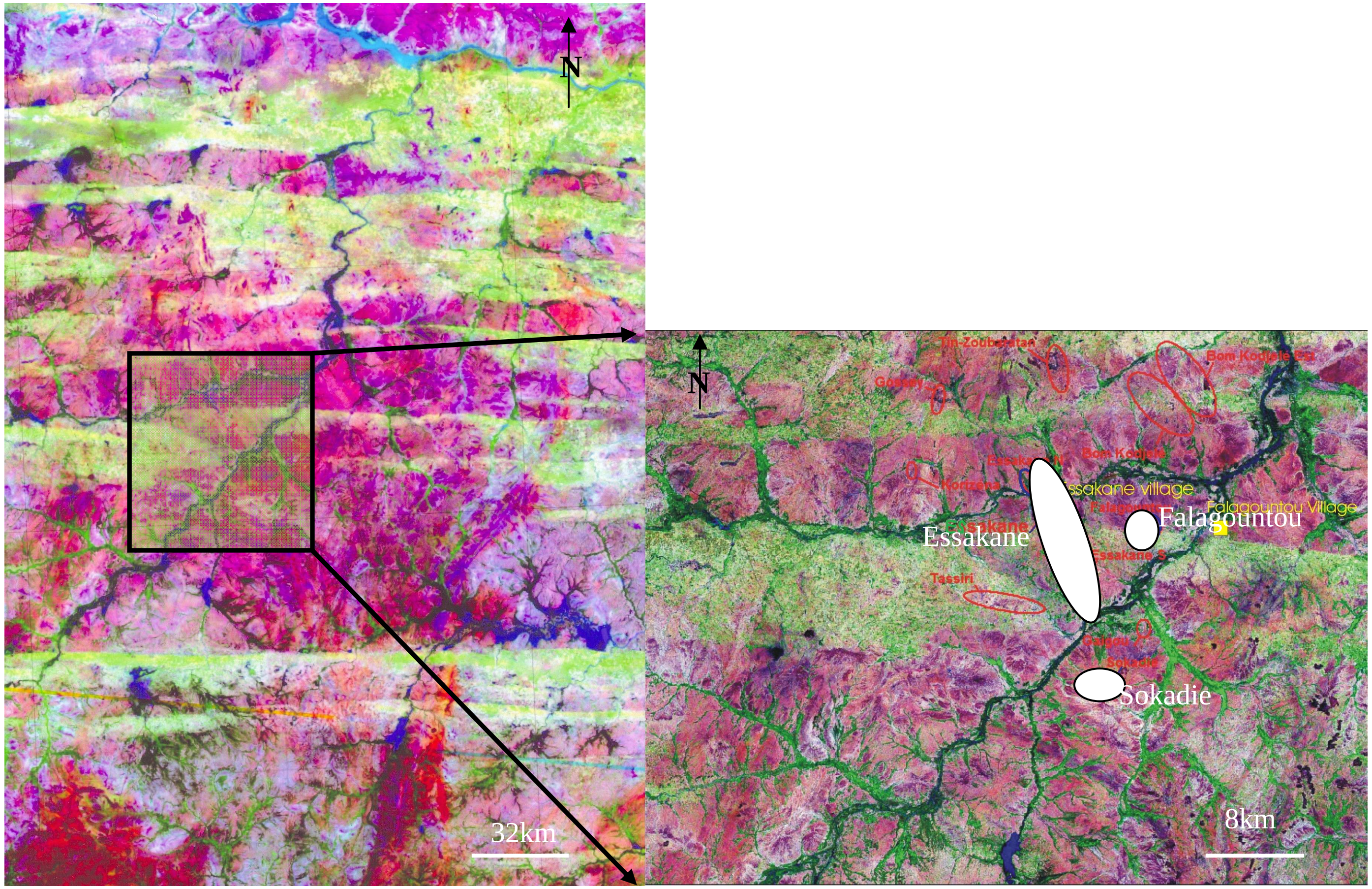


Figure 1.2: LANDSAT image of the Oudalan-Gorouol Greenstone belt in Burkina Faso and the locations of the deposits

1.3 Aims and Objectives of the Project

The main aim of the project is to characterise the metallogenic system for each deposit through petrographic study and development of a paragenetic sequence to constrain an ore genesis model (mineralogy, alteration, microstructure, host rocks, etc.) for exploration for gold throughout the greenstone belt.

Objectives:

- to select 15 samples and do petrography, mineralogy and ore petrology of the study areas
- to determine the genesis of the ore in the greenstone belt

Chapter 2: Geology

2.1 Regional Geology

The West African craton (WAC) is ~ 4.5 million km^2 and comprises two shields, the Reguibat Rise in the north and the Leo-Man Rise to the south (Milési et al., 1992; Villeneuve and Cornée, 1994; Attoh and Ekwueme, 1997; Potrel et al., 1998). The Taoudeni basin, situated in the central part of the craton, separates the two shields and is Neo-Proterozoic to Devonian in age (Dioh et al., 2006). The Leo-Man Rise in the south comprises two domains: the Archaean Kenéma-Man domain and the Palaeoproterozoic Baoulé-Mossi domain. The Baoulé-Mossi domain is host to Birimian sequences, and these include meta-sedimentary and meta-volcanic rocks (Milési et al., 1991; Dzigbodi-Adjimah, 1993). Based on previous interpretations by Milési et al. (1991), Debat et al. (2003), Dioh et al. (2006) and Béziat et al. (2008), the Birimian terrains consists of sedimentary basins, and linear to arcuate volcanic belts that correspond to the period of accretion during the Eburnean orogeny.

The north-eastern Burkina Faso consists of the Palaeoproterozoic metasedimentary and metavolcanic Birimian sequences (2184–2135 Ma) (Davis et al., 1994). The sequences are divided into the upper and lower Birimian. These are unconformably overlain by the Tarkwa Group (2194-2132 Ma), first described in the Birim River in Ghana and are believed to be derivatives of the upper Birimian (Hastings, 1982; Milési et al., 1992; Dzigbodi-Adjimah, 1993; Bossiére et al., 1996; Davis et al., 1994). The sequences were deformed during Eburnean orogeny (2.2-2.0 Ga) (Hastings, 1982; Liégeois et al., 1991). The area was also intruded by a series of syn- to post orogenic granitoids, which constitute ~70% of the Birimian group (Naba et al., 2004).

The Birimian can be divided into the upper and lower Birimian (Junner, 1940). The upper Birimian consists of a detrital sedimentary pile i.e. volcaniclastics, turbidites, shale and carbonate units and these are interbedded with calc-alkaline volcanics (Leube et al., 1990; Hirdes et al., 1996; Roddaz et al., 2007). The lower Birimian consists of a thick sequence of pillowed tholeiitic basalts, dolerites and gabbros; interlayered with the basalts are immature sediments and carbonates (Leube et al., 1990; Roddaz et al., 2007). There is a controversy on the stratigraphic position of the Birimian rocks, whether the B1 is younger than the B2 or vice-versa (Hirdes et al. 1996). The Birimian in Burkina Faso was deposited within an active continental margin/ marginal marine setting in which the detritus was derived from an adjacent volcanic arc (Hein et al., 2004; Roddaz et al., 2007).

The Birimian sequences were intruded by syn- to post orogenic, alkaline to calc-alkaline granitoids during the Eburnean Orogeny (Leube et al., 1990; Naba et al., 2004). The emplacement resulted in ~ 70% of the Birimian formation being intruded by granitoids. The granitoids range from granodiorite-tonalite-trondjemite (TTG) suite to peraluninous granite plutons; U-Pb zircon dating of the granitoids put the age of emplacement at 2190-2108 Ma (Hirdes et al., 1996; Béziat et al., 2000; Naba et al., 2004; Hein (in press)). These granitoids are referred to as the Eburnean granitoids (Pons et al., 1995; Naba et al., 2004). Naba et al. (2004) described the granitoids as circular to elliptical, isolated to nested coalescent bodies and are aligned or more/less interlocked. The TTG suite contact metamorphosed the Birimian sequences (Hein, et al., 2004; Naba et al., 2004).

The rocks were metamorphosed to lower greenschist facies during the Eburnean orogeny which is characterised by the development of the mineral assemblage of prehnite, chlorite, actinolite, albite in mafic rocks, and muscovite, albite and quartz in the sedimentary sequences (Leube et al., 1990; Dzigbodi-Adjmah, 1992; Debat et al., 2003; Naba et al., 2004; Béziat et al., 2000). In the contact aureole of the granitoids, the metamorphic grade is low- to medium grade amphibolite facies, which is characterised by biotite, muscovite and quartz (Leube et al., 1990; Naba et al., 2004, Tunks et al., 2004). The Palaeoproterozoic Birimian sequences in NE Burkina Faso are also crosscut by late WNW-trending dolerite dykes, which are younger in age than the granitoids (Hein, 2009; Tshibubudze et al., 2009).

The Birimian sequences are unconformably overlain by the Tarkwa Group, which was first described in Ghana. Tshibubudze et al. (2009), refutes the notion that the conglomerate units in the Birimian of Burkina Faso are Tarkwaian.

North-eastern Burkina Faso is characterised by three tectonic events; D1, D2 and D3 termed the Tangaean event, Eburnean Orogeny and the Wabo-Tampelse event, respectfully (Hein, 2009; Tshibubudze et al., 2009). The Tangaean event resulted in the development of a NW-NNW trending fold-thrust belt ca. 2171-2130Ma (Hein, 2009). The Oudalan-Gorouol greenstone belt was intersected by NE-trending shear zones, related to deformation during the Eburnean orogeny (Tshibubudze et al., 2009; Hein, 2009). The deformation D2 is characterised by the development of NNE-NE trending mylonite and shear zone, F2 folds and a penetrative schistocity (S-C2 to S2), which crosscut the D1 structures (Hein, 2009; Tshibubudze et al., 2009). The deformation D3 is not defined in the Oudalan-Gorouol greenstone belt, but is well developed in the Goren greenstone belt and post-dates the Eburnean orogeny (Hein et al., 2004; Hein, 2009).

The Palaeoproterozoic Birimian sequences were sheared by a first-order crustal scale structure, the Markoye Shear Zone, which marks the western boundary of the Oudalan-Gorouol greenstone belt

(Tshibubudze et al., 2009). This is a NE-trending zone characterised by large scale faulting, shearing and mylonite zone (Tshibubudze et al., 2009). The Markoye Shear Zone underwent two phases of reactivation with two deformation events i.e., D1 and D2, occurring concurrently to that. The D1 deformation event as previously discussed resulted in the development of folds that trend towards the NW-NNW during the dextral reverse displacement of the Markoye Shear Zone. During the D2 deformation event, the Markoye Shear Zone underwent SE-NW crustal shortening and sinistral-reverse displacement (Tshibubudze et al., 2009).

2.2 Local Geology of the Study Area

The three areas that have been designated for this project are located in the Oudalan-Gorouol greenstone belt. Two of the three sites i.e. Falagountou and Sokadie are still artisanal mining sites and Essakane is a developing mine. Essakane is the main deposit and is 11km×3km in dimension, with Falagountou and Sokadie located to the East and south of the Essakane metasedimentary belt, respectively (Kerr(b), 2004).

The dominant stratigraphic sequences that have been identified in the Oudalan-Gorouol greenstone belt are a volcaniclastic greywacke sequence and an interbedded conglomerate-greywacke-siltstone-shale sequence, which have been contact metamorphosed to hornblende-hornfels facies during the emplacement of igneous bodies (Tshibubudze et al., 2009). The environment of deposition is interpreted to be a shallow marine continental shelf (Tshibubudze et al., 2009).

The supracrustal rocks of the Oudalan-Gorouol greenstone belt have experienced two deformation events that resulted in the formation of shears, folds, mylonite zones and regional metamorphism; contact metamorphism resulted from the dolerite dykes intruding the area and the emplacement of syn- and post-orogenic plutons (Tshibubudze et al., 2009).

The Essakane deposit is described as quartz-carbonate hosted sulphide stockwork, with arsenopyrite-pyrite gold mineralisation (Kerr (b), 2004; Tshibubudze et al., 2009), which formed during the D2 deformation event (Tshibubudze et al., 2009). The Sokadie deposit is hosted in a shear zone, and it is situated proximally to the Dori batholith (Kerr (a), 2004). The mineralisation in the Falagountou deposit has been interpreted to be a stockwork of veinlets of quartz±carbonate-sulphide (Kerr (c), 2004). The veinlets are hosted in the metasedimentary rocks together with the intrusive rocks found in the area (Kerr (c), 2004).

2.3 Gold Metallogeny in West Africa

Gold deposits in West Africa have been classified as orogenic gold deposits (Goldfarb et al., 2001; Groves et al., 1998). The gold forming stage of the Palaeoproterozoic is interpreted as being the third global episode of orogenic gold-vein formation, where greenstone-sedimentary sequences became important hosts for gold (Goldfarb et al., 2001). In orogenic gold deposits, the formation of the ores is attributed to the compressional to transpressional deformation processes that occur during the convergence of plate margins in accretionary and collisional orogens (Groves et al., 1998). The orogenic deposits can further be classified as syn-orogenic and post-orogenic, the former describing ore-forming fluids that were generated and set in motion by thermal processes at depth (Groves et al., 1998); and the latter considers the fact that the ore hosting rocks are undergoing uplift and cooling (Groves et al., 1998). These gold deposits are characterised quartz-vein systems, with mainly Fe-sulphides and carbonate minerals (Milési et al., 1992; Groves, 1998; Béziat et al., 2008), the gangue minerals associated with the greenschist facies host rocks include albite, fuchsite, chlorite, schheelite and tourmaline (Groves et al., 1998). These orogenic gold deposits are further divided into zones based on their temperature and depth, epizonal deposits (<6km at 150°C-300°C), mesozonal deposits (6-12k at 300°C-475°C), hypozonal deposits (>12km at temperatures exceeding 475°C).

Gold mineralisation in the Birimian of the West African craton has been associated with the Eburnean orogeny (Hastings, 1982; Milési et al., 1992; Dzigbodi-Adjimah, 1993). Dzigbodi-Adjimah, (1993) distinguished two types of gold-bearing orebodies; the quartz vein type (QVT), where the gold occurs with carbonate vein-filling along fractures in the quartz vein and the disseminated sulphide type (DST), where the gold occurs in sheared metavolcanic rocks. These two types of gold-bearing orebodies are characterised by sulphides such as pyrite, arsenopyrite, sphalerite, chalcopyrite, aurostibite, bornite, bournonite, tetrahedrite, buolangerite, jamesonite with galena occurring as a minor phase (Dzigbodi-Adjimah, 1993).

In agreement with the classification of Groves et al., (1998), the gold deposits in Burkina Faso have been classified as orogenic-type gold deposits (Béziat et al., 2008). Two types of gold mineralisation were identified, which are similar to the type of mineralisation classified by Leube et al.

(1990); quartz-vein hosted gold (QVT) which is associated with pyrite or tourmaline and disseminated gold (DST) which is commonly associated with sulphides (Fig. 2.1) (Béziat et al., 2008) .

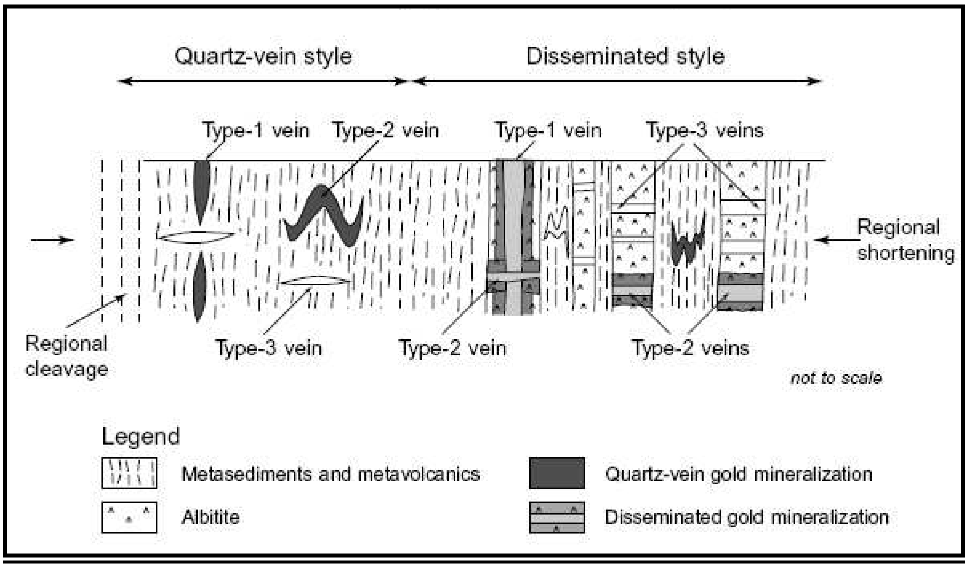


Figure 2.1: A sketch of the two gold mineralisation styles in Burkina Faso, after Béziat et al., 2008.

Chapter 3: Methodology

3.1 Data Collection

The project entailed petrographic work and field study of the deposits. The deposits were mapped over the June/July break, through the sponsorship of IAMGOLD Corporation. The field visit spanned 22 days and a car was provided for transportation to and from the deposit sites.

A LANDSAT image of a portion of north-east Burkina Faso was used to obtain coordinates of the deposit and thus delineate the deposits. The equipment used for the mapping was graph paper, a northern hemisphere compass clinometer, a geographical positioning system (GPS), a hand lens, a digital camera and a geological hammer. The UTM (WGS 84) grid coordinates were drawn in on the graph paper using the LANDSAT image. The deposits were each visited on separate days and assigned three days to complete mapping.

Before the actual mapping commenced, a reconnaissance of each deposit was conducted. From each deposit north-south traverses were made. From each outcrop in the area the lithologies were identified, bedding, structural features and veins were recorded. In areas where there was no significant outcrop subcrop mapping from orpaillage diggings was used to identify the lithologies, but no structural data was recorded. No samples were collected from the field.

Core logging was the other aspect of the field visit. The petrographic component of the project was done at the University of the Witwatersrand laboratory. The samples were documented by Professor Kim Hein and sent to the SGS laboratories in Booysens, Johannesburg to create polished thin sections. The petrography work involved the use of both transmitted light and reflected light components of a microscope, to identify sulphides and minerals in the sections. Photographs were taken of thin sections of interest.

3.2 Data Documentation

The collected data (structural, lithological and petrographic) was documented on a Microsoft® Excel Spreadsheet (Appendix B) for convenience. The structural data was interpreted on the program, GEOrient® (Holcombe, 2008).

Chapter 4: Lithologies and Structure

4.1 Lithologies

4.1.1 Preamble

The lithologies for the three deposits predominantly consist of volcaniclastic-sedimentary and sedimentary sequences, which have been intruded by numerous plutonic rocks. The dominant cover over the sediments is laterite and sand dunes. The alteration noted in some of the sequences is oxidation, kaolinisation and sericitisation. Field data was collected from 47 station points (see Appendix for station point spreadsheet).

4.1.2 Falagountou

The Falagountou orpaillage is located to the East of the Essakane main deposit. The pit is ~100×200m in dimension (Fig. 4.1). It is covered by an extensive laterite profile and there is abundant sand dune cover south of the pit. The laterite and sand dunes made mapping of the area challenging; subcrop mapping from the artisanal mining workings was used to determine the lithologies. The artisanal miners follow a series of quartz veins which crosscut the lithologies. The veins include extensional veins, buck quartz veins and stockwork veins.

In the Falagountou artisanal mine area lithologies included: metasiltstone/shale, metagreywacke/sandstone, and gabbro dyke inferred from subcrop (boulders) in the mine.

Metasiltstone-shale

The pit is dominated by metasiltstone/shale. The unit is foliated, has sandstone partings and it is oxidised and kaolinised. Malachite staining is common in this unit, indicating the presence of copper sulphide. This unit is cross-cut by stockwork, sheeted and extensional quartz-carbonate veins. The extensional veins (V1) trend approximately WNW. The quartz-carbonate-chlorite stockwork veins (V2) displace the extensional veins (V1), and this was followed by the development of a third generation quartz veins (V3).

Metagreywacke-sandstone

A subcrop of foliated metagreywacke-sandstone was identified on the margin of the pit. The metagreywacke-sandstone outcrops were located to the north of the pit and are oxidised.

Gabbro and Diorite

The Falagountou deposit is crosscut by gabbro dykes composed of pyroxene, plagioclase and arsenopyrite; and diorite dykes composed of orthoclase, plagioclase, quartz, hornblende and biotite. In diamond drill core, the diorites occur at a shallow depth and the gabbro occurs towards the end of hole. The intrusives are coarse-grained and are cross-cut by extensional quartz-carbonate veins (V1). Chloritisation is the most common type of alteration developed in the intrusives.

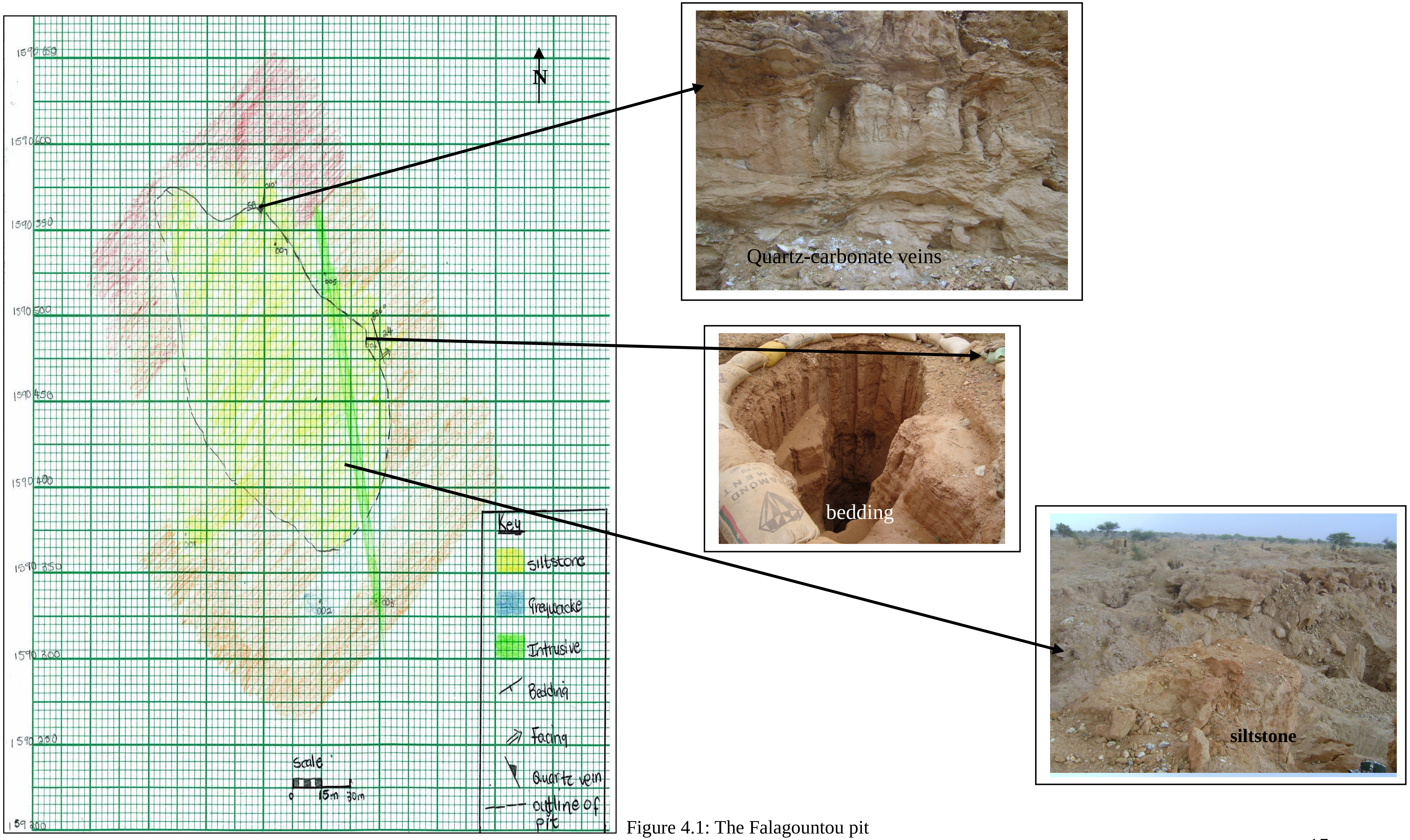


Figure 4.1: The Falagountou pit

4.1.3 Essakane

The Essakane pit (Fig. 4.2) is located in the Essakane main zone. The deposit is north-west trending. The deposit is hosted in a volcaniclastic-sedimentary sequence covered by laterite and saprolite profiles.

The Essakane deposit is intersected by dolerite dykes and gabbroic sills. These intrusive rocks are composed of pyroxene and feldspar. The sills have coarser grained euhedral, feldspar crystals. Most of these intrusives occur towards the end of hole in diamond drilling core. The dolerite dykes are trending at 334°.

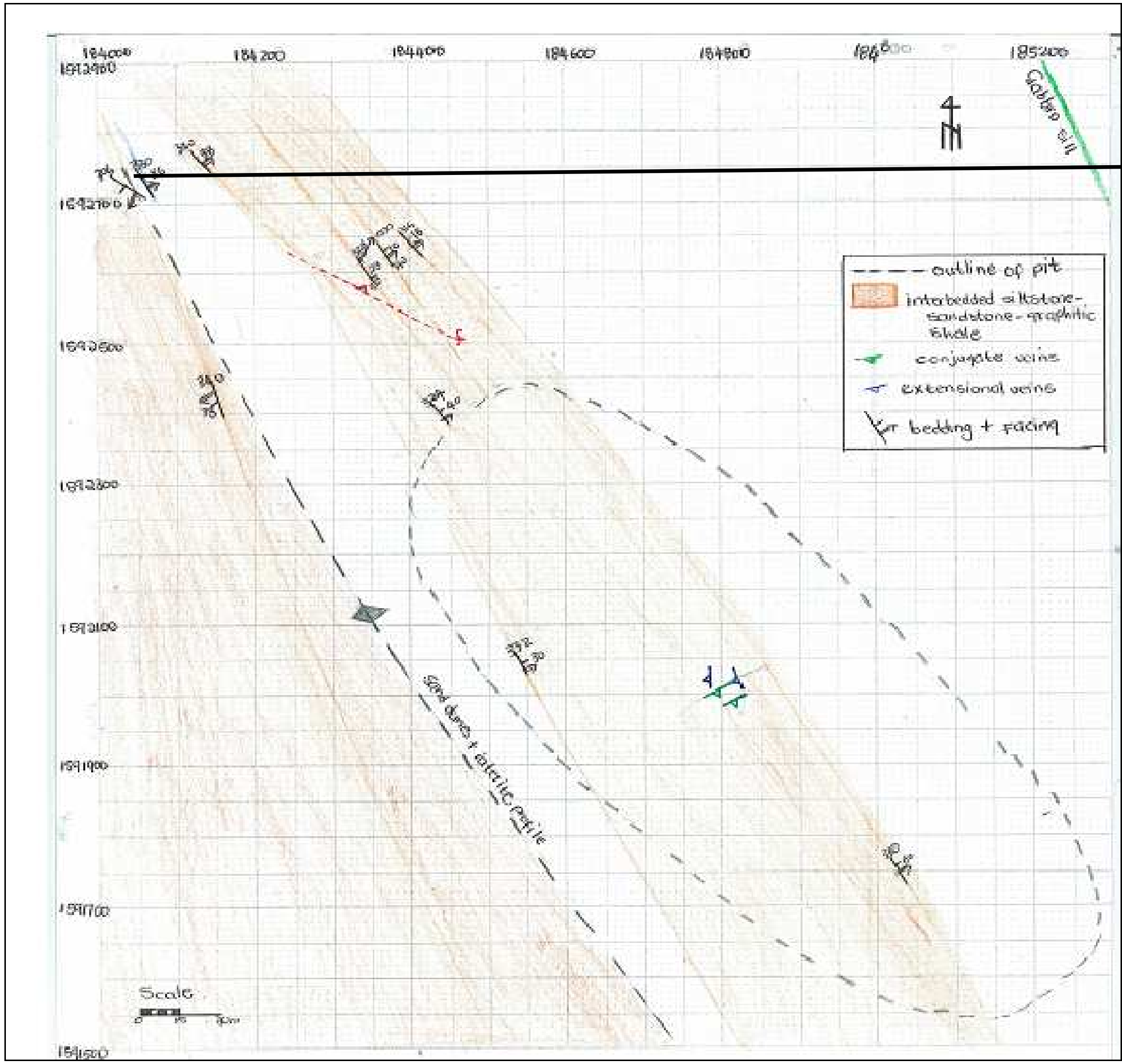
The sedimentary sequences include metavolcaniclastic greywacke, quartzite and interbedded sandstone, siltstone, and shale.

Quartzite

The quartzite is oxidised. The sulphides are weathering out, indicated by red oxidised pyrite spots on the surface. The foliation is developed parallel to the bedding. The quartzite has shale laminations and is cross-cut by quartz-carbonate veins, with no sulphides concentrated in the veins.

Interbedded sandstone-siltstone-graphitic shale

This sequence of rocks is kaolinised. The sandstone and laminated siltstone/shale are interbedded in a fining upward sequence. Facing is to the north-east, as determined by graded beds, scour and fill. Metavolcaniclastic greywacke also occurs at the base of the interbedded sandstone-siltstone-graphitic shale unit. Pyrite and arsenopyrite mineralisation occurs in these units. The development of chlorite on the siltstone was noted on the drill core (ERC1196D-136m). The sequences that occur lower in the stratigraphy are brecciated (identified in the diamond drilling core). The unit of rocks is cross-cut by north-east trending quartz-carbonate, quartz and quartz-chlorite extensional veins (V1); NW trending conjugate veins ($V1'$) and stockwork-sheeted veins (V2).



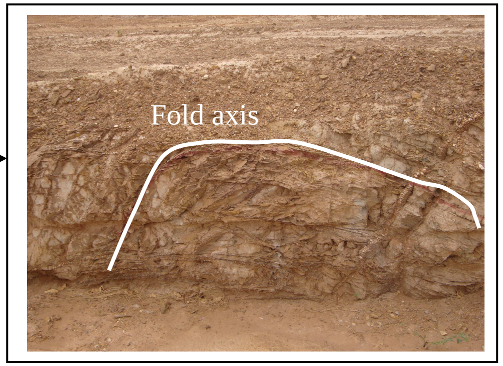


Figure 4.2: The Essakane Pit + Essakane anticline

4.1.3 Sokadie

The Sokadie shear zone (Fig. 4.3) is located south of the Essakane main deposit. The units include schistose greywacke, sandstone, siltstone, quartzite (which were identified on outcrop), and greenschists (mainly in the drill core). The artisanal mine workings are located south of the shear zone. The units are cross-cut by folded and boudinaged quartz-carbonate veins. The structural features and kinematics indicate that Sokadie is shear-hosted.

Metagreywacke

The metagreywacke unit occurs to the north of the shear zone. It has a pockmarked surface, resulting from the weathering out of the mineral pyrite. The rocks are oriented towards the north-east. The outcrop of the metagreywacke has randomly oriented fractures. The unit is foliated and it is cross-cut by randomly oriented quartz-carbonate veins. The unit is chloritised; hence it is termed a chloritised metavolcaniclastic greywacke.

Quartzite

The quartzite unit oxidised with two generations of foliation and penetrative crenulation cleavage is developed throughout the rock. The unit is cross-cut by quartz-carbonate veins.

Metasandstone-siltstone

The metasandstone-siltstone units are folded; they have a well developed foliation and a schistose texture. These units are highly altered, with chloritisation and sericitic alteration developed; and they are weathered. The units are brecciated (noted in the drill core) and occur mainly higher in the stratigraphy. The quartz veins are not frequent in these higher units.

4.1.5 Laterite Profile

This provides the cover for large amounts of the deposits visited. It is an iron-rich profile and forms in tropical to subtropical conditions, mainly on the surface of rocks due to their longer exposure to the atmosphere and the hydrosphere (Dequincey et al., 2006). These rocks that are covered by the laterite profile are hard, ferruginous and cemented (Bierschenk, 1968).

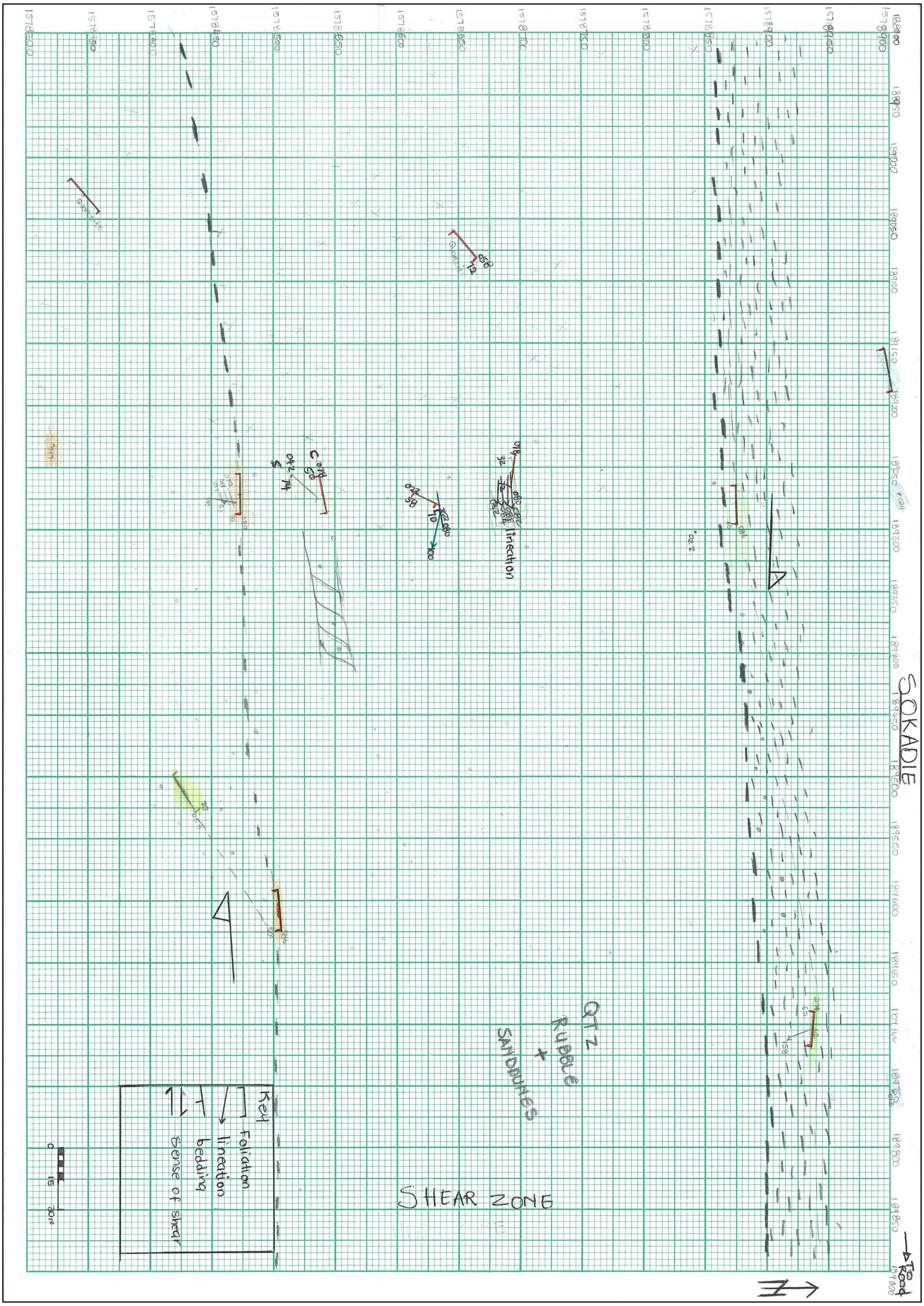


Figure 4.3: The Sokadie Shear zone

4.2 Structural Features

4.2.1 Essakane

The deformation event, D1, in the Essakane deposit is recognised by the development of a NNW-NW trending anticline (F1). The anticline is open, asymmetrical and verges to the SW (Fig. 4.4; 4.5). Due to poor exposure few measurements were obtained for the south-west limb, but that limited data suggests the limb trends NW and dips steeply SW. The north-east dipping limb is shown on the equal area stereographic projection in Fig. 4.4, with a calculated mean of 325°/38°E. The facing of the limbs was determined using graded bedding and scour and fill and indicate that the fold is an inclined anticline. A palaeostress (δ1) applied from a north-eastern direction produced the asymmetry of the fold (Fig. 4.5).

The rock units are cross-cut by quartz-carbonate veins which include extensional veins, conjugate veins, bedding-parallel veins and stockwork veins. An equal area stereographic projection of conjugate and extensional veins is presented in Fig. 4.6 (a) and with photograph from station point N1591992; E0184823. The calculated mean for the extensional veins and conjugate veins in Essakane have been tentatively determined as 061°/82°S and 164°/79°W, respectively. Based on the data the conjugate veins are oriented parallel to the fold axis and extensional veins are oriented perpendicular to the fold axis, with the palaeostress was tentatively interpreted to be in NE direction.

The deformation event, D2, resulted in the development of a NE- trending, normal-slip fault with a mean direction of 300°/58° during the flexural-slip folding of the bedding and caused brecciation of the footwall sequence (Fig. 4.8).

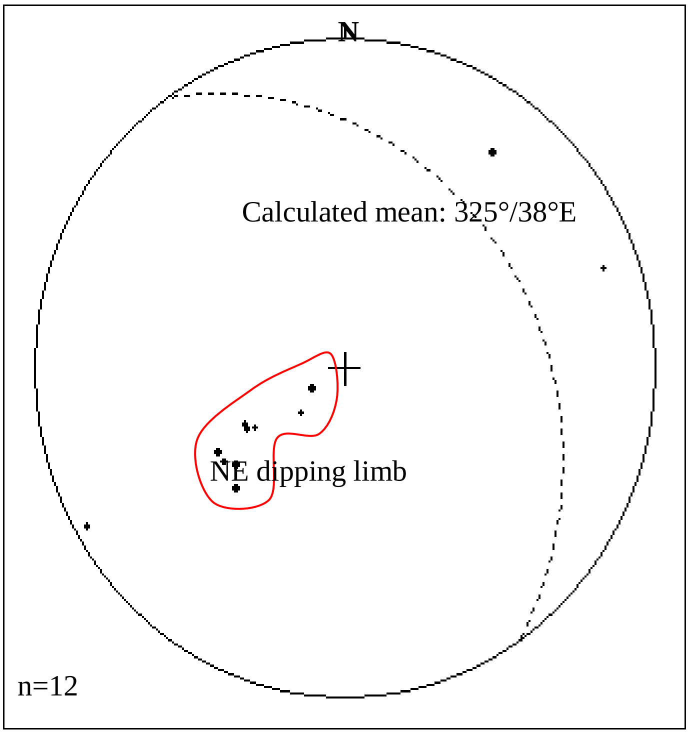


Figure 4.4: Equal area stereographic projection of the Essakane bedding of NE dipping limb

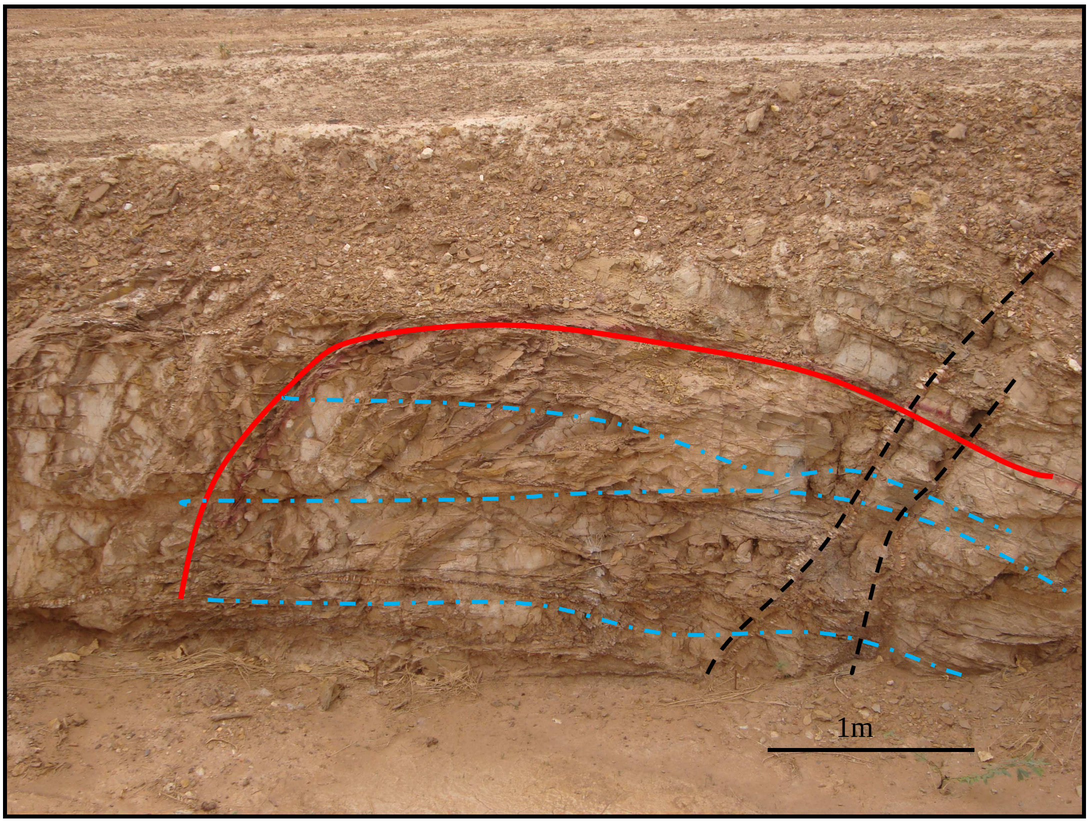


Figure 4.5: Fold axis of the NW-trending anticline hosted in siltstone in the Essakane exploration trench, crosscut by extensional veins (black stiples) and sheeted veins (black stiples).

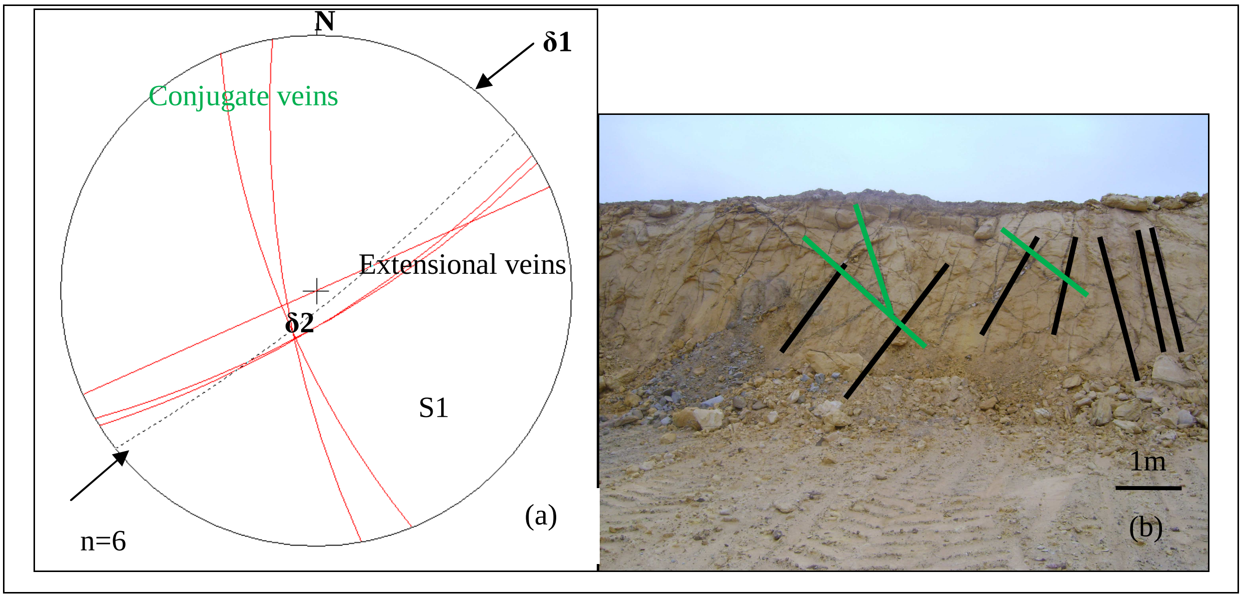


Figure 4.6: (a) Equal area stereographic plot of the conjugate and extensional vein sets mapped on the Western wall of the Essakane pit (b)

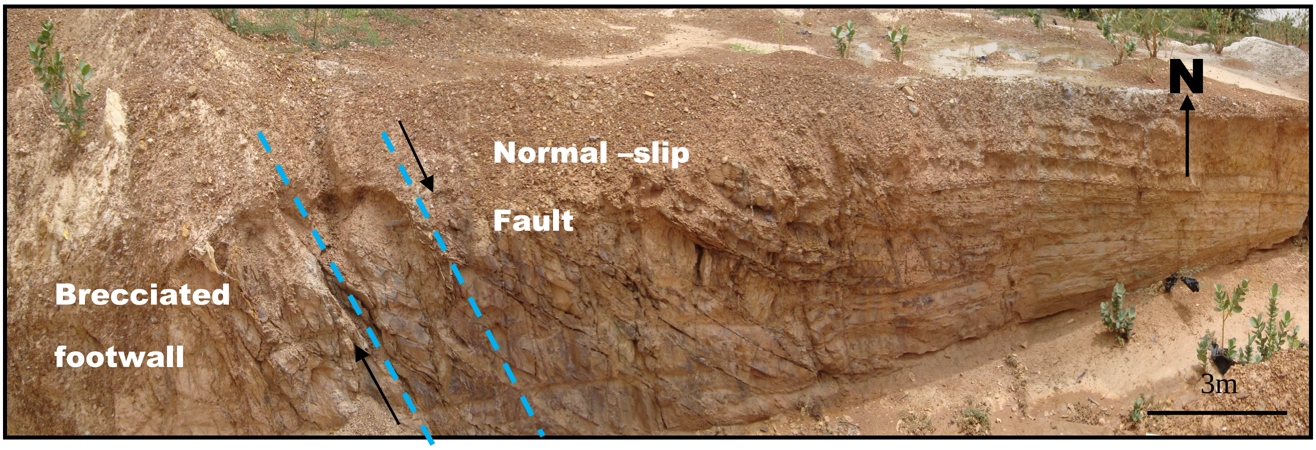


Figure 4.7: NE-trending normal-slip fault in the exploration trench in Essakane (facing south-east).

4.2.2 Sokadie

The metamorphic rocks in the Sokadie deposit are strongly deformed with well developed foliation, intersection lineation and crenulation cleavage. The structures mapped indicate that the deposit is in a shear zone. The shear zone is characterised by intensely foliated, crenulated, chloritised greenschist rocks. The greenschist rocks are composed of quartz, plagioclase, epidote, chlorite, muscovite with developed of arsenopyrite.

The quartz-carbonate veins cross-cutting this unit are intensely folded and boudinaged, and brecciated buck quartz veins occur within the shear zone. The rock outcrops become progressively sheared when approaching the shear zone (towards the south). The foliation of the rocks, with a calculated mean strike and dip of 078°/66°S, indicates that the shear zone is steeply dipping to the south with a NE-trend (Fig 4.5). Crenulation cleavage, intersection lineation and S-C fabric were formed subsequent to the shearing. The sense of shear determined using the S-C fabric, boudins and quartz-carbonate veins is tentatively interpreted as dextral reverse.

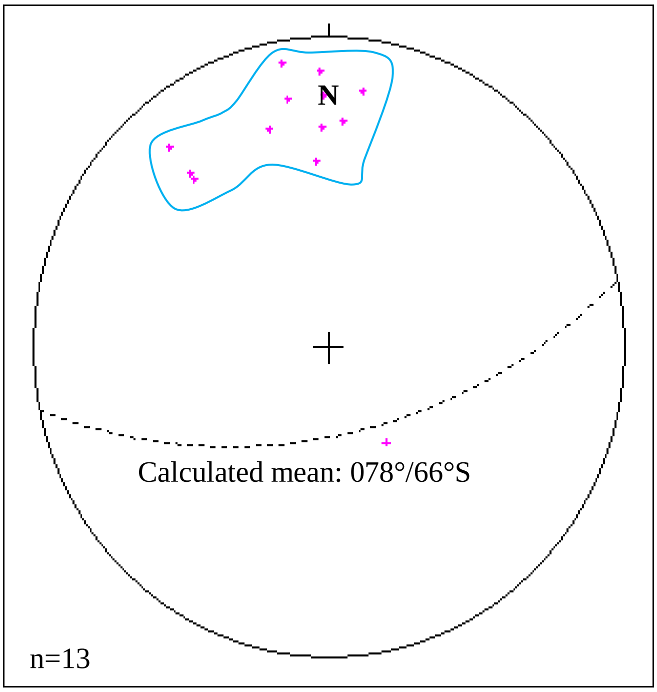


Figure 4.8: Equal area stereographic plot of foliation in the Sokadie shear zone

Chapter 5: Observations

Mineralogy, Petrography and Ore petrology[1]

5.1 Preamble

Fifteen polished thin sections were analysed for this project, with five thin sections from each deposit. The petrography section aims to realise the main aims and objectives of the project. In the thin sections the rock types, mineralogy of the rocks, alteration types and microstructures were identified to determine a paragenetic sequence for the gold occurring in the Oudalan-Gorouol greenstone belt. The dominant sulphides included arsenopyrite and pyrite, with minor sphalerite, hematite, magnetite, chalcopyrite and pyrrhotite.

5.2 Essakane

The Essakane deposit is hosted in an inclined, asymmetrical NW-NNW trending anticline. The rock types that were identified in the thin sections are sandstone, siltstone, shale and volcaniclastics (Fig 5.1). These rocks are constituted by a number of minerals that are common across the Essakane deposit.

The arenaceous sedimentary units i.e. sandstone and siltstone, are dominated by common rock forming minerals i.e. quartz, orthoclase, plagioclase and biotite. The volcaniclastic is made up of volcanic clasts, quartz and feldspar in a fine-grained matrix. The samples also record lithological contacts on a microscopic scale (Fig 5.2A).

The quartz has undulatory extinction with sutured grain boundaries, indicating dissolution and subsequent overgrowth. The quartz displays a 'butterfly' texture (Fig. 5.3A, B) along the euhedral boundaries of the sulphides, it is the quartz is strained and indicates direction of compression. The minerals developing next are elongated hornblende and minor biotite < 2%. These are altered to chlorite. The hornblende is has two preferred mineral orientations and produces foliation in the rocks. The sample EDD4-178B consists of more than 50% hornblende and it is termed hornblendite (Fig. 5.2B).

The secondary minerals that appear include muscovite, sericite, kaolinite and chlorite. These minerals form the wallrock alteration. The sericite is the most developed wallrock alteration (Fig. 5.4A) and it has preferred orientation i.e. it is cleaved. Muscovite occurs as needle-like blades with preferred linear orientation. The chlorite cross-cuts the all the minerals and has high iron content; it is found in the

[1] The oxide and sulphide textures depicted in the photomicrographs are found in all the deposits

centre of the veins and in the distributed in the whole sample. The abundant chlorite may be due to biotite-chlorite alteration or the alteration of hornblende. The sheet silicates have a preferred orientation that produces a pronounced foliation (S1) in the rocks.

The veins in the samples are quartz-ankerite veins and quartz-ankerite-chlorite veins; with chlorite in the centre (Fig. 5.4B). They form simple open-space fill morphology. The order of the minerals in the veins is quartz in contact with the wall rock, followed by ankerite with chlorite and sulphides at the centre. The veins are coarse-grained texture to fine-grained in texture. The chlorite and sericite dominate the alteration zone that is enveloping the quartz veins.

Three sulphides occur in the samples i.e. pyrite, chalcopyrite and arsenopyrite with the oxide phase as rutile. Pyrite is most common and occurs as both euhedral crystal and anhedral masses, and it is undergoing supergene alteration to marcasite. Arsenopyrite occurs as monoclinic crystals and the chalcopyrite is anhedral. The chalcopyrite forms a small proportion of the sulphides in the Essakane samples ~1%. The arsenopyrite replaces the pyrite in these samples and occurs within the chlorite.

Paragenesis of the sulphides: Pyrite- Chalcopyrite -Arsenopyrite

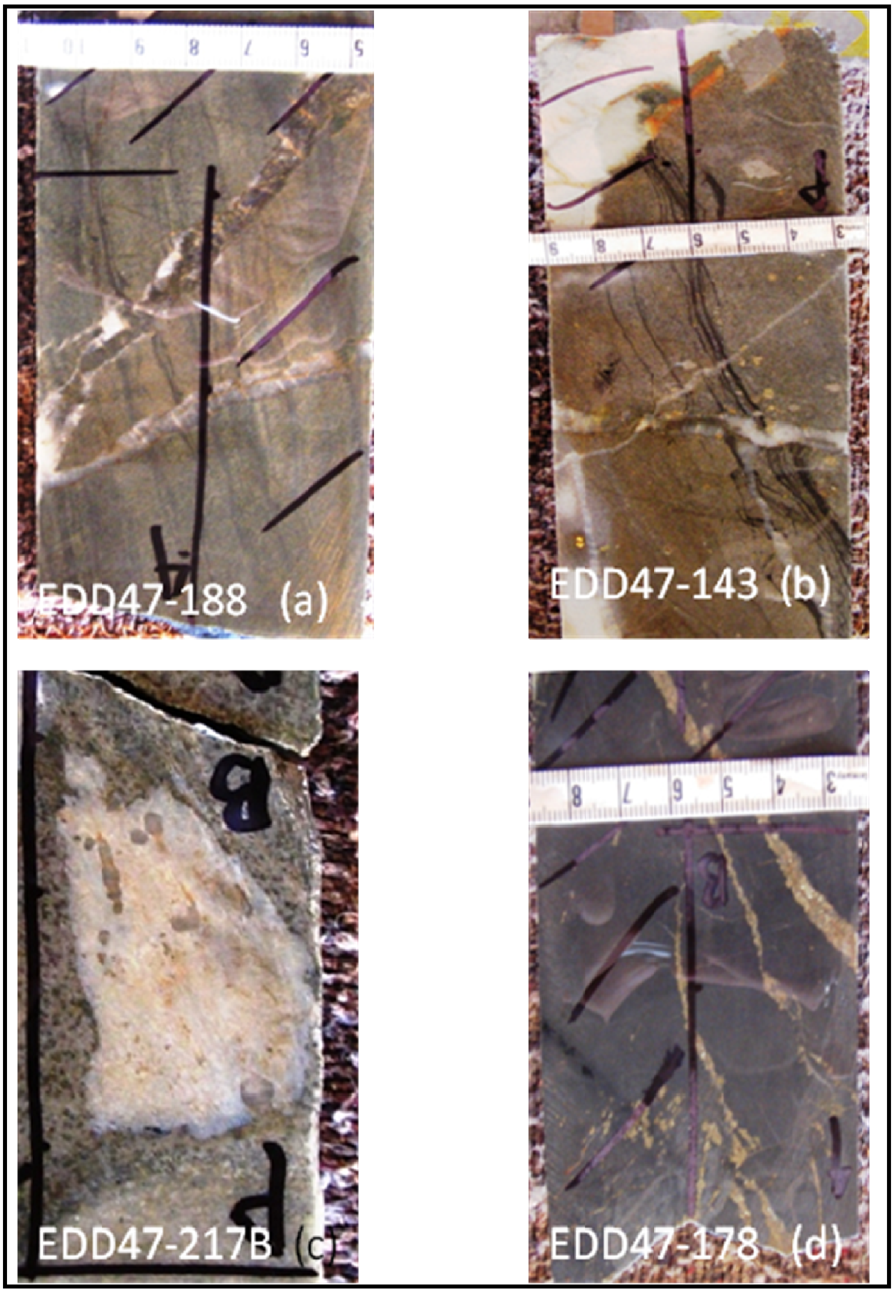


Figure 5.1: Drill core photographs from the Essakane deposit of (a) shale+ volcaniclastic+ siltstone (b) volcaniclastic with sulphides (c) siltstone (d) shale with sulphides

(Photographs courtesy of Prof Kim Hein)

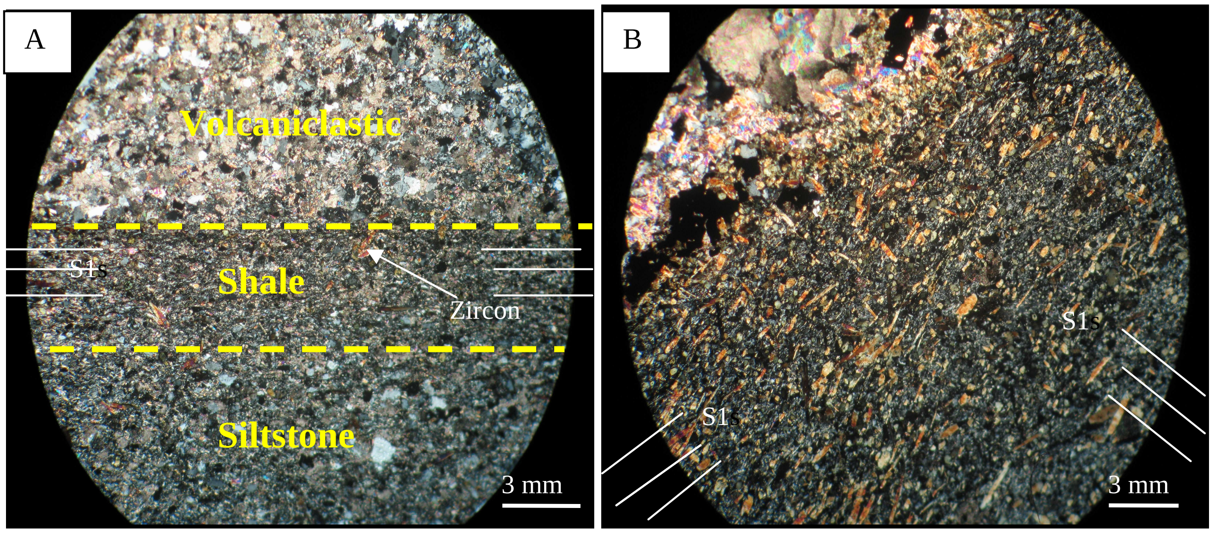


Figure 5.2[2]: (A) Photomicrograph illustrating the contacts lithological contacts with zircons in the shale & S1
(B) Photomicrograph of hornblendite with two foliation directions

[2] Scale on photomicrographs indicates width of field of view

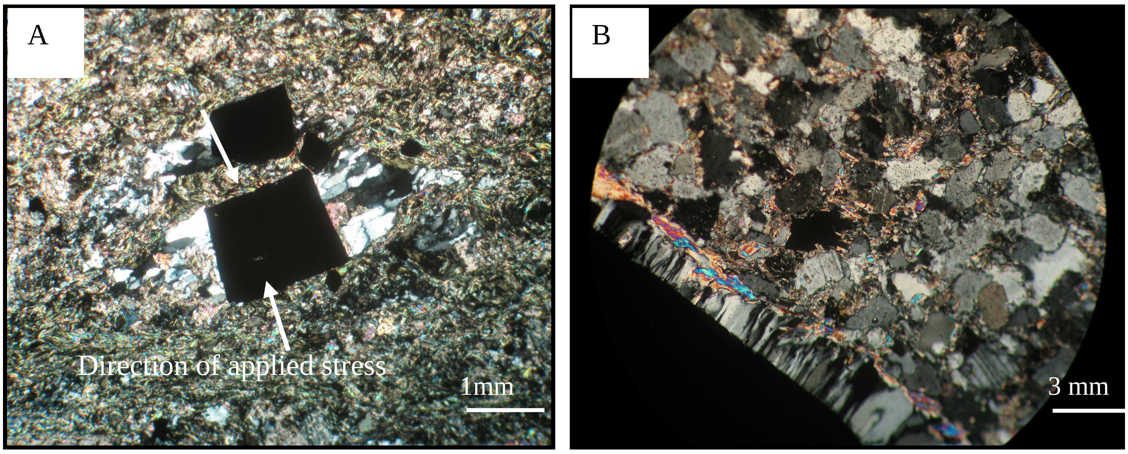


Figure 5.3: (A; B) Photomicrograph of ‘butterfly’ texture in quartz developing against sulphides

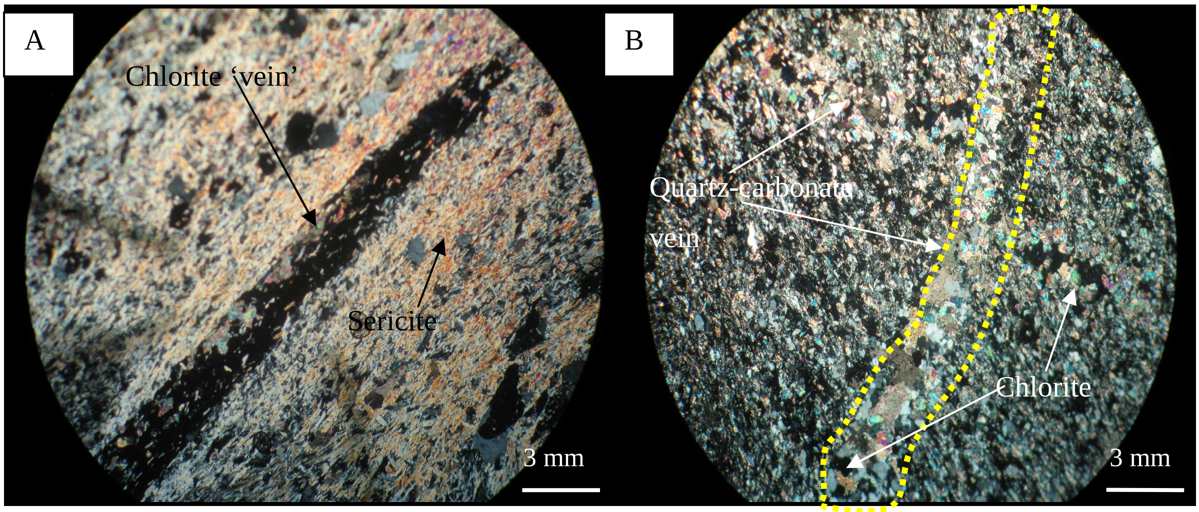


Figure 5.4: (A) Photomicrograph of anomalous blue chlorite vein with sericitisation on the wall rock. (B) Photomicrograph illustrating chlorite within quartz-carbonate veins

5.3 Falagountou

The sedimentary sequences of the Falagountou deposit are intruded by monzonites and monzodiorites (Fig 5.5). These rocks are alkaline to calc-alkaline with plagioclase feldspars and alkali feldspar making up a bulk of the mineralogy of the rocks. The alkaline intrusive rocks are quartz syenite and quartz monzonite. The samples are phaneritic and are composed of medium-grained to coarse-grained alkali feldspar (mainly orthoclase), plagioclase feldspar and quartz.

The silicate mineralogy in the Falagountou deposit includes alkali feldspar, plagioclase, and quartz, with muscovite, epidote, sericite, chlorite, biotite, hornblende, calcite and cordierite; however most dominant silicates found in the samples are feldspars, quartz and sericite. The two type of feldspars identified are alkali feldspar and plagioclase. The alkali feldspar comprises of orthoclase and microcline; and has a coarse-grained, equiangular texture. Grain boundaries in the feldspars have been dissolved and recystallised. The feldspars have a cloudy appearance and are altering to sericite (Fig. 5.6A). The calcite develops in the wallrock and it is abundant in the sample with a proportion of ~20% in each sample. Quartz occurs in smaller proportions than feldspars. It is polycrystalline and subhedral, with sutured grain boundaries. The feldspars and quartz are in eutectic growth with each other.

Sericite is the first alteration mineral to form and constitutes the groundmass. It is cleaved and has two preferred orientations. Muscovite occurs in the samples as elongate crystals, with random in the igneous rocks and linear orientation in sedimentary rocks. Chlorite forms later with sulphides concentrated within the chlorite (Fig. 5.6B).

The sulphides in the Falagountou deposit are arsenopyrite, pyrite, chalcopyrite and sphalerite; and the oxides include hematite, magnetite and ilmenite. The hematite replaced the both magnetite (Fig. 5.7A, B) and arsenopyrite. Magnetite is anhedral with exsolved skeletal ilmenite developing within its structure; it may be a product of the alteration of biotite to chlorite or the replacement by muscovite. The presence of ilmenite is attributed to its tendency to be a common accessory mineral in igneous rocks. The sphalerite occurs as irregular anhedral masses and is replaced by chalcopyrite. The arsenopyrite is euhedral; and pyrite occurs as both euhedral crystals and anhedral masses. Free native gold (Fig. 5.8A, B) was observed in a sample (FDD023-87), the grains occur within the sericitised wallrock.

Paragenesis of the sulphides: Pyrite-sphalerite- chalcopyrite-arsenopyrite

Magnetite-(ilmenite)- arsenopyrite??-hematite

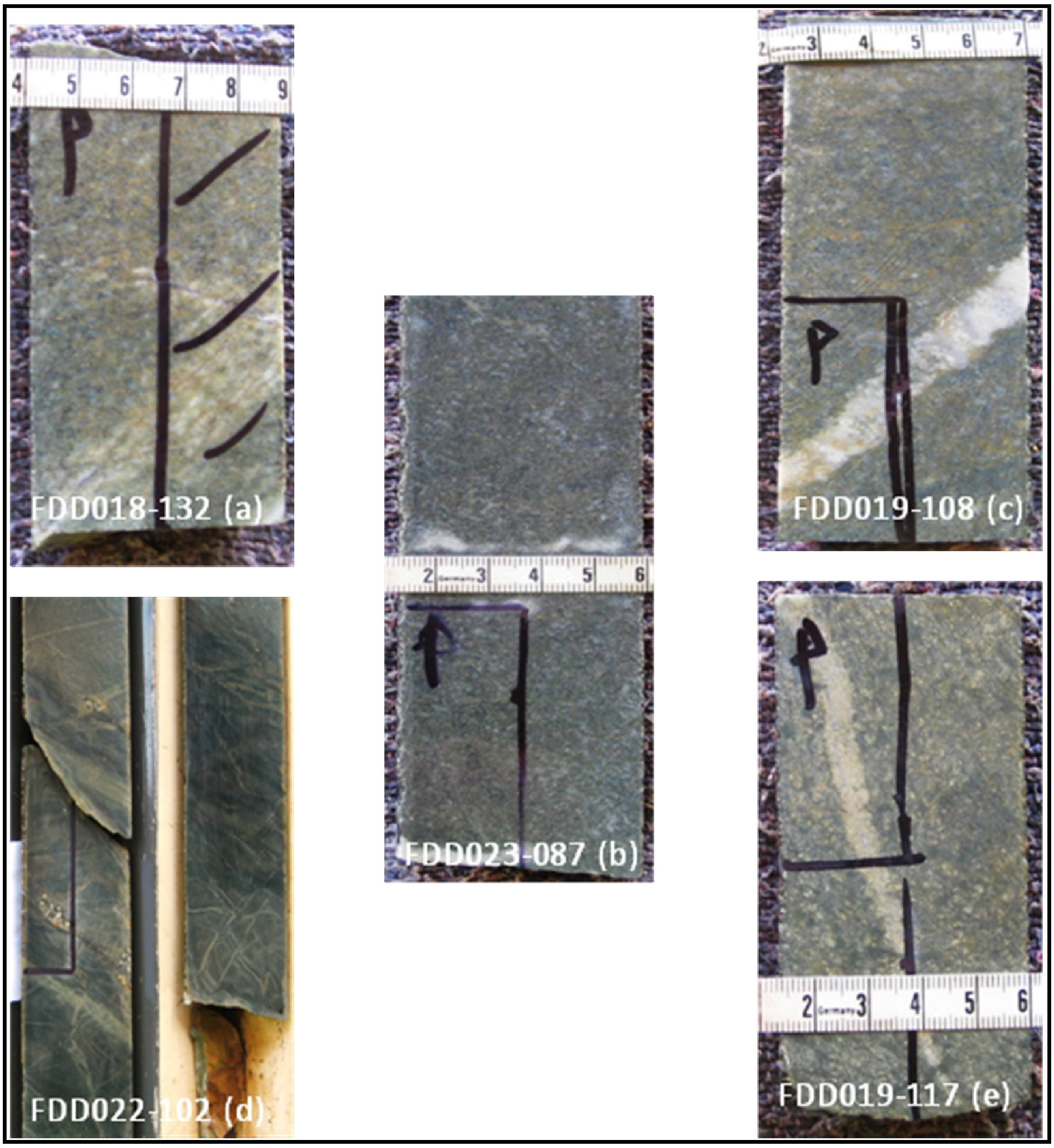


Figure 5.5: Drill core photographs from the Falagountou orpaillage (a) monzodiorite (b) monzonite (c) monzodiorite (d) shale (e) monzodiorite (although thin section indicates no feldspar present)

(Photographs courtesy of Prof Kim Hein)

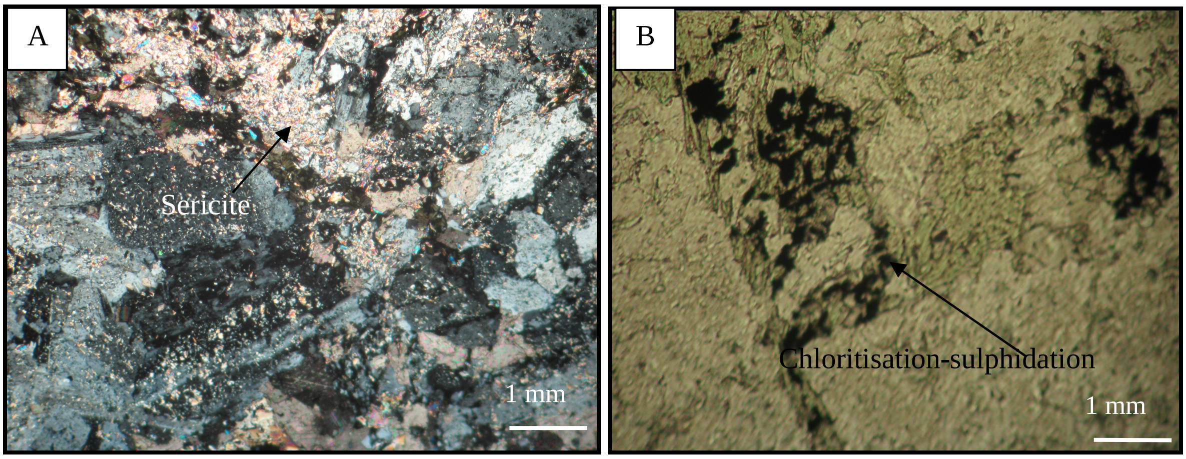


Figure 5.6: (A) Photomicrograph of monzonite with intense sericitisation. (B) Photomicrograph of sulphides concentrated within the chlorite zone

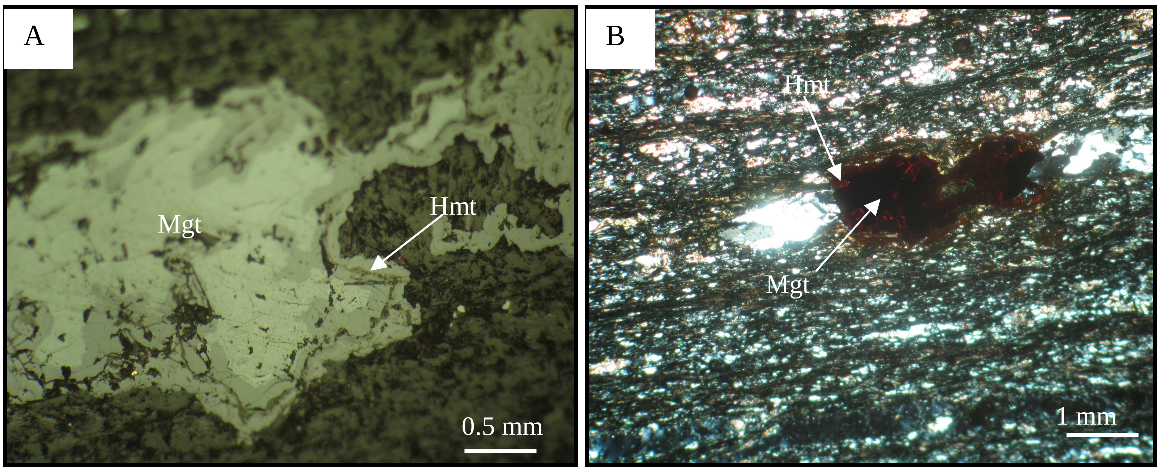


Figure 5.7: (A) Photomicrograph of magnetite altering to hematite in PPL (B) Photomicrograph of magnetite altering to hematite in XPL

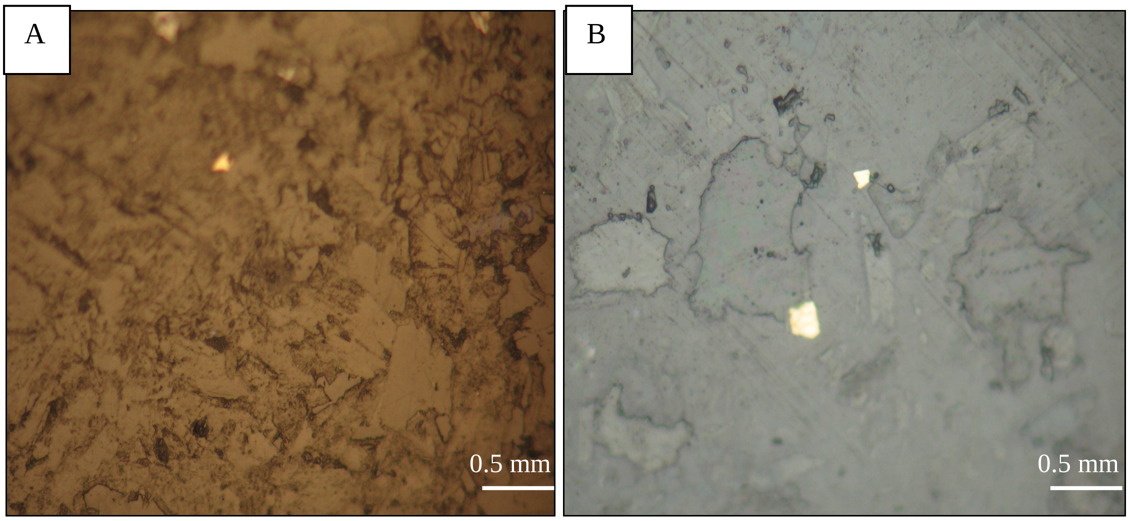


Figure 5.8: (A, B) Photomicrograph of free Au in Falagountou samples

5.4 Sokadie

Sokadie is a shear hosted deposit. The rocks are mainly greenschists i.e. quartz-plagioclase-chlorite-muscovite schist, chlorite-mica schist, muscovite-quartz-chlorite schist, quartz-plagioclase-epidote schist, quartz-chlorite-muscovite schist and quartz-muscovite-plagioclase schist) (Fig. 5.9). Greenschist facies minerals dominate and include chlorite, sericite, epidote, actinolite and muscovite. Other minerals in the samples include quartz, orthoclase, plagioclase, cordierite, biotite and calcite.

The rocks are very fine-grained and foliated, with micaceous minerals having a preferred orientation. The first preferred orientation forms a crenulation cleavage in some samples and in other samples the orientation is linear. The veins cross-cutting these rocks are folded. S-C fabric is evident in some samples (SOK02-50m); this is formed by the orientation of the minerals. The quartz in the sample is polycrystalline and has pressure solution, and it is in eutectic growth with the orthoclase. Calcite appears later, because it has not been affected by the deformation of the earlier minerals.

The sulphides in the Sokadie are disseminated and include pyrite and arsenopyrite; and the oxides are hematite and magnetite. The pyrite in the samples occurs as anhedral masses with a few cubic crystals occurring (Fig 5.10A, B, C). The hematite occurs as a psuedomorph and replaces pyrite and fractured arsenopyrite (Fig. 5.11A, B, C). The magnetite is altered to hematite. In the sample SOK04-216mB, the pyrite is oriented along the crenulation cleavage.

Paragenesis of the sulphides: anhedral pyrite-cubic pyrite-(magnetite)-arsenopyrite

Figure 5.9: Drill core photographs of the Sokadie orpaillage (a) quartz-muscovite-plagioclase schist (b) quartz-chlorite-muscovite schist (c) quartz-plagioclase-epidote-schist with folded quartz-carbonate vein (d) muscovite-quartz-chlorite schist (e) chlorite-mica-schist

(Photographs courtesy of Prof Kim Hein)

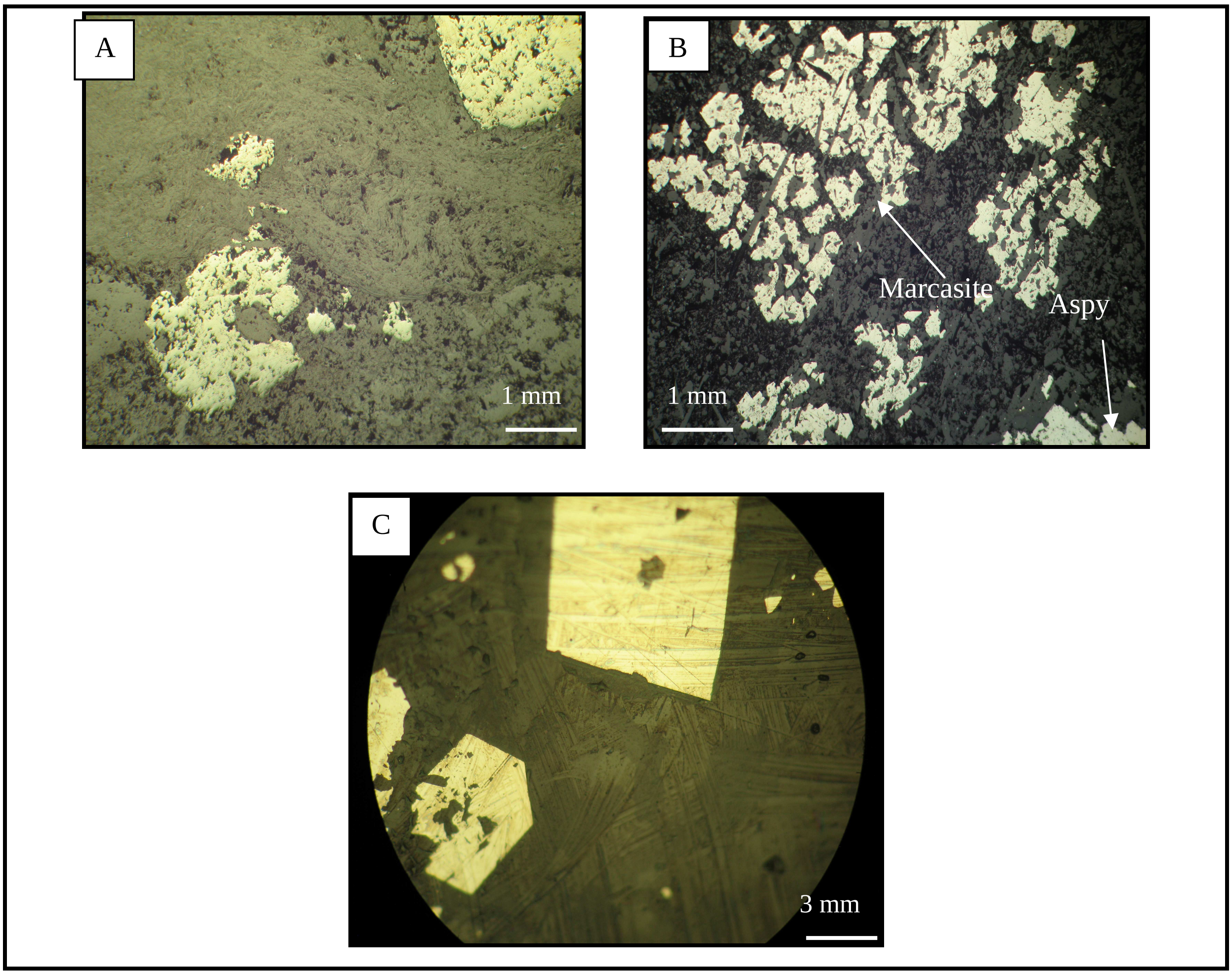


Figure 5.10: Photomicrographs of different textures of pyrite grains (a) Anhedral pyrite masses (B) Pyrite altering to marcasite with subhedral arsenopyrite (C) Cubic pyrite

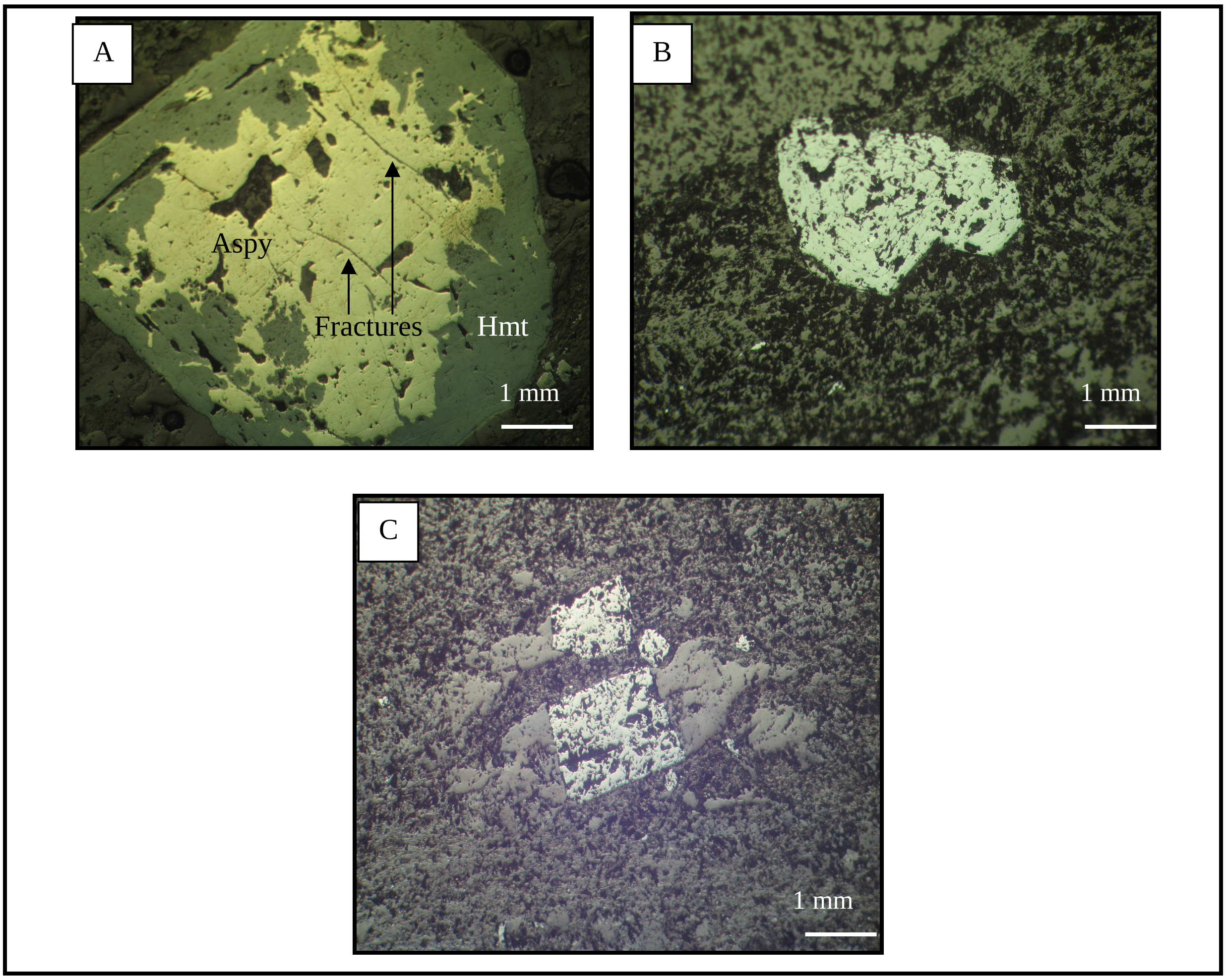


Figure 5.11: Photomicrographs of arsenopyrite textures (A) Photomicrograph of arsenopyrite replaced by hematite (B) Photomicrograph of irregular with arsenopyrite growth zoning and irregular overgrowths (C) Photomicrograph of euhedral arsenopyrite with ‘butterfly’ texture

Chapter 6: Discussion

6.1 Discussion

6.1.1 Depositional environment

The deposition of supracrustal rocks includes sandstone, siltstone, shale, greywacke and volcaniclastic in a sedimentary basin. The most recognisable sedimentary structures in the sedimentary sequences are graded beds with a fining upwards sequence on a local scale, scour and fill and finely laminated sediments. On the basis of the sedimentary structures and laminations in the sediments, the sequences are interpreted to have deposited in a low energy environment. Mass flow on a continental shelf is interpreted to be the mode of transport of the conglomerates observed by Tshibubudze, 2009 in the OGGB. Based on the limited data collected for the sedimentary structures, the depositional environment is tentatively interpreted shallow marine continental shelf, with the volcaniclastics derived from an adjacent volcanic arc. The interpretation is in accordance with the observations made by Hein et al. (2004) for the Boromo-Goren Greenstone belt, Roddaz et al. (2007) for the Upper Birimian and Tshibubudze et al. (2009) for the OGGB.

6.1.2 Metamorphism

The supracrustal rocks were regionally metamorphosed to greenschist facies, characterised by the development chlorite, sericite, muscovite and anhedral pyrite, which formed due to breakdown of feldspars into sericite combined with iron from iron-silicates and sulphur (Stanton, 1972). The supracrustal rocks were metamorphosed to quartzite, metavolcaniclastic, metagreywacke, metasiltstone and greenschists. The supracrustal rocks are tentatively interpreted to have undergone two phases of deformation. The first deformation is associated with the development of NW-trending folds (F1), foliation (S1) and extensional-conjugate quartz-carbonate vein sets (V1), these are interpreted as D1 (Tangaean) structures. The second deformation is associated with the development of vein stockwork (V2), NE-trending faults, NE-trending foliation (S2) associated with the dextral shear zones and are interpreted as D2 (Eburnean) structures.

The supracrustal rocks were intruded by granitoid plutons and prograde contact metamorphosed to hornblende-hornfels facies, indicated by the development cordierite spots, amphiboles and hornblende. Leube et al. (1990) and Tunks et al. (2004) recognised the low- to medium grade amphibolite facies metamorphism of supracrustal rocks within the contact aureole of granitoids; Hein et al. (2004) noted the development of hornblende-hornfels facies around the contact aureole of granitoids in the Boromo-Goren greenstone belt. Data for the size and mineralogy of the plutons was not available, but they are interpreted large, calc-alkaline plutons. The absence of minerals kinked, zoned biotite and tourmaline in the samples support the notion that the supracrustal rocks are not intrusion-hosted but proximal to the intrusions; hence the interpretation is that supracrustal rocks lie in the contact-aureole of granitoids.

6.1.3 Alteration and mineralisation

Alteration in supracrustal rocks is inferred to be concomitant to regional and contact metamorphism. Alteration types are silicification, sericitisation, carbonatisation, chloritisation and sulphidation. The fluids causing the alteration in the rocks are interpreted as derived from dewatering of sediments by compression and convective currents created by the raised geothermal gradient from cooling and recrystallisation of the plutons in proximity to the deposits (Fig 6.1). This phase is interpreted as the retrograde path of the contact metamorphism of the supracrustal rocks. Sericitisation of the wallrock occurred first and is recognised by alkali metasomatism forming the mineral sericite. The mineral pyrite occurred in the form of anhedral masses as minor product of the reaction of feldspars to produce sericite (Robb, 2007). Subsequent to sericitisation, silicification appears through the addition of quartz in the wallrock. Quartz-carbonate veins are interpreted to be the result of silicification and carbonatisation of the sequences. These veins crosscut the lithology and they follow open-space fill morphology with the quartz rimming the outside of the veins and the ankerite developing towards the centre of the veins. Calcite is the product of later carbonatisation and is extensive in the wallrock of the intrusions in Falagountou. Sericitisation, silicification and carbonatisation are tentatively interpreted as prograde reactions of contact metamorphism.

Chloritisation and sulphidation succeed prograde reactions. This alteration is characterised by the development chlorite and epidote, with quartz-chlorite veins and the development of sulphides concentrated within chlorite. The interpretation is that retrograde reactions resulted in these low temperature minerals forming and overprinting the earlier high temperature minerals. This alteration is tentatively interpreted as the likely Au forming phase.

The alteration sequence is as follows:

Sericitisation

Silicification

Silicification and carbonatisation

Carbonatisation

Chloritisation with silicification and sulphidation

Time ↓

The sulphides in these deposits include pyrite, chalcopyrite, sphalerite and arsenopyrite. The sulphides are coarse-grained and disseminated. Sulphidation is synchronous with the chloritisation phase and is a product of addition of Cu, S, As and Zn during hydrothermal activity. The Au is intimately associated with the mineral arsenopyrite. A paragenetic sequence of the sulphides was determined from the replacement textures between the sulphides. It occurs as follows:

Pyrite

Sphalerite

Chalcopyrite

Arsenopyrite (-Au)

Time

6.1.4 Timing of Gold mineralisation and genetic model

According to Tshibubudze et al. (2009), the D1 and D2 events are both mineralised giving rise to two phases of gold mineralisation in the OGGB. The D1 is characterised by the metasomatic alteration of the wall rocks to form quartz vein hosted arsenopyrite-pyrite gold mineralisation and subsequent to this was the development of vein-stockwork mineralisation of D2. The V1 and V1′ observed in the Essakane deposit are interpreted to be mineralised during D1, with V2 mineralised during D2. The V2 (stockwork veins) are typical of thermal-aureole vein assemblages noted by Wall (1991). The plutons intruding the OGGB are syn- to post Eburnean (Leube et al., 1990; Naba et al., 2004; Tshibubudze et al., 2009) and this provides a time constraint for the mineralisation of the deposits. A tentative interpretation is that the Au mineralisation in these deposits is post-D1; but is synchronous to D2, during the cooling of the granitoids.

The Au mineralisation was formed by hydrothermal activity and is associated with the last phase of alteration identified in the samples, i.e. chloritisation. It is associated with contact metamorphism of granitoids. The Au forming stage is interpreted as a retrograde path during contact metamorphism, i.e. post peak thermal metamorphism. The mineralisation is dominantly a quartz-chlorite-pyrite-arsenopyrite system. Wall and Taylor (1991) observed retrograde mineralisation in the thermal-aureole of deposits at Victoria and Elsewhere, Australia. The stockwork vein system and disseminated sulphides (mainly pyrite-arsenopyrite (Au)) typify the thermal-aureole gold deposits identified in Quigleys and Batman, Australia (Hein, 2003). The mineralisation, i.e. chlorite-epidote-pyrite-arsenopyrite is located in the lower temperature field of the thermal aureole. The mineralisation in the OGGB is tentatively interpreted as orogenic under the subdivision of thermal-aureole gold.

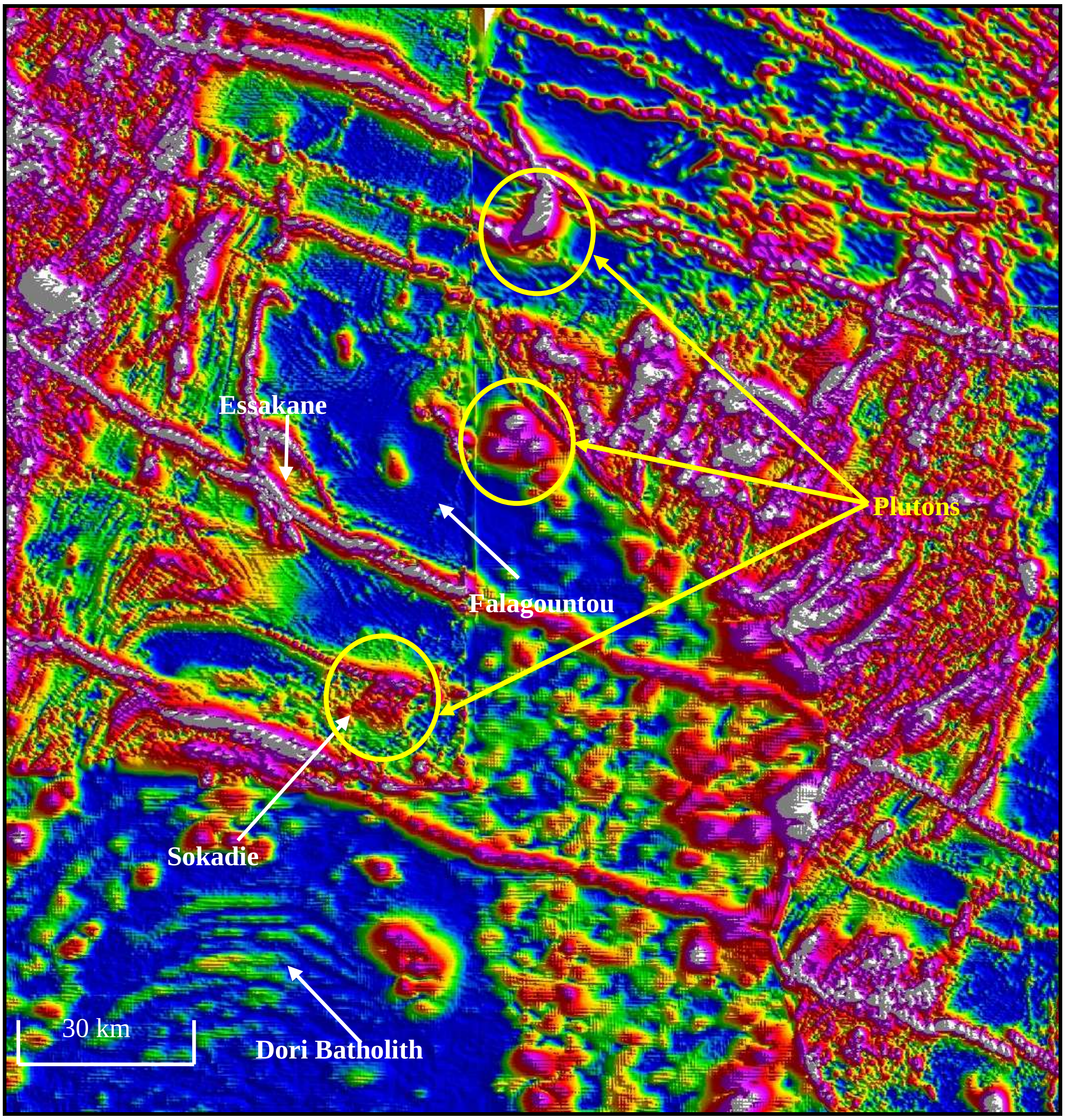


Figure 6.1: Aeromagnetic photograph of the study area indicating the locations of the plutons in the area

(Photograph courtesy of A. Tshibubudze)

Chapter 7: Conclusion

The rock sequences in the Oudalan-Gorouol greenstone belt underwent regional metamorphism characterised by greenschist facies mineral assemblages, with the development of hornblende-hornfels assemblages during contact metamorphism. The sequences were cross-cut by quartz and quartz-carbonate dominant veins. The events leading up to the formation of the ore can be summarised as follows:

1. The deposition of lithologies on the greenstone belt, which include interbedded shale-siltstone-sandstone and volcaniclastic sedimentary sequences.

2. The regional metamorphic event led metamorphism and deformation of the sequences, characterised by the development of greenschist facies mineral assemblages and NW-NNW trending structures (D1) and NE-NNE trending structures (D2).

3. The intrusion of granitoids during the Eburnean orogeny contact metamorphosed supracrustal rocks to hornblende-hornfels facies during the prograde path of metamorphism.

4. Heat released from cooling of granitoids remobilised the fluids in the sediments and introduced retrograde mineral assemblages.

5. Alteration of the sequences occurred concurrent to metamorphism resulting in the development of quartz, quartz-chlorite and quartz-carbonate veins. The precipitation of sulphides and gold followed during this process. Chloritisation with sulphidation is interpreted as the Au forming phase.

The interpretation of the data indicates that the deposits of Falagountou, Essakane and Sokadie formed during the Eburnean orogeny subsequent to the intrusion and cooling of granitoid plutons. The mineralisation occurred during post peak metamorphism and is defined by chloritisation of the sequences. The mineralogy indicates that the deposits are situated proximal (middle-aureole) to the granitoids. The mineralisation is hosted in quartz-carbonate-chlorite stockwork veins. Based on the previous discussion (Chapter 6) the deposits are tentatively classified as orogenic gold deposits under the subdivision of thermal-aureole gold deposits.

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Appendix A: Thin Section Descriptions

EDD01-164A

This is a very fine-grained sample with shale in contact with siltstone. The mineralogy consists of quartz, feldspar, sericite, muscovite and is dominated by chlorite. There are cordierite spots and hornblende crystals. Three generations of veins are identified; the first-generation vein is quartz-chlorite rich and cross-cut by a second-generation quartz-carbonate vein, the third-generation vein terminates along the second-generation vein.

The sulphides in the sample occur in the chlorite mineral. The arsenopyrite is rhomb-shaped and the pyrite is anhedral. The arsenopyrite is dominant and the sulphides have no relationship with each other.

EDD47-188

Thin section is composed of three rock types i.e. shale, siltstone and volcaniclastic. The mineralogy of the sample comprises of plagioclase, orthoclase and quartz, with the commencement of metamorphism the following minerals, sericite, muscovite and an anomalous blue chlorite (Fe-rich) developed. There are zircons on the boundary layer between the shale and volcaniclastic. The boundaries between the lithologies are sharp contact boundaries. The veins in the section are almost completely composed of quartz and feldspar, with ankerite.

The sulphides occur within the ankerite veins, the arsenopyrite is growing into the pyrite. The sulphides are enclosing the silicate minerals. The arsenopyrite is diamond-shaped to subhedral and cubic pyrite occurs along the edge of the thin section. The arsenopyrite is replacing the pyrite grains.

EDD47-143

The thin section is of a volcaniclastic sample, which is characterised by an abundance of quartz, orthoclase and plagioclase. The grains in the sample are sub-angular and randomly oriented. The quartz grains are sutured, due to application of pressure to the grains. It is a medium-grained sample. There are metamorphic minerals such as muscovite and chlorite in the sample.

Two large crystals of arsenopyrite crystals and they are rimmed by ‘butterfly’ textured quartz grains.

EDD47-217B

The sample is of siltstone. There is ~ 40% fine-grained, bladed muscovite in the sample. The quartz is large, polycrystalline, overgrown and sutured. The contact of the micaceous minerals and the quartz is very fine-grained. The chlorite is an anomalous blue colour and constitutes ~20% of the mineralogy. The lithology is cross-cut by ankerite-quartz veins.

The sulphides in the sample are arsenopyrite, pyrite and chalcopyrite. They have a skeletal texture. The pyrite is subhedral and is being replaced by anhedral chalcopyrite. The arsenopyrite is replacing the pyrite in the sample.

EDD47-178B

This is a shale sample, with >70% hornblende, therefore the sample could be a hornblendite or amphibolite; other minor minerals include quartz, feldspar, sericite, muscovite and chlorite. It is very fine-grained, with ankerite-muscovite veins. The hornblende is randomly oriented. The large rhombohedral sulphides occur within the veins and are also disseminated around the sample. There is also rutile in the sample.

The sulphides are pyrite and arsenopyrite, with the arsenopyrite enclosing the pyrite i.e. it is replacing the pyrite. The pyrite occurring along the edge of the thin section is cubic. The sulphides are growing around the hornblende.

FDD018-132

The sample consists of orthoclase, plagioclase, quartz, muscovite, epidote and calcite. The modal abundances of the three major constituents of the sample indicate that the sample is a monzodiorite. The sample is coarse-grained and the quartz and orthoclase are in eutectic growth with each other. The orthoclase is being cross-cut by the quartz veins. The feldspars are highly sericitised. The crystal boundaries between the minerals are destroyed. The ankerite is forming around the other crystals.

Orthoclase ~25%, Quartz ~5%, Plagioclase~70%

The sulphides consist of zoned sphalerite anhedral chalcopyrite, hematite, arsenopyrite and pyrite.

FDD019-108

Alkali feldspars constitute the sample, these are orthoclase and microcline. Microperthite and plagioclase can be observed in the sample. The feldspars are undergoing sericitisation. There is green chlorite in the sample and it occurs around the feldspars, the sulphides are growing within the chlorite.

The quartz is polycrystalline. The feldspars are not in eutectic growth with the quartz. There is carbonate in the section. This is a monzodiorite.

Orthoclase ~35%, Quartz <5%, Plagioclase~65%

The sulphides include magnetite which has skeletal texture, with ilmenite exsolving into the magnetite. The arsenopyrite occurs as diamond-shaped crystals. The arsenopyrite is replacing the chalcopyrite.

FDD023-087

The thin section has orthoclase, polysynthetic quartz, plagioclase and ankerite. The metamorphic minerals present are muscovite and anomalous blue chlorite. The feldspars are undergoing sericitisation. The mineral grain boundaries are starting to disintegrate. An ankerite vein is cross-cutting the lithologies and it is rimmed by the chlorite. It is a sample of a monzonite.

Alkali feldspar (Orthoclase; Microcline) ~40%, Plagioclase ~50% Quartz <5%

Arsenopyrite, chalcopyrite, minor pyrrhotite and pyrite are the sulphides in the sample. The pyrite is skeletal; the pyrrhotite is taking on the shape of arsenopyrite, behaving as a pseudomorphs.

FDD019-117

The sample consists of polycrystalline quartz, calcite and no feldspars. The muscovite and chlorite constitute the metamorphic minerals; the muscovite occurs as elongated crystals and the chlorite is ‘infilling’ the spaces. The sample is cross-cut by a quartz-ankerite vein, with the quartz occurring in the centre of the vein. The sulphides are growing within the chlorite. The high amounts of quartz and carbonate indicates silicification and carbonation of the sample, but the protolith might be a monzodiorite.

Quartz < 40%, Carbonate~30%,

Chalcopyrite is replacing the hematite, and the anhedral hematite is the abundant sulphide in the sample. The hematite is overprinting the sphalerite, and rhombohedral arsenopyrite occurs as isolated crystals.

FDD022-102

The sample is very fine-grained it is a sample of shale. The muscovite >50%, has preferred linear orientation i.e. cleavage and it has parallel extinction. The sericite in the sample is cleaved. There are elongated hornblende crystals which constitute ~10% of the sample. The ankerite occurs as a vein and is cross-cut by later ankerite veinlets. Cordierite ‘spots’ are scattered around the sample

Zoned sphalerite occurs in the sample.

Sok01-64m (A)

The thin section consists of >60% calcite, which forms ‘bands’, the quartz is very fine-grained, monocystalline and has undulatory extinction. Muscovite occurs with a preferred orientation and is very fine-grained. The sample displays biotite-chlorite alteration, with the biotite changing into the chlorite. The sample is quartz-muscovite-plagioclase schist.

The sulphides found in the sample are pyrite, hematite, magnetite and arsenopyrite. The hematite replaces pyrite and arsenopyrite. Arsenopyrite also occurs as a euhedral (diamond) shape.

Sok02-50m

The sample is very fine-grained, with the minerals being ‘folded’. There is quartz, anomalous blue chlorite, plagioclase, muscovite, sericite and biotite in the sample. The lithology is by ankerite veins. The minerals indicate s-c fabric orientation. The sample is quartz-chlorite-muscovite schist.

The arsenopyrite is rimmed by hematite and it is rhombohedral.

Sok03-115m

The sample consists of muscovite, actinolite, chlorite, epidote, orthoclase, plagioclase, quartz and ankerite. The quartz is stretched along the crystal boundary of the sulphides and forms ‘butterfly’ texture against the sulphides. Actinolite in the sample has a preferred linear orientation. The sample is quartz-plagioclase-epidote schist. The quartz-ankerite veins have a crack-seal texture and cross-cut the lithology.

The sulphides in the sample occur around the areas in the sample where the minerals appear to be ‘folded’. The sulphides in the sample include pyrite, arsenopyrite and hematite. The pyrite is elongate and anhedral. The hematite is replaces pyrite and arsenopyrite.

Sok04-216m (B)

The thin section is identified as muscovite-quartz-chlorite schist. It is very fine-grained and minerals are oriented in a crenulated cleavage fashion. The dominant mineral is muscovite >50% with polycrystalline quartz, calcite, sericite and chlorite. The calcite is twinned on the surface and it occurs in a vein with the quartz. The chlorite is abundant in the sample and also forms between the muscovite and the quartz-calcite vein.

The dominant sulphide is pyrite; it occurs as elongated, anhedral masses and is oriented along the crenulation cleavage.

Sok05-73m

The thin section consists of biotite, chlorite, muscovite, cordierite spots, orthoclase and quartz. The biotite, chlorite and muscovite are elongated. Calcite is intergrown with the other minerals. The sample is quartz-chlorite-mica schist.

The sulphides in this sample are magnetite, hematite and arsenopyrite. The hematite is zoned and is replaces magnetite and arsenopyrite (euhedral).

Appendix B: Table of Field Data

STN P	NORTHINGS	EASTINGS	HOST ROCK TYPE	description	STR	DIP	DIP DIR	STRUC	FACING
001	1590378	0192582	siltstone	subcrop, iron oxide grains					
002	1590337	0192695	greywacke	subcrop, foliated, medium-grained					
003	1590339	0192746	intrusive	subcrop, rich in Fe, irregular pyrite grains, elongated green mineral(feldspar)					
004	1590485	0192746	siltstone	altered yellow colour	336	24	NE	bedding	
005	1590525	0192701	intrusive	coarse-grained, weathering into soft rock(sericitic alteration)					
006	1590564	0192648	siltstone	wall is cross-cut by quartz veins	282	82		extensional veins	
					010	50	W	buck-quartz vein	
					024	50	W	buck-quartz vein	
					030			quartz fibres	
007	1590543	0192659	siltstone	malachite profile towards top of siltstone					
008	1591212	0193102	sandstone	orange-yellow colour, ironised, lithified					
009	1590816	0192290	intrusive	subcrop, propylitic alteration of plagioclase, mafic matrix					
010	1590346	0192167	sandstone						
011	1590834	0192277	siltstone	ironised, foliated surface, cross-cut by boudinaged quartz veins	032	70	NE	foliation	
012	1591063	0190817	sandstone + greywacke	*beginning of Essakane					
013	1579002	0189751	metavolcaniclastic greywacke	chloritised, pockmarked surface, coarse-grained, grey-green colour, stagasaurous orientation, fractured surface					
014	1578936	0189707	quartz-chlorite-muscovite schist	green colour, soapy texture, foliated	274	62	S	foliation	
						62	158	lineation	

015	1578505	0189610	sandstone	ironised, sericitic alteration, intensely foliated	086	50	S	foliation	
016	1578427	0189511	siltstone	intensely foliated	058	30	N	foliation	
017	1578323	0189231	sandstone	quartz breccia covering sandstone outcrop					
018	1578472	0189274	quartzite, quartz-chlorite-muscovite schist	ironised, penetrative cleavage, sericite, boudinaged quartz veins	089	70	S	foliation	
					010	48	NE	72	
					070			quartz fibres	
					068			quartz fibres	
					068			quartz fibres	
					072			quartz fibres	
019	1578540	0189273	siltstone + sandstone	S-C fabric	078	50	S	C fabric	
					042	74	E	S fabric	
020	1578635	0189281	siltstone		080	70	S	bedding	
					022	58	SW	S1	
						32	100	intersection lineation	
021	1578694	0189254	siltstone	chloritised	098	72	S	foliation	
					080	82	S	foliation	
						16	084	intersection lineation	
						12	088	intersection lineation	
						16	082	intersection lineation	
022	1578843	0188301	siltstone	buck-quartz overlying siltstone					
023	1578875	0189278	quartz-chlorite-muscovite schist	weathered brown colour	088	60	S	foliation	
024	1579003	0189272	greywacke	cross-cut by quartz vein, grey-green colour					
025	1579000	0189147	greywacke	intensely foliated	078	72	S		

026	1578656	0189073	siltstone + sandstone	argillic alteration	050	73	SE	foliation	
027	1578346	0189030	quartzite						

028	1578520	0188781	quartzite	argillic alteration	050	60	SE	foliation	
029	1578709	0188777	quartzite	oxidation, buck quartz rubble in between rock	050	62	S	foliation	
						60	150	lineation	
030	1578874	0188542	quartz-chlorite-muscovite schist	cross-cut by quartz veins	074	62	S	foliation	
031			siltstone + sandstone	oxidation, foliated	080	70	S	foliation	
032	1578653	0188398	quartzite		088	78	S	foliation323	
033	1592765	0184127	argillite + arenite	graphitic shale cross-cut by quartz veins	320	38	NE	bedding	NE
034	1592737	0184061	graphitic shale	graded bedding, scour and fill, axial plane of fold	330	86	NE	bedding	NE
035	1592725	0184033	siltstone + sandstone	interbedded, oxidation (hematite and limonite)	306	70	SW	bedding	SW
036	1592469	0184152	siltstone	argillic alteration	340	78	SW	bedding	SW
037	1592574	0184340	siltstone + sandstone		300	58	NE	fault	
					328	28	NE	bedding	NE
						40	022	lineation	
					330	10	NE	bedding	NE
					316	16	NE	bedding	NE
038	1592400	0184438	siltstone +sandstone	oxidised quartz veins, oxidation argillic alteration	324	40	E	bedding	NE
039	1591952	0184002	laminated shale + greywacke	subcrop					
040	1591808	0183900	dolerite dyke	green-blue colour, fine-grained					
041	1592041	0184546	siltstone + sandstone	argillic alteration, sheeted dykes parallel to bedding	332	30	E	bedding	NE

042	1591992	0184823	siltstone + sandstone	interbedded, cross-cut by extensional and conjugate veins	060	80	SE	extensional veins	
					058	80	SE	extensional veins	
					060	80	SE	extensional veins	
					066	90	SE	extensional veins	
					350	80	W	conjugate veins	
					338	78	W	conjugate veins	
					328	40	NE	bedding	NE
043	1591507	0185815	gabbro dyke	olivine-pyroxene-feldspar crystals, medium-grained	338				
044	1591253	0185407	quartzite	oxidised, foliated	314	42	NE	bedding	NE
045	1591755	0185021	siltstone + sandstone	interbedded	330	30	NE	bedding	NE
046	1591582	0184795	siltstone + sandstone	fold axis					
047	1591233	0192424	buck quartz vein	carbonatisation					