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A THESIS REPORT ENTITLED

PETROGRAPHY AND GEOCHEMISTRY OF AKYEM MINE GOLD DEPOSIT, ASHANTI BELT-GHANA

BY

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SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN GEOLOGICAL ENGINEERING

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TARKWA, GHANA

MARCH 2019

DECLARATION

I declare that this thesis is my own work. It is being submitted for the degree of MSc in Geological Engineering in the University of Mines and Technology (UMaT), Tarkwa. It has not been submitted for any degree or examination in any other University.

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(Signature of candidate)

…… day of …… (year)……

ABSTRACT

Petrographic and geochemical investigations on rocks that host the Akyem Mine gold deposit situated in the north eastern flank of the Ashanti Belt, Ghana were used to determine the lithologies and textures within the host rocks and ore zone. The work also studied the styles of alteration and mineralisation and their relationship. The rocks generally are fine to medium grained, weakly to strongly foliated with mineral compositions dominantly made up of plagioclase, amphibole, chlorite and quartz with moderate sericite, epidote, dolomite, calcite. Ore minerals such as pyrite, pyrrhotite, magnetite, arsenopyrite, gold and chalcopyrite occur in the deposit. Appropriate rock names could be amphibole-chlorite schists and quartz-chlorite schist. The primary minerals are strongly altered leaving relict bytownite, therefore the rocks are subjected to geochemical classification. Geochemical data in wt % SiO_2 (39-62.5, average 54.19), Al_2O_3 (9.44-19.4), Na_2O (0.51- 8.64), total FeO (4.37-14.2), CaO (0.48-10.6), MnO (0.07-0.22), MgO (1.13-6.31), and TiO_2 (0.39-1.33). The values were used in discrimination diagrams to deduce protoliths of andesite to sub-alkaline basalts. The altered rocks in the Akyem Mine deposit exhibit varying intensity of silicification, sulphidation, sericitisation, carbonatisation and albitisation, so, were categorised based on the extent of alteration. Hence, weakly altered rocks contain alteration package of dolomite-calcite-chlorite-sericite with gold up to 0.98 g/t. Moderate to highly altered rocks are characterised by silica-albite-calcite-epidote with gold grade >0.98 g/t. Two generations of gold, pyrite and arsenopyrite occur respectively. Both generations of gold are more closely associated with fine anhedral pyrite 2 and arsenopyrite 1 and 2 respectively. Gold 1 is fine grained and may also occur along sheared quartz veins whilst Au 2 is medium grained and usually overprint these veins.

DEDICATION

To my children Jaydon & Janice and my wife Claudia

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First of all, I thank the Almighty God for the strength and wisdom He bestowed unto me throughout this research. Many thanks to the Area Geology Mine Manager, Mr Cornelius Mireku-Antwi and the Mine Geology team of Newmont Golden Ridge Limited for the permission to conduct this research on the Akyem Mine gold deposit. My profound gratitude goes to Dr G. M. Tetteh and Prof J. S. Y. Kuma for their guidance. I am thankful to all other staff of Department of Geological Engineering for their assistance throughout this research. Mr Clement Benyarko, though on retirement, assisted with thin and polished sections preparation.

I will forever remain thankful to my family for their sacrifices and support throughout this work.

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CHAPTER 1

INTRODUCTION

1.1 Statement of the Problem

Akyem Mine Gold deposit is on the north-eastern flank of the Ashanti belt and is bounded by the metasedimentary Akyem and Kumasi basins to the east and west respectively (Perouty *et al.*, 2012). Mineralisation is hosted in metasedimentary rocks overlying a sequence of metavolcanic rocks (Machiridza and Mireku-Antwi, 2012). Separating these two lithologies is a regional fault marked by a graphitic shear zone referred to as the Akyem Carbon Fault (Machiridza and Mireku-Antwi, 2012). With the exception of some granitic intrusive rocks and Phanerozoic sedimentary rocks, all other lithological units in the Birimian system have been regionally metamorphosed to greenschist facies.

Gold mineralisation is wholly in the hanging wall volcanoclastic metasedimentary rocks in lenses of altered mylonites and breccia resulting from shearing, faulting and alteration of quartz-sericite-ankerite-calcite-siderite-albite-pyrite (Machiridza and Mireku-Antwi, 2012). Atule (2007), however, believes that mineralisation is hosted also in metavolcanic rocks. Higher gold grades of up to 4 g/t occur as discontinuous lenses whereas lower grades of about 0.7 g/t are continuous (Machiridza and Mireku-Antwi, 2012). These varying gold grades occurrence suggest that there could probably be different styles of gold mineralisation.

This research sought to characterise the lithological differences, structure and styles of gold mineralisation in the ore section. The various mineralisation styles were compared with similar gold mineralisation in the Birimian and elsewhere in order to consider applying successful exploration methods in these places in the Akyem district.

1.2 Objectives of the Research

The objectives of this research were to:

1. Determine the lithologies and textural difference within the ore section;

2. Describe the styles of alteration and mineralisation in the ore section;
3. Relate the alteration and mineralisation to the geochemistry.

1.3 Methods Used

The methods adopted in this research include:

1. Review of relevant literature on gold mineralisation in the Birimian in general and Ashanti belt in particular;
2. Geological pit mapping, drill core logging and sampling for petrographic studies;
3. Polished and thin section preparation for petrographic studies;
4. Whole rock analysis of representative samples using X-ray fluorescence and ICP-AES methods; and
5. Data analysis and interpretation using geochemical plots and multivariate statistics.

1.4 Facilities Used

The facilities used for this research include:

1. Library, computer and internet facility of University of Mines and Technology and Newmont Golden Ridge Limited;
2. Rock preparation facilities at UMaT; and
3. XRF, ICP-AES and ICP-MS analysers at SGS Limited, South Africa.

1.5 Thesis Organisation

This thesis is organised in six chapters. Chapter 1 contains the introduction, gives a brief outline of the work and background of the study area. Chapter 2 consists of the literature review, Chapter 3 consists of the methods used and results from petrographic and mineralogical studies. Chapter 4 deals with the presentation of the results from geochemical analysis. In Chapter 5 the results are discussed. Chapter 6 deals with conclusions and recommendations from the study.

1.6 Background to the Study Area

The Akyem Mine gold deposit is a recent discovery that resulted from a geochemical exploration programme carried out in the early 1990s. The initial emphasis during the exploration was on the Tarkwaian around the old Ntronang mine which operated between 1934 - 1948 and produced about 542000 tonnes of ore at an average gold grade of 4.8 g/t. After litho- geochemical sampling to outline the continuity of the Ntronang reef identified some stream anomalies in the underlying Birimian, a follow up with geochemical soil sampling was carried out. This outlined a 3 km long soil anomaly. Trenches were sited on the best anomalous zones and these returned good gold grades that indicated continuity of the anomaly into the saprolite zone. Drilling commenced in April 1999, and continued to 2011 with a hiatus between 2002 and 2008, delineating a gold deposit over an ENE / WSW strike length of at least 1,300 m and 700 m deep from surface (Machiridza and Mireku-Antwi, 2012).

Open pit mining commenced in the last quarter of 2012 in the Akyem deposit and has provided a unique opportunity to study the petrography and geochemistry at the deposit scale. This open pit permits, for the first time, a detailed mapping of hydrothermal fluid pathways and other structures associated with gold within the unweathered bedrock, providing unprecedented detail not available to previous researchers. This research therefore sought to take advantage of these opportunities to fill the knowledge gap on the types of lithologies, styles of alteration, paragenesis and mineralogical siting in the ores of the Akyem Mine gold deposit.

1.7 Background to the Mine

1.7.1 Location of Akyem Mine Deposit

The Akyem Mine gold deposit, whose centroid is latitude 6º21’N, longitude 1º01’W, is located in the Birim North District of the Eastern Region of Ghana, West Africa. The deposit is located approximately 3 km west of the District capital, New Abirem, 133 km west of the regional capital, Koforidua and 180 km northwest of Accra (Machiridza and Mireku-Antwi, 2012)

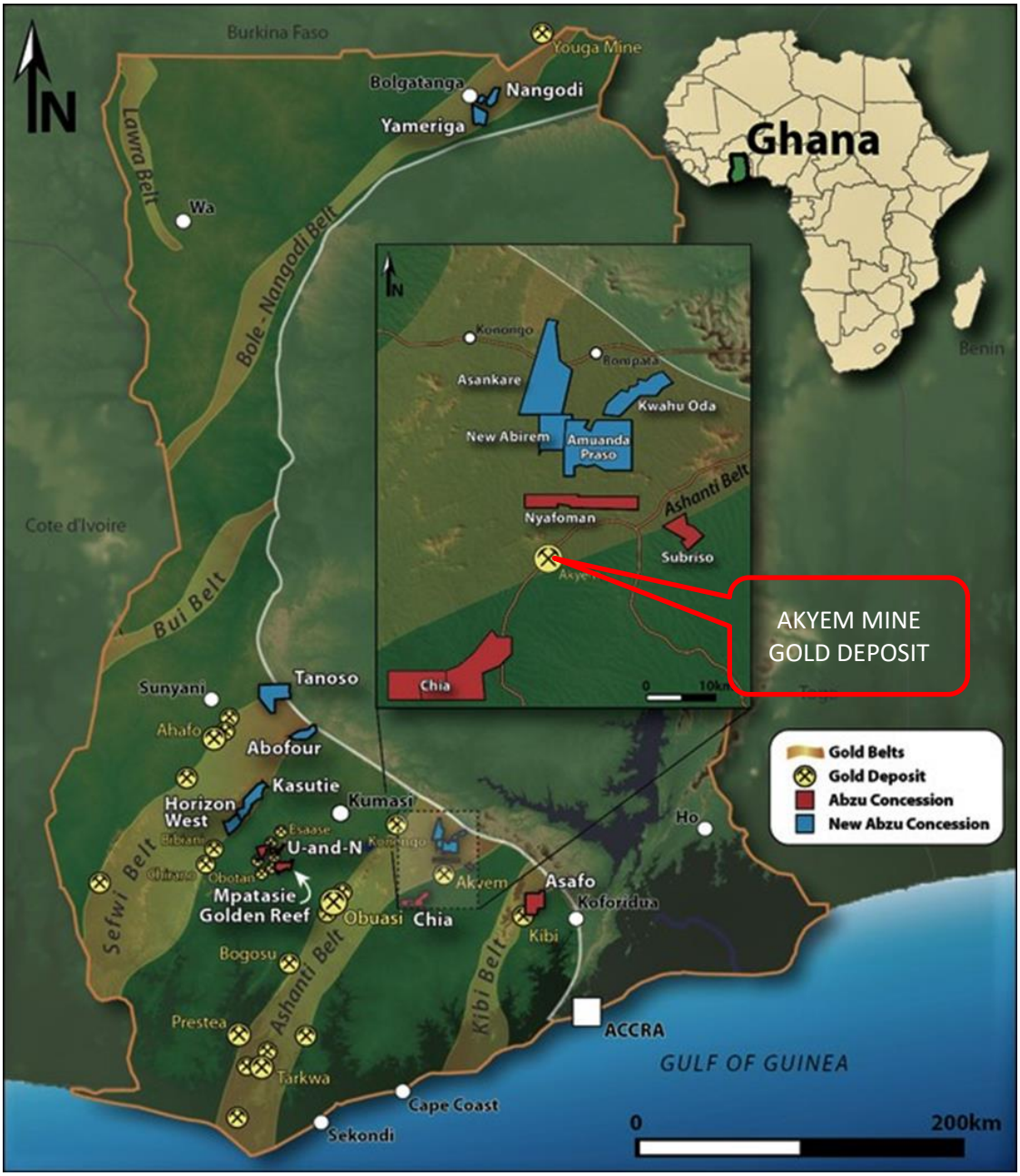

Fig. 1.1 Map of Ghana showing gold belts and the location of Akyem Mine gold deposit (After Leube *et al.*, 1990)

1.7.2 Relief and Drainage

The relief of the Birim north district is characterised by undulating landscape with prominent ridges of about 180 to 250 m above sea level in the east and western flanks of the district. The central part of the district, comprising the area stretching from the south of New Abirem (the district capital), through Nkwateng, Brenase, Ofoase, and Ayirebi to Otwereso

in the south and Akokoaso in the east, is described as low lying with maximum elevation of 61 m above sea level (Anon, 2009).

The Birim North district is drained mainly by two historical rivers, the Pra and the Birim. The Pra River serves as the boundary between the Birim North district and two other districts in the Ashanti Region (Asante Akyem South and Adansi South), while the Birim River serves as the southern boundary. The tributaries of these rivers include the Nwi, Mamang, Adechensu, Sukrang and Afosu. All these rivers and streams flow generally from the northeast to the southwest to join the Pra, which flows southwards and enters the sea in the Western Region (Anon, 2009).

1.7.3 Climate and Vegetation

The Birim North district experiences a double maxima rainfall pattern. The first rainy season starts from late March to early July, and the second season from mid-August to late October. The amount of rainfall received in the district is between 150 cm and 200 cm, reaching its maximum during the two peak periods of May-June and September-October yearly. The temperature ranges from a minimum of 25.2 ^{o}C to a maximum of 27.9 ^{o}C. The humidity is about 55-59 per cent during the entire year.
The Birim North District is one of the forested districts in the country. Parts of these forests have been reserved to ensure sustainable use of the natural resources resulting in the creation of nine forest reserves to preserve part of the original vegetation in the district (Anon, 2009).

1.8 Regional Geology

Ghana is located in the West African sub-region, which is largely underlain by the West African craton. The craton is sub-divided into two domains, the Archaean Reguibat Shield in the north around Mauritania and the Palaeoproterozoic Man Shield in the south between Ghana and Senegal (Leube *et al*. 1990).

The Man Shield covers the southernmost third of the craton. It is divided into two sectors, a western portion made up of rocks of Liberian age (3.0–2.5 Ga) and an eastern terrain underlain by Palaeoproterozoic Birimian rocks.

The Birimian rocks in southern Ghana consist of four evenly-spaced tholeiitic to acidic volcanic belts trending NE–SW. These are Bui, Sefwi, Ashanti and Kibi-Winneba belts from west to east, respectively (Leube *et al*. 1990). The belts are separated by sedimentary basins namely the Sunyani, the Kumasi and the Akyem Basins, respectively (Agyei Duodu *et al.*, 2009). These basins between the volcanic belts are filled with predominantly turbiditic sediments (Leube *et al.*, 1990; Allibone *et al*., 2002a). The transition zones between the volcanic rocks and the sedimentary rocks are filled with chemical sediments. All the units are contemporaneous, and may be lateral facies equivalents (Leube *et al.*, 1990).

Tarkwaian detrital metasedimentary sequences unconformably overlie and are interbedded with the Birimian units and contain clasts derived from Birimian rocks. The Tarkwaian conglomerates, sandstones and phyllites appear to have accumulated in restricted basins within the volcanic belts of the Birimian towards the end of the volcanic cycle (Leube *et al.*, 1990). Three granitic successions have intruded the Birimian rocks:

- The basin (Cape Coast) type granitoids in the sedimentary basins, which are dominated by two-mica granites;
- The belt (Dixcove) type granitoids associated with the volcanic belts, which are dominated by hornblende-bearing granites;
- Bongo, Tongo, and Banso post-Tarkwaian granitoids that are late-stage and K-rich granitoids.

The study area is located on the north eastern flank of the Ashanti Belt. The Ashanti Belt is one of the great gold mining districts in the world with recorded production of 60+ Moz of gold (Perouty *et al*., 2012). There are three distinct suites of gold deposits in the belt; Birimian-hosted, Tarkwaian-hosted and Recent alluvial deposits:

- Birimian hosted gold in Ghana is present as two major types: (A) the disseminated sulphide type which is generally lithofacies controlled, thus controlled by chemical sediments, and to a lesser extent by selvages of gold-quartz veins; and (B) the quartz vein type which is exclusively structure controlled (Leube *et al.*, 1990). Birimian-hosted deposits are the most important in terms of total gold production and are well-represented on the western margin of the Ashanti belt (Obuasi, Bogosu, and Prestea). These deposits are hosted by shear zones where gold occurs in individual quartz veins as disseminations in wall rock alteration assemblages or in quartz veins and

stock-works with disseminated sulphides. Arsenopyrite is the major sulphide in the deposits located on the western margin of the belt and pyrite is dominant in the deposits located on the eastern margin (Wassa, Akyem). Gold associated with arsenopyrite is often refractory in nature.

- Tarkwaian -hosted deposits consist primarily of auriferous, silicified quartz pebble conglomerates (Tarkwa, Bogosu, and Teberebie). Sheeted quartz vein stockworks hosted by Tarkwaian sediments are exploited at Damang.
- Alluvial deposits occur in almost all the major rivers draining the Ashanti belt (Ofin, Ankobra and Pra Rivers) (Oberthür *et al*., 1994).

CHAPTER 2

LITERATURE REVIEW

Gold mineralisation around the world occurs in a wide variety of host rocks and structural settings. The dominant host rocks are zones of mafic to ultramafic rocks like basalts and granitic intrusions. However, there are commonly district-specific lithological associations acting as chemical and/or structural traps for the mineralising fluids as illustrated by tholeiitic basalts and flow contacts within the Tisdale Assemblage in Timmins, Canada (Hodgson and MacGeehan, 1982; Brisbin, 1997). A large number of deposits in the Archaean Yilgarn craton in Australia are hosted by gabbroic sills and dykes (Solomon *et al*., 2000). Palaeoplacer deposits such as the Witwatersrand in South Africa are believed to be late Archaean deposits that were eroded from Middle Archaean lode sources (Goldfarb *et al*., 2001). Similar deposits occur in Serra de Jacobina region in north-eastern Brazil.

Gold occurs in preserved Archaean greenstone belts like the Yilgarn in Western Australia, Abitibi of the Superior Province in southern Canada and Barberton in South Africa to recently-active Phanerozoic metamorphic belts particularly greenschist facies rocks e.g. the Otago gold deposit of South Island, New Zealand (Groves *et al*., 1998, 2000).

Rocks of the Birimian Supergroup host all the major gold deposits in Ghana apart from the Paleoplacer deposits which are hosted in the Tarkwaian Group (Pigeois *et al*., 2003). The Birimian rocks comprise evenly spaced belts of volcanic rocks separated by successions of sedimentary rocks into which most of the granitoids have been intruded. Available field evidence suggests that the volcanic and sedimentary rock sequences were originally lateral equivalents (e.g. Leube *et al*., 1990; Hirdes *et al.*,1993). Birimian volcanic rock sequences are estimated to have originally been 4,000 to 12,000 m thick (Sylvester and Atoh, 1992), although they are now highly attenuated. They comprise basaltic and andesitic lavas interlayered with volcanogenic turbidites with rare rhyolitic and dacitic lavas and pyroclastic rocks, and some clastic sedimentary rocks at the base (Leube *et al.*, 1990; Hirdes *et al.*, 1993). Thick sedimentary rock successions fill the basins between the volcanic belts and are intercalated along strike with the volcanic rocks. Greywackes and

argillites are the dominant lithologies regionally but chert, ferruginous chert and carbonate rocks may be common at the transition between volcanic and sedimentary successions (Leube *et al.,* 1990).

Observation of various metamorphic belts worldwide by Groves *et al.* (1998) indicated a strong association of gold and greenschist facies rocks. However, some significant deposits occur in higher metamorphic grade Archaean terranes (e.g. McCuaig *et al*., 1993) or in lower metamorphic grade domains within the metamorphic belts of a variety of geological ages. In the Archaean of Western Australia, a number of syn-metamorphic deposits extend into granulite facies rocks (Groves *et al*., 1992). Pre-metamorphic protoliths for the auriferous Archaean greenstone belts are predominantly volcano-plutonic terranes of oceanic back-arc basalt and felsic to mafic arc rocks. Clastic marine sedimentary rock dominant terranes that were metamorphosed to greywacke, argillite, schist and phyllite host most of the younger ore deposits and are important in some Archaean terranes (e.g. Slave Province, Canada). Higher grade metamorphism, typically upper amphibolite to granulite facies, may also be associated with gold mineralisation as in Hemlo gold deposit in the Superior province, Canada and Griffin's Find in the south-west Yilgarn Craton, Australia (Philips and Powell, 2009).

In the Birimian of Ghana, all lithologies, apart from some late Eburnean granitoids, dolerite dykes and Phanerozoic sediments, have undergone metamorphism that generally does not exceed upper greenschist facies (Perrouty *et al*., 2012). Studies on amphibole-plagioclase assemblages suggest the peak temperature and pressure was 500–650 ◦C and 5–6 kbar respectively (John *et al*., 1999) and dated at 2092 ± 3 Ma (Oberthür *et al*., 1998).

There is strong structural control of mineralisation at a variety of scales. The controlling structures are commonly ductile to brittle stockwork or breccia zones in competent rocks (Kerrich *et al*., 2000). Deposits are normally sited in second or third order structures, most commonly near large-scale (often trans crustal) compressional structures (Groves *et al.,* 1998). Although the controlling structures are commonly ductile to brittle in nature, they are highly variable in type, ranging from: (a.) brittle faults to ductile shear zones with low-angle to high-angle reverse motion to strike-slip or oblique-slip motion; (b). fracture arrays, stockwork networks or breccia zones in competent rocks; (c). foliated zones (pressure solution cleavage) or (d). fold hinges in ductile turbidite sequences. Mineralised structures

have small syn- and post-mineralisation displacements, but the gold deposits commonly have extensive down-plunge continuity (hundreds of metres to kilometres). Extreme pressure fluctuations leading to cyclic fault-valve behaviour (Sibson *et al.*, 1988) result in flat-lying extensional veins and mutually cross-cutting steep fault veins that characterise many deposits (e.g. Robert and Brown, 1986). Birimian mineralisations are often hosted within shear zones that transect sediments, mafics or granitoids (Perrouty *et al.*, 2012).

In most deposits the alteration zones are composed of mineral assemblages that are stable in similar pressure and temperature conditions as the metamorphic assemblages in surrounding rock commonly calcite, ankerite, quartz, dolomite, sericite and sulphide minerals such as chalcopyrite, sphalerite, galena, etc. (Ridley, 2013). Since Fe is present only in carbonate and sulphide minerals in these zones, the rocks often appear bleached compared with less strongly altered rocks. These minerals grow over the earlier rock textures in such a way that phyllic altered rock appears bleached and often almost textureless in hand sample. Other gangue minerals can include K-feldspar, kaolinite, biotite, rutile, anhydrite, topaz and tourmaline.

Phyllic alteration occurs at moderate temperatures (200 – 450 ^{o}C) and is the result of a moderately to strongly acidic fluid such that the metasomatic reactions involve addition of H^+ and dissolution of K, Na, Ca, Mg, Ti, Fe from the rocks (Ridley, 2013), as in the replacement of K-feldspar by sericite: $3KAlSi_3O_8 + 2H^+ \Longleftrightarrow KAl_3Si_3O_{10}(OH)_2 + 6SiO_2 + 2K^+$. Chlorite and calcite are dominant in distal zones. The essential hydrothermal alteration produce zoned alteration envelopes which are characterised principally by progressive carbonatisation and K (and Na) metasomatism resulting from progressive interaction of the wall rocks with hydrothermal fluid (Robert and Brown, 1986). Gold in the wall rocks may be associated by fixation of K, Si, Ca, and Na and depletion of Mg, Fe, and Al in the wall rocks (Robert and Brown, 1986). Trace element enrichments of As, Ag, Sb, Zn, Pb, Cu, S, Mo, Te, W, and depletion of Co, Cr, Ni, Rb, Sr and rare earth elements in the alteration zones are commonly observed (Aliyari *et al.*, 2014).

All lithologies of the Man-Leo Shield, including mafic and intermediate volcanic rocks, granitoids, clastic sedimentary rocks, and BIFs, host economic gold lodes (Markwitz *et al.*, 2016). Most gold deposits of the Man-Leo Shield, the majority of which were originally mined from associated alluvial gold concentrations by artisanal miners, show typical

characteristics of the orogenic gold model (Groves *et al.,* 1998; Goldfarb *et al.,* 2005) that specifically describes gold-rich lodes in deformed and metamorphosed rocks. The gold ores throughout the Man-Leo Shield have features that are typical of orogenic gold deposits worldwide.

Gold belts in Ghana, as reported by Para *et al*. (2015) comprise of basaltic flows, andesitic lavas, pyroclastic and sedimentary rocks. These constitute the Palaeoproterozoic Birimian Supergroup (2.2-2.1 Ga) that extends to the south western part of the country. Two distinct granitic suites occur in the Birimian Supergroup; the belt granitoids (2.172 Ga) and the basin granitoids (2.104 Ga) intrude the metavolcanic and metasedimentary rocks respectively (Oberthur *et al.,* 1998). The Tarkwain palaeoplacer deposits are spatially restricted to the volcanic belts and are believed to have been sourced from the Birimian (Oberthür *et al.,* 1994).

Mineralisation in the Birimian is structurally controlled by multi-phase ductile deformation of the host rock (Allibone *et al.,* 2002a). Three (3) major mineralisation types have been identified in the Birimian. These are mesothermal ores in quartz veins as in Obuasi, sulphide hydrothermal mineralisation as in Bogoso, and disseminated and stockwork-type hydrothermal mineralisation in granitoids like the Ayanfuri gold deposit.

Gold mineralisation in mesothermal ores in quartz veins and sulphide ores are found in and adjacent to quartz carbonate-albite veins surrounded by halos of intense ankerite–albite alteration. The proximal zone consists of ankerite, quartz, dolomite, sericite and sulphide minerals. Pyrite is the dominant sulphide in most ores and typically coexists with pyrrhotite and/or arsenopyrite (Oberthur *et al.,* 1994; Mumin *et al.,* 1994; Allibone *et al.,* 2002a, b; Allibone *et al.,* 2004).

The Akyem gold deposit is on the north-eastern flank of the Ashanti belt, bounded by the metasedimentary Akyem and Kumasi basins to the east and west respectively (Perouty *et al.,* 2012). Mineralisation is hosted in metasedimentary rocks overlying a sequence of metavolcanic rocks. Separating these two lithologies is a regional fault marked by a graphitic shear zone referred to as the Akyem Carbon Fault (Machiridza and Mireku-Antwi, 2012). All primary lithological units have been regionally metamorphosed to greenschist facies (Atule, 2007). Mineralisation is wholly in the hanging wall

metasedimentary rocks in lenses of altered mylonites and breccia resulting from shearing, faulting and alteration of quartz-sericite-ankerite-calcite-siderite-albite-pyrite (Machiridza and Mireku-Antwi, 2012). Atule (2007), however, believes that mineralisation is hosted also in metavolcanic rocks. Higher grade of 4 g/t occurs as discontinuous lenses whereas lower grades of about 0.7 g/t are continuous (Machiridza and Mireku-Antwi, 2012). These show that there could probably be different styles of gold mineralisation.

The ore zone at the Akyem mine is exposed for about 8 km along strike and down to 1650 m below surface. The ore zone consists of several ore bodies which run sub parallel to the regional strike and measure up to several hundred meters both horizontally and vertically at thicknesses of up to 50 m. The ore bodies and their immediate host rocks are further characterised by intense shearing, pronounced sulphide impregnation of country rocks, and/or multiple to massive quartz veining.

CHAPTER 3

METHODS USED

3.1 Methods Used

In order to get good representation of the rocks mapped and logged in boreholes, samples for geochemical and petrographic studies were selected from drill cores in the Akyem gold deposit that intersected the ore section (ore zone and host rocks) Sampling was done across the local strike of the deposit as shown in Fig. 3.1. All the samples were taken from oriented diamond drill cores in fresh rocks in order to derive maximum information.

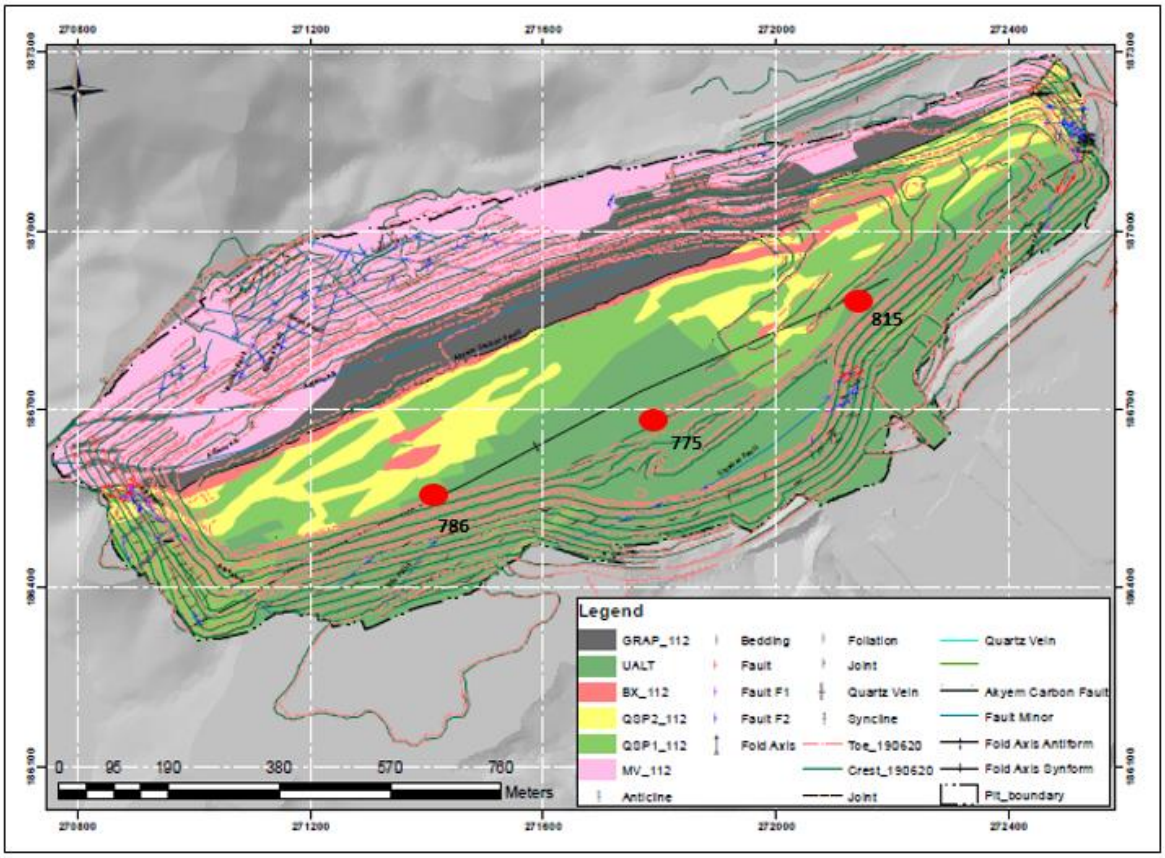

Fig. 3.1. Map of Akyem Main Pit showing Collar Locations of Sampled Drill holes (Anon, 2019)

A total of thirty-eight (38) samples were taken across the deposit such that a minimum of three samples occur in each rock units taking into consideration the alteration and sulphide mineralisation. Hand specimen description was conducted on all the rock samples and sixteen thin and polished sections from fresh rock samples were investigated in transmitted

and reflected light microscopy to determine the petrographical characteristics at the Geological Engineering Laboratory at University of Mines and Technology (UMaT), Tarkwa. Thin sections preparation were carried out according to the procedure outlined in Hutchinson (1974) and studied under SM Lux Leitz microscope. Minerals identification was done using colour, texture, pleochroism, bireflectance, and anisotropy. Mineral abbreviations used were after Whitney and Evans (2010). Modal percentages were by point counting.

Polished sections were prepared for the identification and characterisation of the opaque phases in the samples and their textural relationships using SM Lux Leitz microscope with Canon camera attached. Mineral identification and textural relationships were aided by Picot and Johan (1982) and Spry and Gedlinske (1987). The modal percentages were normalised and plotted on QAP diagram (Streckeisen, 1974).

Thirty-three (33) representative samples, some of which were examined in thin and polished sections, were selected from the hanging wall in the ore section through the ore zone into the footwall for whole-rock analysis. Standard procedures were followed during preparation of samples for whole-rock geochemical analysis at SGS laboratory in South Africa. The samples were weighed and crushed to about 70 % below 2 mm and subsequently split using the riffle splitter, pulverised and split to 85 % passing through < 75 µm. Powdered samples were obtained by mechanical crushing and pulverisation using an agate mortar. Whole rock major element analysis was performed on fused discs by automated XRF-06 at SGS laboratory Services, South Africa. The specimens were prepared using 50 % lithium tetraborate ($Li_2B_4O_7$) and 50 % lithium borate ($LiBO_2$). A calcined or ignited sample (0.9 g) was added to 9.0 g of lithium borate flux (50 % - 50 % $Li_2B_4O_7$ – $LiBO_2$), mixed well and fused in an auto fluxer between 1050 – 1100 °C. A flat molten glass disc was prepared from the resulting melt. This disc was then analysed by X-ray fluorescence spectrometry. The upper detection limit is 100 % and lower detection limit is 0.01 %.

For Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) analysis, specimens were prepared using hydrofluoric (HF) acid, nitric acid (HNO_3) and perchloric acid ($HClO_4$) digestion and hydrochloric acid (HCl) leach. A prepared specimen (0.25 g) was digested with perchloric, nitric, hydrofluoric and hydrochloric acids. The

residue was topped up with dilute hydrochloric acid. Following this analysis, the results were reviewed for high concentrations of bismuth, mercury, molybdenum, silver and tungsten and diluted accordingly. Samples meeting this criteria were then analysed by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). Results were corrected for spectral inter-element interferences. Standard reference samples were used in the quantitative analyses of the elements. Further details of the analytical procedure, accuracy, precision and standards are available at the SGS laboratory, South Africa. The lower detection limits (in ppm) for the minor and trace elements are 10.0 (Ba, Cr, Cu, Li, Sr, V, Zn), 5.0 (As, Be, Ni, Pb, Sc), 2.0 (Mo), 1.0 (Si, Ag, Ga, Ge, Nb, Sn, W), 0.5 (Co, Sb, Ta, Tl, Y), 0.2 (Cd, In, Rb), 0.1 (Ca, K, S, Bi, Ce, Cs, La, Nd, Sm, Th), 0.05 (Dy, Er, Eu, Gd, Ho, Lu, Pr, Tb, Tm, U), 0.01 (Al, Fe, Mg, P, Ti) and 0.001 (Mn).

CHAPTER 4

GEOCHEMISTRY AND PETROGRAPHY

4.1 Results from Petrography

All alteration characterisation in this research are done with respect to the hanging wall of the Akyem fault since alteration and gold mineralisation are largely confined to this unit (Machiridza and Mireku-Antwi, 2012; Atule, 2007). Characteristics such as the rock texture, mineralogy, alteration and structures, are the main highlights used in this petrographic analysis. In general, all rock units display varying degrees of carbonatisation, sulphidisation, quartz veining and silicification, as well as development of phyllosilicate minerals such as chlorite, sericite and fuschite (Machiridza and Mireku-Antwi, 2012). Previous studies by Atule (2007) classified the rock sequence into greywacke, quartz epiclastic, hanging wall mafic volcanic unit, graphitic mylonite and footwall mafic volcanic unit. The petrographic evidence available to determine the rock type at this stage was scanty as the primary textures have been altered by late alteration minerals such as silica, albite, carbonate and epidote. The rock was therefore subjected to geochemical classification described later in this study.

The rock samples studied comprise non-mineralised and mineralised rocks as well as hydrothermally altered and unaltered rocks. They were classified based on alteration intensity as: unaltered rock, weakly altered rock, moderately altered rock, highly altered rock (all in hanging wall) and footwall rock.

4.1.1 Unaltered Hanging Wall Rock

In hand specimen the rock is dark green, medium to fine grained, thinly foliated with foliation marked by chlorite alternating with plagioclase and fine to medium grained varieties of quartz.

In thin section, textures vary from medium to fine grain, they are strongly sheared with foliations marked by plagioclase alternating with chlorite in amphibole rich layers. Calcite

is euhedral to subhedral, shows twinkling and overprints foliation (Fig. 4.1A). Dolomite replaced plagioclase in the chlorite-rich zone and is porphyroblastic with chlorite weaving around the margins (Fig. 4.1B). Both dolomite and calcite are rich in inclusions of chlorite. Epidote also replaced amphibole, is colourless and shows pink and green colouration under cross nicols. Muscovite is rarely present, is fine to medium grained, parallel to and associated with sheared plagioclase.

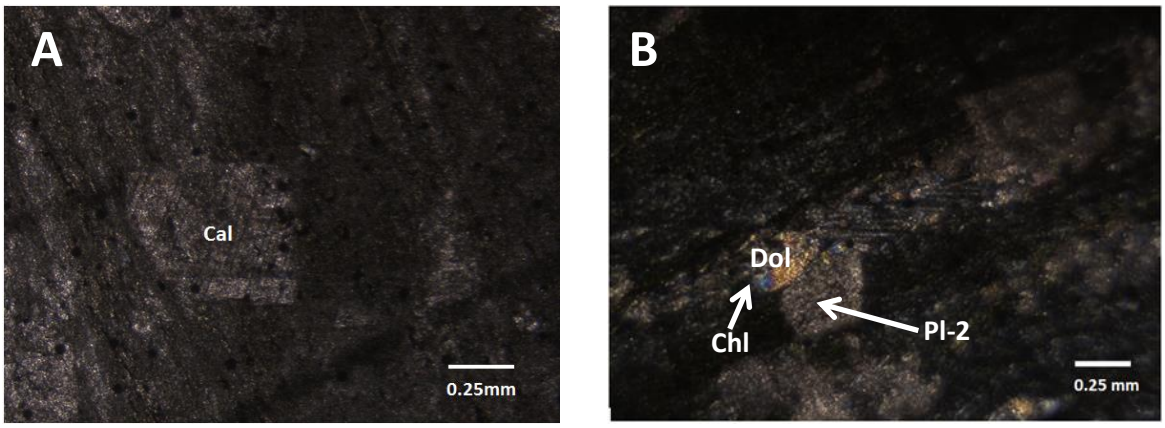

Fig. 4.1 Photomicrograph of 'metavolcanic' rock showing: A. Euhedral calcite which overprints foliation in thin secton under plane polarised light. B-Subedral medium grained plagioclase 2 that partially replaced dolomite in thin secton under cross nicols.

Table 4.1 Modal Percentages of Minerals in the Unaltered 'Metavolcanic' Rocks On Akyem Mine Gold Deposit

	Sample ID		
Mineral	786_16	815_4	775_1
Plagioclase	15	25	15
Amphibole	20	-	-
Chlorite	28	22	30
Quartz	10	40	40
Sericite	3	5	3
Epidote	5	5	5
Dolomite	10	-	-
Calcite	5	-	-
Carbonate (Undifferentiated)	-	-	2
Muscovite	3	-	-
Ore minerals	1	3	5
Total	**100**	**100**	**100**

4.1.2 Weakly Altered Rock

The rock is green, fine to medium grained, thinly foliated.The rock is spotted by pervasive fine quartz-carbonate joints at high angle to foliation. It is marked by light green recrystallised quartz. The rock is also banded green with patches of light green, fine to medium grains. Light green zones have patches of dark green alteration. There are dark grey quartz veins with wormy shape offset by quartz- feldspatic veins. Fine dark grey quartz cuts across the rock. Sulphides aggregate into pockets along foliations.

In thin section, the rock is fine to medium grained, strongly sheared with foliations marked by partially altered, elongated plagioclase and amphiboles (Fig. 4.2A). Plagioclase 1 is partially replaced by sericite and quartz whilst amphiboles 1 are altered to chlorite. Occasionally, dolomite replaces plagioclase in the chlorite rich zone and is porphyroblasitic with chlorite weaving around margins. Elsewhere, foliations are slightly thicker and made up of medium grained recrystallised quartz out of the fine grained strongly sheared quartz and show undulous extinction (Fig. 4.2B). There is also coarse grained plagioclase 2 that overprints earlier plagioclase 1 and appear to be a patch introduced during veining (Fig. 4.4D). Later amphiboles (Amph 2) are irregularly aligned, medium grained, weakly pleochroic from yellowish to green and show extinction at 54° (Fig. 4.5A). Quartz veins

occur in various forms. Fine grained quartz-plagioclase with chlorite appear to have been sheared and overprinted by medium grained quartz carbonate chlorite veins before quartz-carbonate veins with epidote of fine to medium grains. This is recrystallised into medium to coarse grained quartz which shows weak recrystallisation along green margins and also associated with medium grained epidote. The modal percentage of rock is shown in Table 4.2.

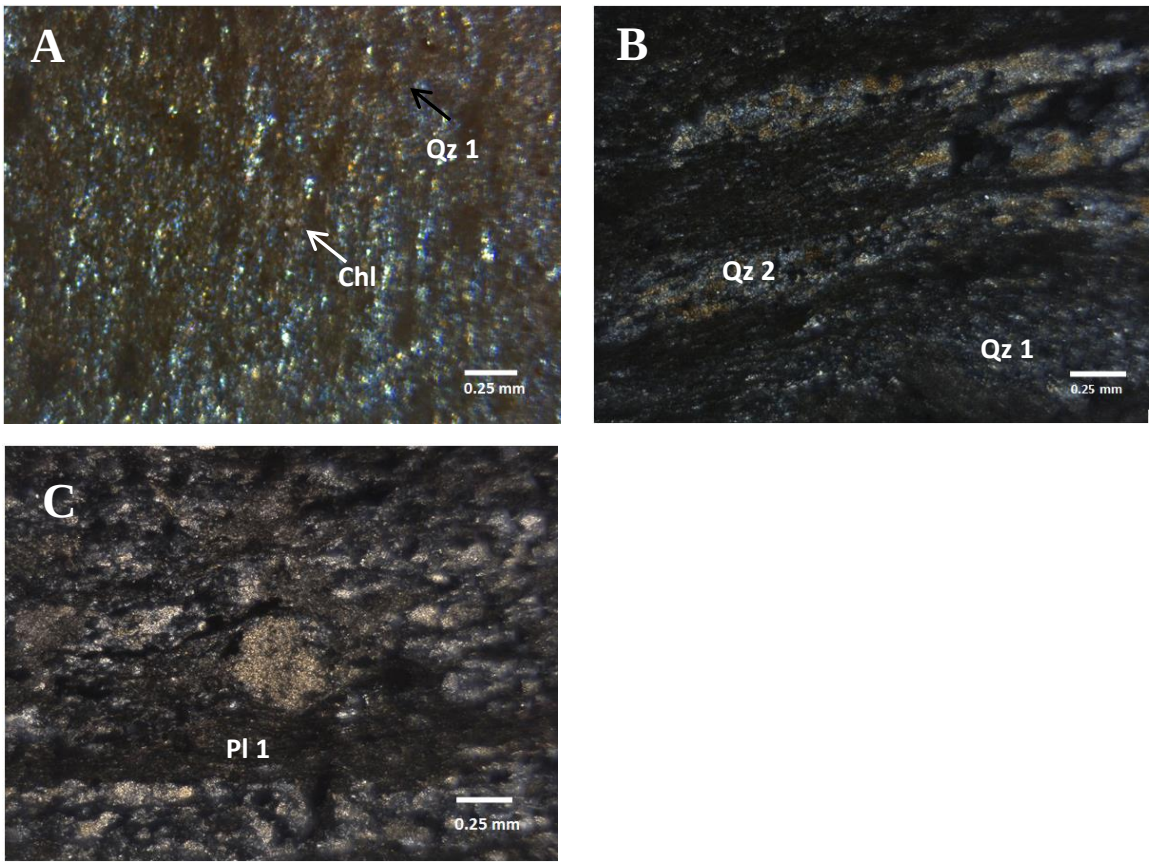

Fig. 4.3 Photomicrographs of Thin Sections of Massive Rock Showing A: Strong foliation marked by alternation of elongated plagioclase partially altered to sericite and quartz against amphibole partially altered to chlorite in thin secton under plane polarised light. B: Strongly sheared and recrystallised quartz into medium grained variety that shows undulous extinctionunder cross nicols. C: Foliation marked by plagioclase in thin secton under plane polarised light.

Table 4.2 Modal Percentage of Minerals in the Weakly Altered 'Metavolcanic' Rocks in Akyem Mine Gold Deposit

	Sample ID		
Mineral	**KD815_5**	**KD786_3**	**KD775_2**
Plagioclase	25	40	15
Amphibole	10	25	10
Chlorite	20	20	30
Quartz	27	7	35
Sericite	2	5	3
Epidote	5	2	5
Dolomite	8	-	-
Calcite	-	-	-
Carbonate (Undifferentiated)	-	-	-
Muscovite	-	-	-
Ore minerals	3	1	2
Total	**100**	**100**	**100**

4.1.3 Moderately Altered Rock

The rock is yellowish green, fine to medium grained, strongly foliated with foliation marked by sheared plagioclase alternating with sheared amphibole. In thin section, amphibole is partially altered to chlorite and epidote while plagioclase is partially altered to sericite and quartz and replaced by dolomite in amphibole rich zones. Two varieties of plagioclase exists. Sheared fine grained plagioclase (Pl 1) is replaced by medium grained plagioclase (Pl 2) which is irregularly aligned and aggregates into coarse grain with stellar texture, showing albite twinning at 24° extinction angle (andesine composition) and partially replaced by sericite and quartz. Plagioclase 2 is also partially replaced by dolomite (Fig. 4.4A). It also contains clusters of subhedral disseminated sulphides.The rock also contains zones with medium grained quartz that was probably introduced during shearing. These occur as patches and they are recrystallised into coarser grains which show undulous extinction with inclusions of quartz and sulphides.

Some ore minerals are tabular, euhedral, medium grained with or without inclusions of plagioclase (Fig. 4.4B) but finer grained ore minerals are free of inclusions. Coarse grained ones are parallel to shear whilst the finer grained versions, free of inclusions, cut across

secondary shear. Fine granules anhedral in shape occur along foliations and appear to have been introduced during the secondary shear (Fig. 4.4C). Later alteration of dolomite produced fine grained plagioclase, epidote, sericite and very fine grained ore minerals. These ore minerals also rim dolomite (Fig. 4.4D). The modal percentage of rock is shown in Table 3.3.

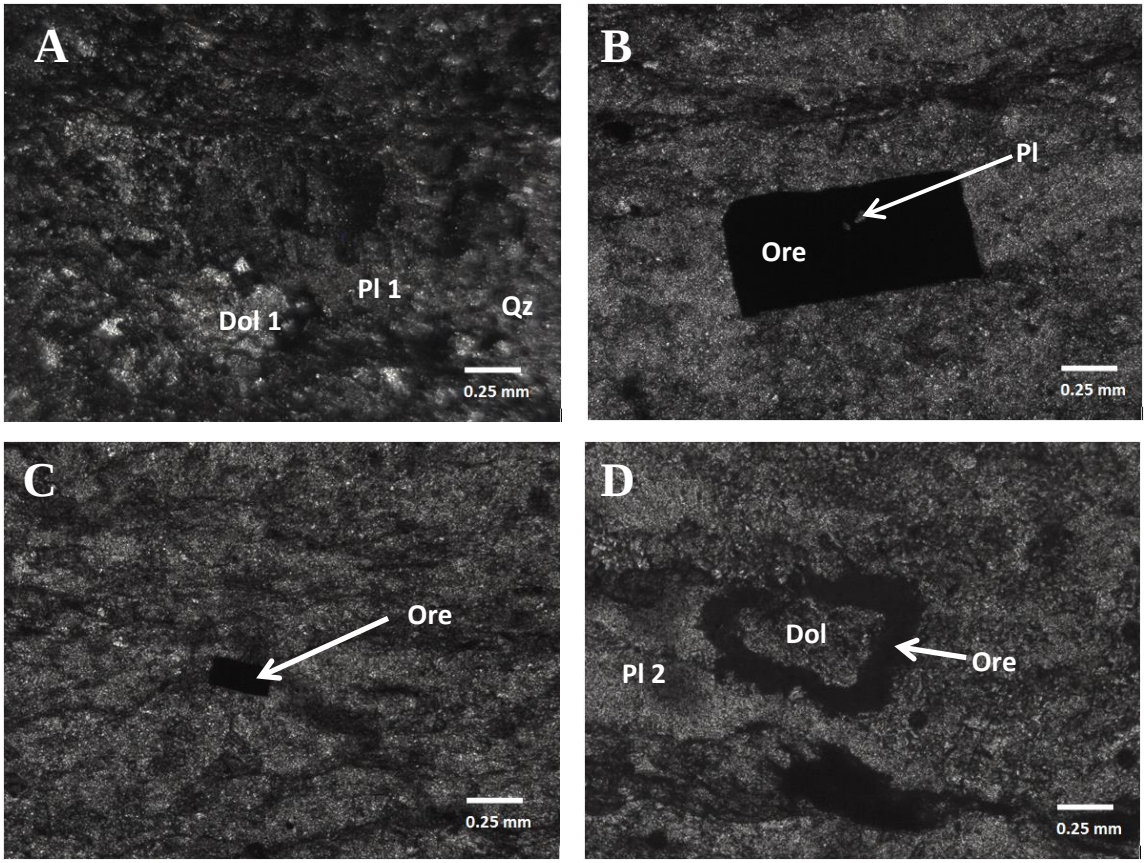

Fig. 4.4 Photomicrographs of Thin Sections of Massive Rocks under plane polarised light showing A: Coarse grained plagioclase 2 that is partially replaced by quartz. B: Medium grained tabular ore mineral with plagioclase inclusion. C: Fine granules of ore minerals anhedral in shape occur along foliations and appear to have been introduced during the secondary shear. D: Ore minerals that rim dolomite.

Table 4.3 Modal Percentage of Minerals in the Moderately Altered 'metavolcanic' Rocks in Akyem Mine

	Sample ID		
Mineral	**KD786_11**	**KD775_3**	**KD815_8**
Plagioclase	25	24	15
Amphibole	15	16	10
Chlorite	20	22	20
Quartz	20	20	35
Sericite	3	5	5
Epidote	5	11	5
Dolomite	10	-	5
Calcite	-	-	-
Carbonate (Undifferentiated)	-	-	-
Muscovite	-	-	-
Ore Minerals	2	2	5
Total	**100**	**100**	**100**

4.1.4 Highly Altered Rock

The rock is generally fine to medium grained, yellowish to dark grey. It is thinly foliated, sheared with alternating bands of green and light grey quartzo-felspartic zones. There are pods of quartz across foliations which have been sheared. Medium grained amphiboles and fine grained sulphides are disseminated in the rock. In thin section, the rock is thinly foliated, strongly sheared with quartz-feldspar drawn out along foliation that is marked by chlorite (see Fig. 4.5B).

Two generations of amphiboles occur; under plain polarised light, amphibole 1 is fine grained, pleochroic from green to dark green, flaky, shows parallel extinction and is overprinted by amphibole 2 which is medium grained, prismatic, subhedral, strongly pleochroic from green to dark green and shows extinction at 32.5^{o} to 53° (Fig. 4.4A). Two generations of plagioclase occur as well. Sheared plagioclase (Pl 1) is replaced by porphyritic plagioclase (Pl 2) with albite twinning at 40^{0} extinction angles (Labradorite composition) and appear to have been introduced during veining (Fig. 4.4D).

Two generations of dolomite were observed. Dolomite 1 that replaced plagioclase 1 and dolomite 2 that replaced Plagioclase 2 (Fig. 4.4D). Plagioclase 2 is rich in inclusions of chlorite. Dolomite 1 that replaced inclusions free plagioclase 1 is observed to only form in close proximity to amphiboles or in amphibole rich zones. Dolomite 2 veins occupy joints and occasionally faults at high angle to the main shear. These dolomite veins are further overprinted by fine irregular chlorite. The late irregular chlorites also overprint the calcites (Fig. 4.4B). Ore minerals occur as fine grain along foliations and as inclusions in amphibole, dolomite and calcite.

Three varieties of quartz were observed; fine grained quartz (Qz 1) with plagioclase and chlorite appear to have been sheared and overprinted by medium grained quartz (Qz 2) that appear to have been introduced probably during shearing (Fig. 4.2B). Quartz 2 is colourless and parallel to foliation, shows inclusions of sericite, under cross nicols, it appears recrystallised into fine quartz at triple junctions. Quartz 3 occurs as patches and they are recrystallised into coarser grains which show undulous extinction with irregular margins and appear as pinch and swell (Fig. 4.5A). Ore minerals occur in association with recrystallised quartz and in the matrix of the fragments. Quartz 3 occurs as disseminated pods across foliation which has been sheared.

Sheared and recrystallised quartz forms sutured margins and appear to be alternating with amphiboles in chlorite rich zones. Chlorite rich cleavages occur across the shear. These occur as patches and they are recrystallised into coarser grains which show undulous extinction with inclusions of quartz and sulphides. Two generations of sulphides are observed. One generation that mark foliation and the other generation that overprint foliation. The one marking foliation is cut by quartz-chlorite veinlet. Two generations of ore zones, the earlier one associated with plagioclase-rich vein or albitisation and the second one associated with sheared quartz. The ore minerals are pyrite, arsenopyrite, magnetite and pyrrhotite. The one associated with albitisation is marked by chlorite and is coarser grained and anhedral but the one associated with silicification is fine grained and shaped as cubic, anhedral or tabular (see Fig. 4.4). The modal percentage of rock is shown in Table 4.4.

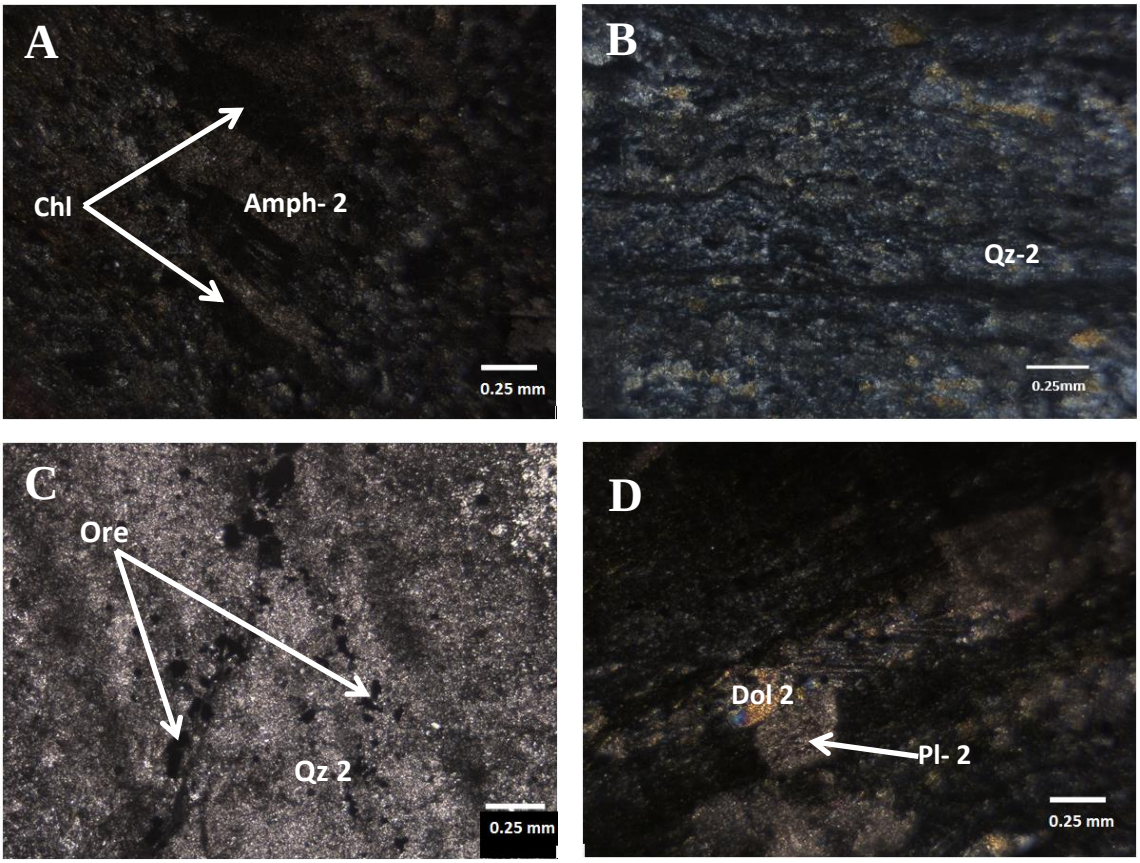

Fig. 4.5 Photomicrographs of Thin Sections under plane polarised light showing A: amphibole 2 that recrystallised from chlorite. B: Sheared and recrystallised medium grained quartz 2. C: coarse grained ore mineral parallel to plagioclase alteration and fine grained ore mineral at moderate angle to sheared quartz D: Subedral medium grained plagioclase 2 that partially replaced dolomite in cross nicols

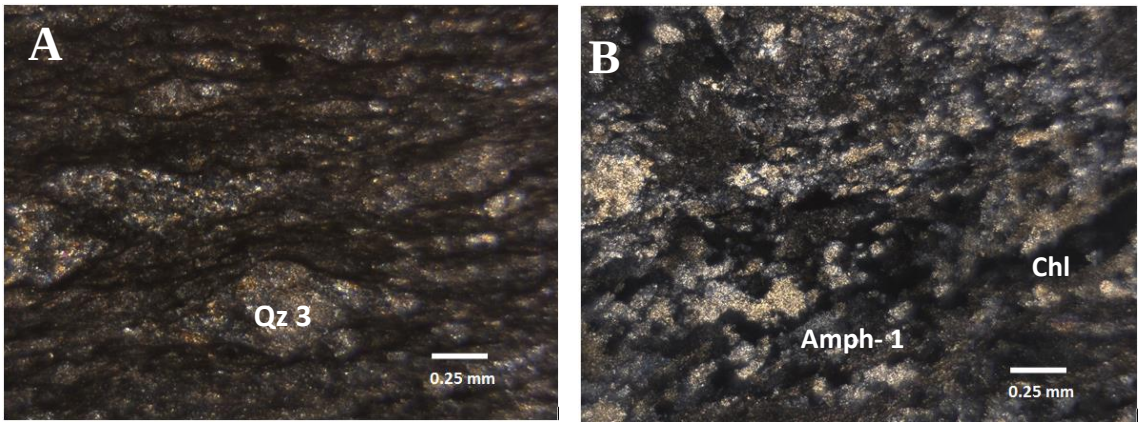

Fig. 4.6 Photomicrographs of Thin Sections under cross nicols showing A: Recrystallised quartz. B: Sheared and recrystallised quartz which form suitured margins and shows zones alternating with amphibole and chlorite.

Table. 4.4 Modal Percentage of Minerals in the Highly Altered 'Metavolcanic' Rocks in Akyem Mine

	Sample ID			
Mineral	**KD786_18**	**KD815_6**	**KD775_4**	**KD786_14**
Plagioclase	15	20	32	25
Amphibole	20	20	20	15
Chlorite	20	15	10	15
Quartz	15	25	30	25
Sericite	3	5	-	5
Epidote	3	5	5	5
Dolomite	-	-	-	5
Calcite	-	-	-	-
Carbonate (Undefrentiated)	20	5	-	-
Muscovite	-	-	-	-
Aspy+Py+Pyr+Mgt+A	4	5	3	5
Total	**100**	**100**	**100**	**100**

4.1.5 Footwall Rocks

The rocks in the footwall of the Akyem mine are pale greenish, largely massive but can appear strongly sheared with elongated plagioclase and quartz in chlorite rich zones. Light green zones have patches of dark green alternations. Fine grained dark grey quartz cuts across the rock. Quartz-carbonate veins occur in patches. There are sulphide marked foliations (sulphides aggregate into pockets along foliations). There are disseminated sulphides.

In thin section, the rock is massive and shows irregular alignment of medium grained plagioclase partially altered to chlorite (Fig. 4.5A). There is also coarse grained plagioclase that overprints earlier plagioclase and appear to be a patch introduced during veining. Later amphiboles are irregular aligned, medium grained, green weakly pleochroic from yellowish to green and show extinction at 54° (Fig. 4.5B).

The rock shows patchy quartz-carbonate and chlorite alteration that are offset by finer zones of the same variety with dark green chlorite veinlets running through it. Quartz veins occur in various forms. Fine quartz-plagioclase with chlorite appear to have been sheared and overprinted by medium grained quartz-carbonate-chlorite veins. These were observed to have then been overprinted by quartz –carbonate veins with epidote of fine to medium grains

(Fig. 3.5C). This is recrystallised into medium to coarse grained quartz which shows weak recrystallisation along green margins and also associated with medium grain epidote.

Ore minerals occur as fine to medium grained irregular, granular and elongated shapes along cleavages and veins. Coarse grained granular ore minerals overlaps all ore minerals. The modal percentage of rock is shown in Table 4.5.

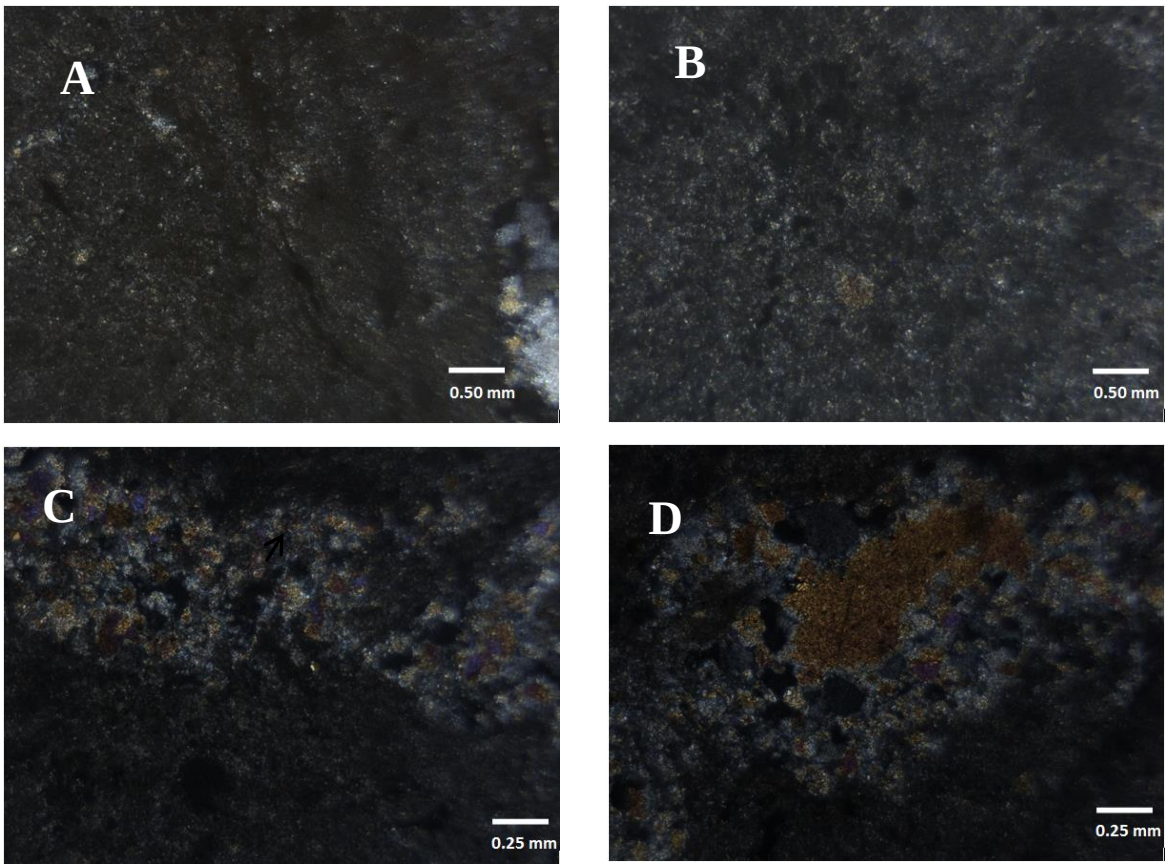

Fig. 4.7 Photomicrographs of Thin Sections of Massive Rock under cross nicols showing A: Weak foliations marked by chlorite across earlier fabric of irregular alignment of plagioclase which is partially altered to sericite and quartz. B: Irregualr alignment if partially altered plagioclase and amphiboles. C: Medium grain quartz carbonate epidote vein. D: Quartz carbonate overprint medium grained quartzo-feldspatic and epidote vein

Table 4.5 Modal Percentage of Minerals in the Footwall 'Metavolcanic' Rocks Akyem Mine Gold Deposit

Mineral/ Sample ID	KD786_19	KD815_14	KD775_5
Plagioclase	20	20	20
Amphibole	15	13.5	15
Chlorite	40	20	20
Quartz	17	10	15
Sericite	-	5	5
Epidote	5	1	3
Dolomite	-	30	-
Calcite	-	-	-
Carbonate (Undifferentiated)	-	-	-
Muscovite	-	-	-
Aspy+Py+Pyr+Hem+Mgt+Au	3	0.5	2
Total	**100**	**100**	**100**

4.2 Ore Mineralogy

The main ore minerals are native gold with pyrite, pyrrhotite, arsenopyrite, magnetite, chalcopyrite and hematite in decreasing amounts. Their intensity and relationship with gold has been ranked and this has resulted in having the rock alteration ranked as highly altered, moderately altered and weakly altered.

Gold is bright yellow, non-pleochroic, isotropic and fine to medium grained (see Fig. 4.8C). It overprints alteration minerals and sometimes occurs as inclusion in pyrite which is partially altered to pyrrhotite (Fig. 4.8B) . A finer grained gold (Au 1) is overprinted by gangue and elsewhere occurs along quartz carbonate veins whilst the medium grain version (Au 2) cut across the vein (Fig4.8C). Fine grained variety is parallel to foliation whilst the medium grained variety is at an angle to foliation (Fig. 4.8D)

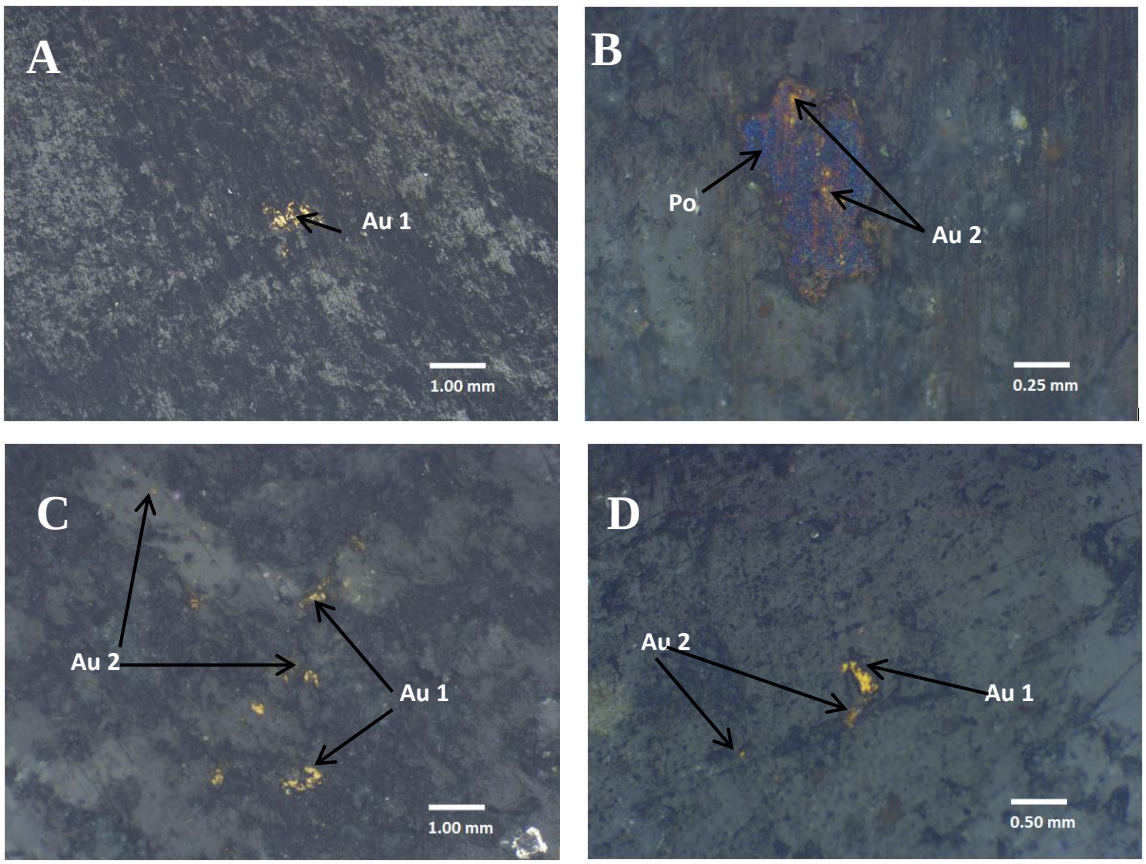

Fig. 4.8 Photomicrographs of Polished Sections showing A: Medium grained Au in crossed nicols. B: Fine grained Au under plane polarised light. C: Fine grained Au occurs along quartz veins whilst medium grained Au cuts across the veins. D: Au1 and Au 2

Three varieties of pyrite are observed; Granular pyrite (Py 1) is sub-parallel to foliation and appear to be an inclusion in gangue minerals that was involved in second shear (see Fig. 4.9 A). Pyrite 1also appears corroded by gangue minerals with arsenopyrite at the margins (see Fig. 4. 9B).

Fine anhedral pyrite (Py 2) is pale yellow and isotropic. It overprints foliation and appears to have come in during D2 phase. It has an inclusion of gangue minerals (see Fig. 4.9C). Elsewhere, Py 1 overprints medium grained gold and has gold inclusion.

The third variety of pyrite which is anhedral occurs at the margins of the granular pyrite and was possibly formed by metamorphism (see Fig. 4.9D).

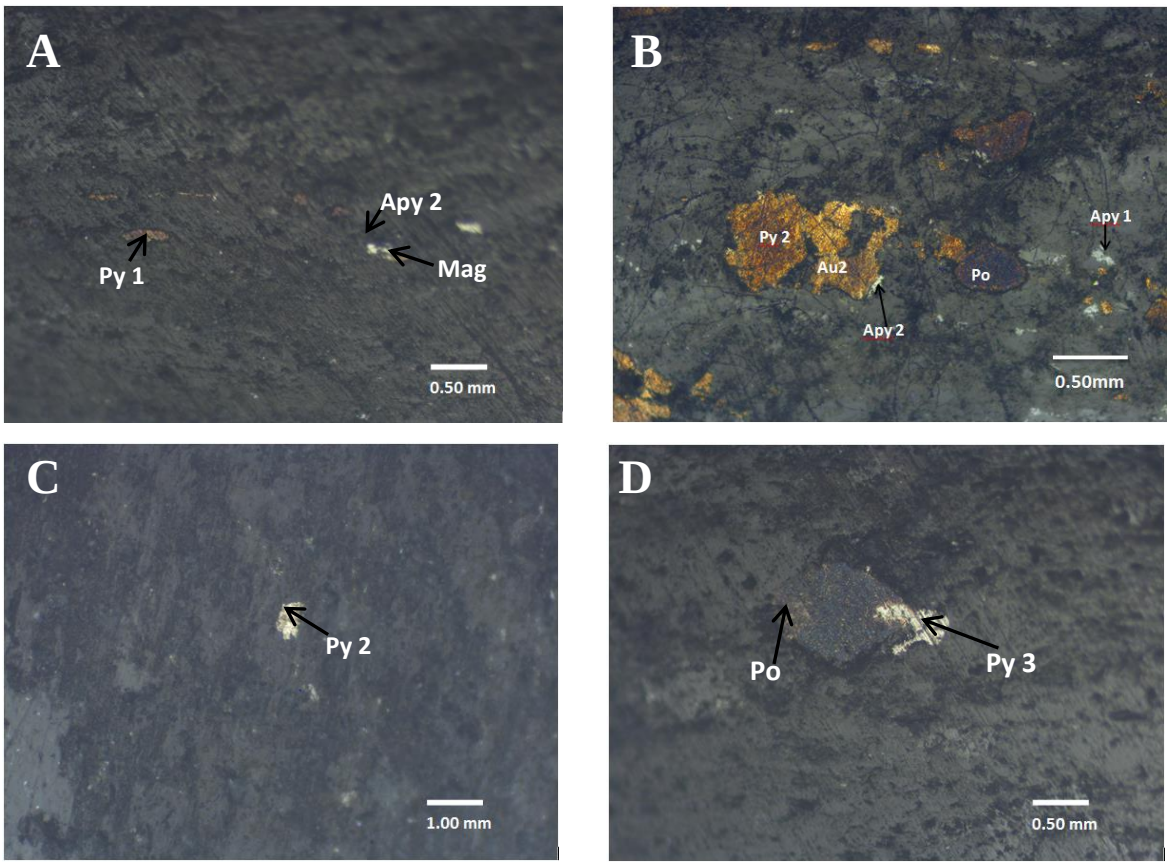

Fig. 4.9 Photomicrographs of Polished Sections under plane polarised light of Massive Rock Showing A: Pyrite 1, arsenopyrite 2 and magnetite. B: Pyrite 2 overprints foliation and has arsenopyrite 2 occuring at its margins. C: Pyrite 2 has inclusion of gangue minerals. D: Pyrite 2 is partially altered to pyrrhotite with anhedral pyrite 3 at its margins.

Pyrrhotite is brownis yellow, weakly pleochroic shows colours of yellow, violet, green, orange, blue and appear to be an alteration product of euhedral pyrite which overprints foliation (see Fig.4.10A). It is generally seen as alteration product of pyrite (see Fig.4.10B)

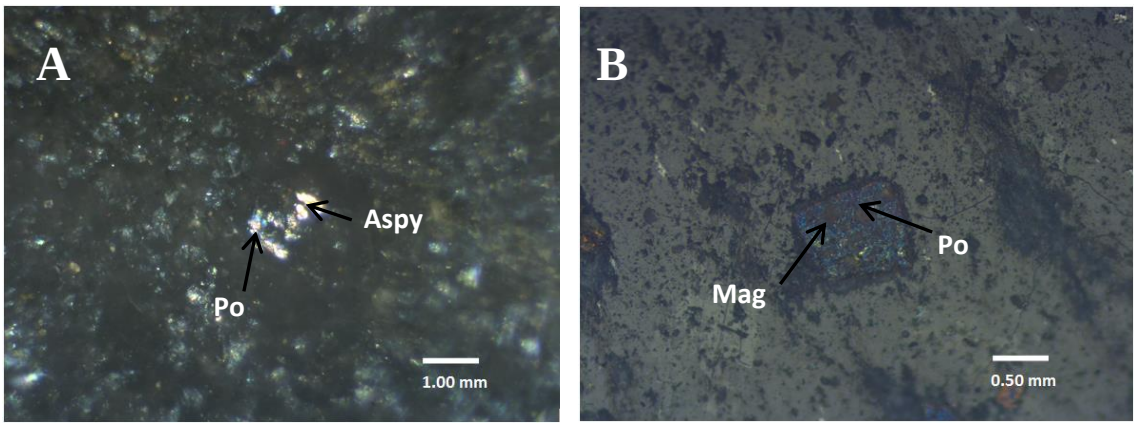

Fig. 4.10 Photomicrographs of polished sections of Massive Rock showing A: Cluster of pyrrhotite which overprints foliation in cross nicols. B: Magnetite and Pyrrhotie as alteration product of euhedral pyrite under plane polarised light.

Magnetite is granular to sub-angular and occur both along and across foliation and at the margins of pyrite or arsenopyrite. It is isotropic, fine to medium grained (see Fig. 4.11A). Magnetite is an alteration product of pyrite and pyrrhotite (see Fig. 4.10B). It might be the results from the break down of ankerite (see Fig. 4.11B) or from partial alteration of arsenopyrite (see Fig. 4.10A).

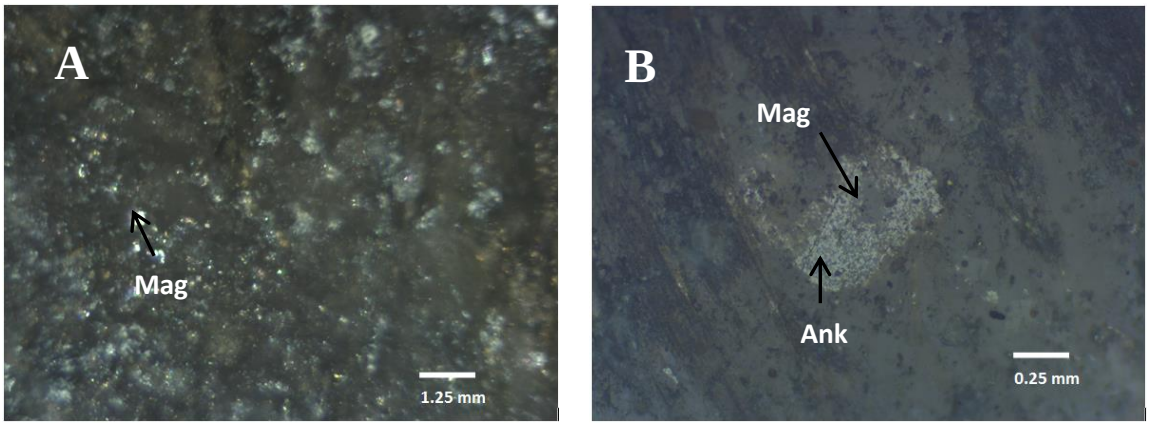

Fig. 4.11 Photomicrographs of polished sections showing A: Granular to sub angular magnetite found both along and across foliation in cross nicols. B: Ankerite partially altered to magnetie under plane polarised light.

Two varieties of arsenopyrite occurr; arsenopyrite 1 is very fine grained, sheared and elongated, creamy white and partially altered to pyrrhotite or magnetite (Fig. 3.9A). Arsenopyrite 2 is subhedral and occurs at the margins of coarse grained gold and sub euhedral pyrite (see Fig. 4.9B). Arsenopyrite 2 is at low angle to foliation whilst

Arsenopyrite 1 is parallel to foliation (see Fig. 4.12A). Arsenopyrite 1 is finer grained compared with arsenopyrite 2. Arsenopyrite 1 which is parallel to foliation is overprinted by fine disseminated gold (see Fig. 4.12B).

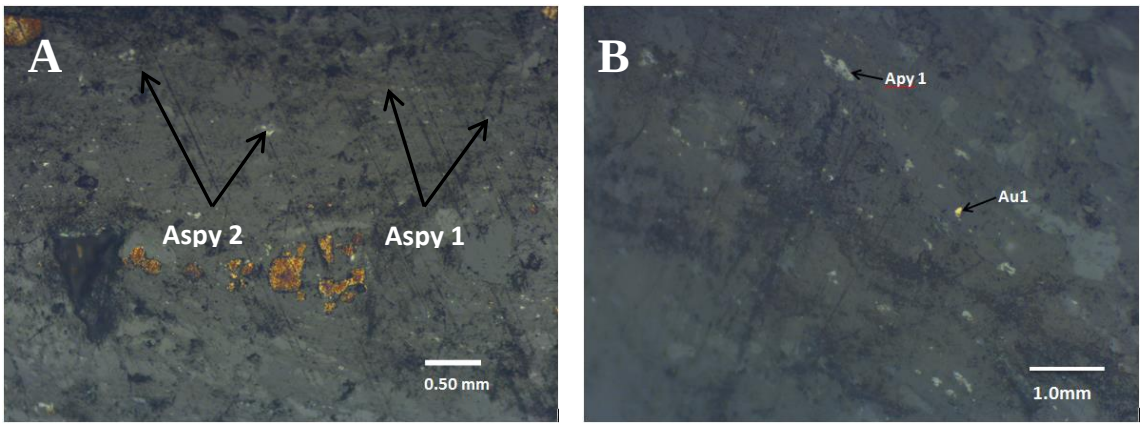

Fig. 4.12 Photomicrographs of polished sections of massive rock (plane polarised light) showing A: Arsenopyrite 1 parallel to foliation whilst arsenopyrite 2 is at an angle to foliation. B: Disseminated fine gold in association with arsenopyrite 1.

Chalcopyrite was formed during the formation of secondary gold. It is brassy yellow, pitted with gangue minerals and cut by gangue minerals. Chalcopyrite shows weak anisotropy whilst gold is bright yellow and isotropic under cross nicols (Fig. 4.13A) and overprints foliation. Chalcopyrite are ring like inclusions in the carbonate. This suggests exolution of chalcopyrite from a gangue possibly ankerite as Cu is unstable in the carbonate mineral structure (Fig. 4.13B)

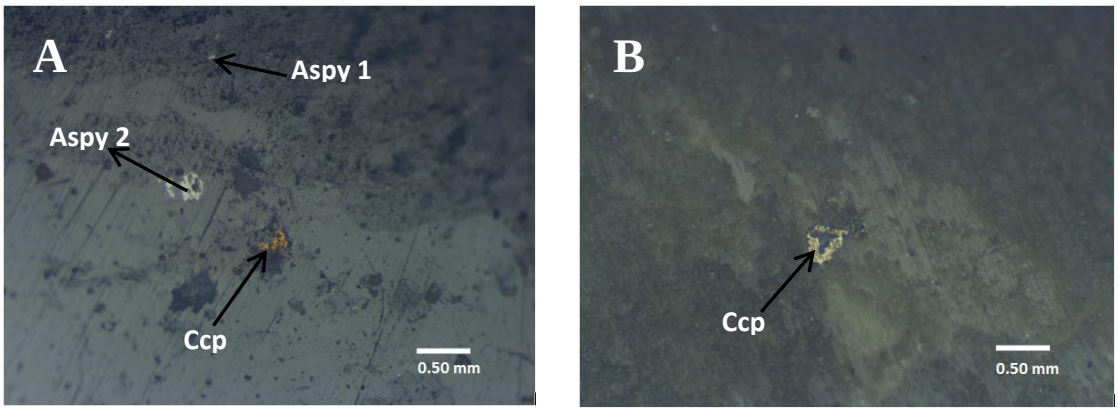

Fig. 4.13 Photomicrographs of polished sections of massive rock showing A: Chalcopyrite pitted with gangue minerals (Plane Polarised Light). B: Chalcopyrite seen as ring-like inclusion in carbonates (cross nicols).

4.3 Results from Geochemical Analysis

The results of whole rock geochemical analysis on composition of major oxides in weight percentage (wt. %) of representative rock samples from the Akyem Mine gold deposit are given in Tables 4.6, 4.7 and 4.8.

Table 4.6 Major Oxides and Trace Elements in the Hanging Wall Unaltered and Weakly Altered Andesitic Rocks in the Akyem Mine Gold Deposit

Major Element (%)	UNALTERED HW ROCK						WEAKLY ALTERED HW ROCK								
	786_4	786_5	786_16	815_2	815_4	815_12	786_3	786_6	786_9	786_13	786_15	815_1	815_5	815_11	815_13
Al_2O_3	17.9	16.8	13.3	19.4	11.6	14	14.3	12.4	14.6	14	14.3	15.1	13.7	11.3	12.1
SiO_2	60.8	59.4	43.3	53.7	43.8	56.3	57.1	39	57.3	59.6	52.9	52.4	51.5	50.8	50
CaO	0.48	1.69	9.77	2.1	5.28	5.58	2.12	10.6	3.59	3.56	4.04	5.91	5.99	7.43	6.11
Fe_2O_3	7.28	7.06	11.8	8.07	14.2	6.8	7.61	10.6	6.9	6.1	7.64	5.47	7.14	9.35	8.58
K_2O	4	3.66	0.4	4.13	1.22	1.8	3.04	1.45	2.29	1.94	3.32	2.03	2.1	0.88	0.68
MgO	2.22	2.65	6.31	2.82	5.2	3.5	2.95	4.92	2.16	1.49	3.49	2.41	2.97	2.76	5.39
MnO	0.08	0.11	0.19	0.07	0.22	0.1	0.09	0.16	0.09	0.13	0.12	0.11	0.11	0.13	0.15
Na_2O	0.76	0.51	1.44	0.75	2.73	3.09	2.24	1.92	4.34	5.19	2.54	5.46	3.73	4.52	4.25
TiO_2	0.65	0.55	0.86	0.61	1.27	0.79	0.62	0.96	0.61	0.52	0.82	0.48	0.6	1.33	0.69
P_2O_5	0.161	0.149	0.079	0.13	0.124	0.272	0.182	0.096	0.177	0.226	0.258	0.102	0.177	0.19	0.253
V_2O_5	0.03	0.03	0.05	0.03	0.07	0.03	0.02	0.05	0.03	0.02	0.03	0.02	0.03	0.05	0.03
Cr_2O_3	0.02	0.03	0.04	0.04	0.01	0.04	0.05	0.03	0.01	<0.01	0.03	0.02	0.02	0.01	0.04
BaO	0.1	0.09	<0.03	0.16	0.06	0.14	0.14	0.06	0.07	0.18	0.17	0.09	0.07	0.04	0.03
SrO	0.01	0.02	0.05	0.06	0.06	0.06	0.05	0.06	0.04	0.05	0.04	0.11	0.07	0.06	0.06
LOI	4.35	6.44	12.24	6.44	13.07	6.46	8.4	15.64	6.24	6.48	9.94	9.35	8.06	11.09	10.8
Total	**98.84**	**99.19**	**99.83**	**98.51**	**98.91**	**98.96**	**98.91**	**97.95**	**98.45**	**99.49**	**99.64**	**99.06**	**96.27**	**99.94**	**99.16**
Trace Element (ppm)															
Ba	804	666	173	1680	368	1170	1340	425	709	1990	1760	1180	554	149	360
Cu	73	56	164	75	151	143	40	99	87	28	132	<10	65	109	175
Li	67	60	218	49	35	45	12	53	18	<10	<10	<10	18	23	51
S	3020	1470	1630	4380	2950	1380	1930	13000	11900	1050	2200	3000	17900	1060	3580
Sr	122	193	431	628	590	550	524	571	302	474	488	1060	677	579	682
V	139	112	305	153	410	163	127	290	188	98	198	113	134	334	183
Zn	108	98	127	161	147	107	118	90	75	140	132	105	93	123	114
As	17	33	9	36	100	12	26	13	10	7	17	26	45	11	20
Ag	2	2	4	4	3	4	3	3	3	3	4	3	5	3	5
Co	21.8	19.8	44.5	21.7	38.4	19.6	24.1	45.3	16.8	11.1	18.4	13.5	20.2	37.9	26
Cs	5.1	4.3	2.1	4.7	2.3	1.5	4.2	2.2	2.6	2.3	5.7	2.2	2.3	1.4	1.5
Dy	3.45	3.12	2.62	3.12	4.02	2.82	3.54	3.25	3.11	3.84	3.1	1.88	2.79	3.96	2.46
Er	2.16	2.08	2.15	2.13	2.75	1.92	2.11	2.28	2.05	2.59	2.01	1.34	1.75	2.67	1.62
Eu	1.22	0.92	0.67	1.27	0.94	1.05	1.18	0.87	0.97	1.14	1.1	0.85	1.01	0.91	0.82
Ga	22	18	15	27	21	25	21	16	19	18	21	23	26	19	21
Gd	4.39	3.66	2.38	3.17	3.28	3.57	3.75	3.02	3.69	3.79	3.61	2.14	3.11	3.72	2.54
Ho	0.73	0.68	0.72	0.61	0.81	0.68	0.87	0.83	0.62	0.9	0.7	0.45	0.51	0.8	0.56
La	24.2	21.2	2.2	20.7	3.4	10.3	23.5	4.8	16.3	15.7	14.2	9.3	17.9	3	7.7
Mo	4	7	2	5	3	4	5	3	4	5	3	5	7	6	5
Nb	7	5	3	8	4	6	7	3	6	5	6	4	6	3	4
Nd	24.9	20.2	6.1	24.7	8.1	15.8	24.5	7.2	20.8	18.7	12.9	13.4	20.5	9	11
Ni	53	62	136	59	69	64	87	95	37	20	56	31	67	60	81
Pb	26	23	21	21	16	34	26	24	23	21	24	20	28	20	21
Pr	5.92	5.12	0.99	5.4	1.57	3.06	5.95	1.51	4.71	3.98	2.91	2.8	4.47	1.39	2.38
Rb	114	93.9	34.6	143	57.1	88.7	93.3	36.8	64.7	62.1	93.6	94.2	85.1	49.8	61.8
Sb	6.5	3.7	18	10.8	5.8	4.6	28.5	4.4	3.6	6.2	11	7.3	29.8	9	4.8
Sc	20	17	44	21	40	16	18	34	18	15	19	13	17	45	25
Sm	4.5	4.8	2	6	3.2	3.8	5.6	2.6	4.3	4.2	3.2	2.9	4.3	3.3	3.3
Sn	7	4	7	8	7	8	9	4	7	6	6	3	9	5	2
Ta	0.8	0.6	0.8	0.8	<0.5	0.7	1	0.6	0.7	0.6	0.8	0.5	1.3	<0.5	<0.5
Tb	0.68	0.55	0.49	0.54	0.69	0.6	0.59	0.57	0.58	0.65	0.59	0.31	0.51	0.81	0.39
Th	3.8	3.3	0.5	4	0.5	1.7	4.2	1	3.8	2.4	1.6	1.2	3.9	0.7	0.9
Tl	0.6	<0.5	<0.5	0.7	<0.5	<0.5	0.7	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Tm	0.37	0.32	0.35	0.31	0.37	0.28	0.39	0.4	0.32	0.39	0.34	0.19	0.32	0.45	0.25
U	2.04	1.43	0.43	1.63	0.32	0.98	2	0.59	1.27	1.45	0.78	0.95	1.69	0.62	0.46
W	4	2	1	5	6	10	7	6	5	3	13	5	7	8	10
Y	18.3	14.9	17.1	16.8	23.5	16.3	17.7	18.1	16.4	21.3	16.5	10.6	15	21.4	13.9
Au (g/t)	**0.01**	**0.005**	**0.005**	**0.03**	**0.01**	**0.01**	**0.4**	**0.01**	**0.93**	**0.12**	**1.46**	**0.06**	**0.07**	**0.03**	**0.05**

Table 4.7 Major Oxides and Trace Elements in the Hanging Wall Moderately and Highly Altered Andesitic Rocks in the Akyem Mine Gold Deposit

Major Element (%)	MODERATELY ALTERED HW ROCK							HIGHLY ALTERED HW ROCK								
	786_1	786_7	786_11	786_12	815_7	815_8	815_10	786_2	786_8	786_10	786_14	786_17	786_18	815_3	815_6	815_9
Al_2O_3	15.4	13.4	15.1	15	17.9	13.2	13.4	13.2	14.6	13.4	11.5	12.8	9.44	14.2	12.4	14.6
SiO_2	55.5	62.7	53.3	53.5	51.8	54.2	58.7	57.2	52.1	53.5	53.6	53.8	55.1	47.5	61.4	56.1
CaO	4.02	3.13	3.84	5.41	3.25	6.08	4.11	4.9	5.28	5.42	6.96	5.77	6.54	6.56	4.18	5.27
Fe_2O_3	6.19	4.83	6.74	6.5	6.7	5.77	6.22	5.84	7.36	6.98	6.09	7.46	7.9	7.66	5.33	4.37
K_2O	0.76	0.06	1.21	0.34	3.23	1.16	0.71	0.4	1.19	0.69	0.51	0.93	1.18	0.85	0.95	0.44
MgO	1.73	1.13	2.62	2.05	2.08	2.38	1.71	1.91	2.37	2.37	2.91	2.47	2.82	2.8	1.67	1.8
MnO	0.12	0.13	0.09	0.13	0.08	0.11	0.11	0.09	0.1	0.11	0.12	0.13	0.12	0.12	0.07	0.13
Na_2O	8.25	8.42	6.88	8.64	4.78	5.64	6.88	7.46	7.04	7.12	6	5.91	3.16	7.14	5.71	8.15
TiO_2	0.54	0.43	0.55	0.6	0.63	0.55	0.39	0.42	0.58	0.54	0.62	0.52	0.63	0.61	0.51	0.49
P_2O_5	0.138	0.091	0.169	0.228	0.091	0.107	0.091	0.117	0.129	0.132	0.161	0.176	0.206	0.149	0.063	0.154
V_2O_5	0.02	<0.01	0.02	0.01	0.06	0.03	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.03	<0.01
Cr_2O_3	0.03	0.03	0.03	<0.01	0.01	0.01	0.01	0.01	0.04	0.01	0.02	0.02	0.04	0.02	0.02	<0.01
BaO	0.05	0.05	0.09	0.04	0.13	0.06	0.05	0.1	0.07	0.07	0.25	0.12	0.11	0.04	0.06	0.05
SrO	0.08	0.07	0.06	0.08	0.07	0.09	0.07	0.16	0.08	0.09	0.14	0.11	0.1	0.14	0.12	0.1
LOI	4.88	3.52	6.24	4.46	5.88	7.22	3.8	5.3	6.32	6.29	8.15	6.09	7.33	5.9	4.24	6.44
Total	**97.71**	**97.99**	**96.94**	**96.99**	**96.69**	**96.61**	**96.27**	**97.13**	**97.29**	**96.74**	**97.05**	**96.33**	**94.70**	**93.71**	**96.75**	**98.09**
Trace Element (ppm)																
Ba	419	405	780	365	1250	676	449	922	436	473	2670	1050	887	454	759	431
Cu	58	29	58	33	77	99	35	19	59	54	120	85	103	38	38	36
Li	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	11	<10	<10	<10	<10
S	19500	22900	>25000	>25000	18000	18100	>25000	21900	>25000	22500	22100	>25000	>25000	>25000	24800	8880
Sr	679	667	634	762	611	908	721	1470	675	809	1430	998	979	1500	1110	1010
V	134	19	127	56	348	190	82	81	169	109	93	99	109	174	156	42
Zn	98	51	127	81	112	78	94	64	75	74	94	78	74	132	77	79
As	21	15	15	14	14	28	32	17	18	9	19	44	38	25	21	16
Ag	4	3	3	3	4	6	4	5	4	4	5	4	2	4	5	4
Co	23.1	10.8	17.6	13.2	23.7	21.7	19.1	16.3	19.9	18.4	15.7	27.4	17.6	20	16.9	9.7
Cs	1.6	0.5	1.9	0.6	3.6	7.6	1.5	0.7	1.9	1.1	1	2.3	6	1.2	1.4	0.8
Dy	2.51	5.28	2.53	4.17	3.31	2.93	3.66	2.19	3.55	2.92	2.69	2.28	2.54	2.5	2.32	3.75
Er	1.58	3.37	1.78	3.1	1.9	1.81	2.45	1.31	2.37	1.83	1.87	1.86	1.77	1.36	1.41	2.62
Eu	1.07	1.1	1.02	1.06	0.99	1.16	0.94	0.87	1.07	0.75	0.98	1.19	0.99	0.88	0.88	0.79
Ga	22	18	18	17	42	36	24	18	24	19	20	26	21	23	25	25
Gd	3.18	4.65	3.77	4.67	3.15	3.01	3.87	2.7	3.77	3.16	2.92	2.58	2.68	2.99	2.44	3.31
Ho	0.75	1.08	0.63	0.92	0.65	0.65	0.88	0.52	0.72	0.68	0.58	0.56	0.57	0.42	0.45	0.81
La	17.7	26.1	17	17.5	17.1	14.9	16.8	14.3	20.8	16.1	10	12.6	11.2	16.4	13.7	11.7
Mo	18	37	5	6	10	6	52	9	16	16	10	167	17	9	5	5
Nb	6	8	5	5	6	6	6	5	6	5	5	6	4	5	5	4
Nd	14.8	27.5	18.2	21.8	22.9	22.8	21.2	13.8	23.4	19.1	12.7	17.6	16	19.3	15.5	16.5
Ni	59	26	73	21	65	52	111	39	66	50	57	90	41	59	72	21
Pb	31	53	24	28	20	20	30	29	23	22	44	37	27	21	27	20
Pr	3.79	6.6	4.28	4.82	5.4	3.98	4.65	3.53	5.29	4.2	2.82	3.34	3.18	4.36	3.71	3.53
Rb	42.5	15.6	42	31.7	120	180	53.9	19.8	44.5	30.3	31.3	85.3	121	43.9	52.2	48.9
Sb	10.1	12.7	12.6	15.9	14.7	88.2	25.7	4.8	6.2	4.4	62.1	64.3	43.1	10.5	23.3	24.5
Sc	14	8	17	14	23	19	15	11	17	15	16	12	19	19	13	12
Sm	3.6	5.9	4.3	5	5.2	4.8	4.1	3.1	5	4	3.4	3.9	4.2	3.9	3.5	3.5
Sn	15	7	7	7	8	13	9	5	5	7	6	21	8	6	6	7
Ta	3.2	0.8	0.6	0.8	0.6	0.5	1.1	1.2	0.8	0.7	0.6	2	0.6	0.8	0.5	0.8
Tb	0.52	0.81	0.57	0.81	0.45	0.55	0.57	0.42	0.69	0.48	0.45	0.44	0.42	0.48	0.36	0.57
Th	3.1	4.8	2.9	3.5	3.4	3.4	4	2	4.4	3	1.4	2.1	1.2	3.1	2.8	2.5
Tl	0.8	<0.5	<0.5	<0.5	0.5	1.1	<0.5	<0.5	<0.5	<0.5	<0.5	1.1	0.6	<0.5	<0.5	<0.5
Tm	0.45	0.52	0.3	0.41	0.34	0.38	0.48	0.26	0.38	0.31	0.25	0.26	0.31	0.21	0.21	0.33
U	2.18	2.03	1.06	0.96	1.3	1.74	2.22	1.13	1.38	1.46	0.97	1.41	0.87	1.07	0.85	1
W	10	11	3	12	11	10	8	11	14	8	10	8	16	8	9	10
Y	12.4	28.4	16.7	22.6	17.1	18.2	23.5	10.7	19.7	15.5	15.7	15	14.7	12.4	12.2	21.9
Au (g/t)	**2.48**	**0.83**	**0.63**	**1.49**	**3.48**	**4.66**	**1.2**	**4.76**	**5.72**	**3.45**	**2.74**	**6.18**	**7.38**	**3.17**	**12.8**	**3.29**

Table 4.8 Major Oxides and Trace Elements in the Footwall Andesitic Rocks in the Akyem Mine Gold Deposit

Major Element (%)	FOOTWALL	
	786_19	815_14
Al_2O_3	15	16
SiO_2	62.5	57.9
CaO	0.52	3.04
Fe_2O_3	7.59	7.06
K_2O	3.12	3.03
MgO	1.14	2.9
MnO	0.09	0.09
Na_2O	2.15	1.59
TiO_2	0.66	0.51
P_2O_5	0.208	0.141
V_2O_5	0.04	0.02
Cr_2O_3	0.03	0.01
BaO	0.13	0.08
SrO	0.02	0.05
LOI	5.68	6.82
Total	**98.88**	**99.24**
Trace Element (ppm)		
Ba	1290	914
Cu	123	37
Li	12	61
S	1890	2990
Sr	229	530
V	250	140
Zn	110	117
As	44	22
Ag	3	3
Co	18.6	20.1
Cs	7	2.6
Dy	3.08	2.42
Er	1.93	1.49
Eu	1.08	0.77
Ga	21	23
Gd	3.04	2.82
Ho	0.62	0.43
La	12.3	12.3
Mo	15	4
Nb	4	4
Nd	17.5	15.6
Ni	40	41
Pb	18	28
Pr	3.57	3.16
Rb	127	110
Sb	46.8	5.3
Sc	24	20
Sm	4.4	3.7
Sn	7	6
Ta	0.6	0.5
Tb	0.52	0.46
Th	1.4	2.8
Tl	0.7	<0.5
Tm	0.38	0.22
U	3.4	1.31
W	17	2
Y	15.7	11.6
Au (g/t)	**0.04**	**0.02**

The results have been categorised into five groups for geochemical characterisation as shown in the tables above. This grouping was based on hydrothermal alteration intensity as well as location relative to the NE striking Akyem Main Fault (Fig.3.1).

The rocks in the Akyem gold deposit generally have high SiO_2 (39-62.5 % and average of 54.19 %) , Al_2O_3 (9.44 %-19.4 % and average of 14.1 %), Na_2O (0.51- 8.64 and average of 4.68) , total FeO (4.37-14.2 % and average of 7.31 %), CaO (0.48-10.6 % and average of 4.80) MnO (0.07 - 0.22, and average of 0.12), MgO (1.13 – 6.31, and average of 2.73 %), P_2O_5 (0.06 – 0.27, and average of 0.16), SrO (0.01–0.16, and average of 0.07 %), Cr_2O_3 (0.01–0.05, and average of 0.02 %), V_2O_3 (0.01–0.07, and average of 0.03 %), BaO (0.03–0.25, and average of. 0.09 %) and low TiO_2 (with average of 0.64 %).

Table 4.4 Average Weight Percentage of Major Oxides in the Rocks in Akyem Mine Gold Deposit

MAJOR OXIDES	HW UNALTERED ANDESITIC ROCK	HW WEAKLY ALTERED ANDESITIC ROCK	HW MODERATELY ALTERED ANDESITIC ROCK	HW HIGHLY ALTERED ANDESITIC ROCK	FOOTWALL ANDESITIC ROCK
CaO	4.15	5.48	4.26	5.65	1.78
Total FeO	9.20	7.71	6.14	6.55	7.33
K_2O	2.54	1.97	1.07	0.79	3.08
MgO	3.78	3.17	1.96	2.35	2.02
MnO	0.13	0.12	0.11	0.11	0.09
Na_2O	1.55	3.80	7.07	6.41	1.87
TiO_2	0.79	0.74	0.53	0.55	0.59
P_2O_5	0.15	0.18	0.13	0.14	0.17
V_2O_5	0.04	0.03	0.03	0.02	0.03
Cr_2O_3	0.03	0.03	0.02	0.02	0.02
BaO	0.11	0.09	0.07	0.10	0.11
SrO	0.04	0.06	0.07	0.12	0.04

The geochemical freeware programme GCD Kit Version 4.1 was used to plot the data and trace element normalization values are also taken from this software. Results of rock classification using trace elements and silica as proposed by Winchester and Floyd (1977) is shown in Fig. 4.1. The trace elements used are niobium on yttrium. The AFM ternary plot

proposed by Irvine and Baragar (1971) shows that the Akyem rocks plot mostly in the calc-alkaline field with few plotting completely within the tholeiitic field.

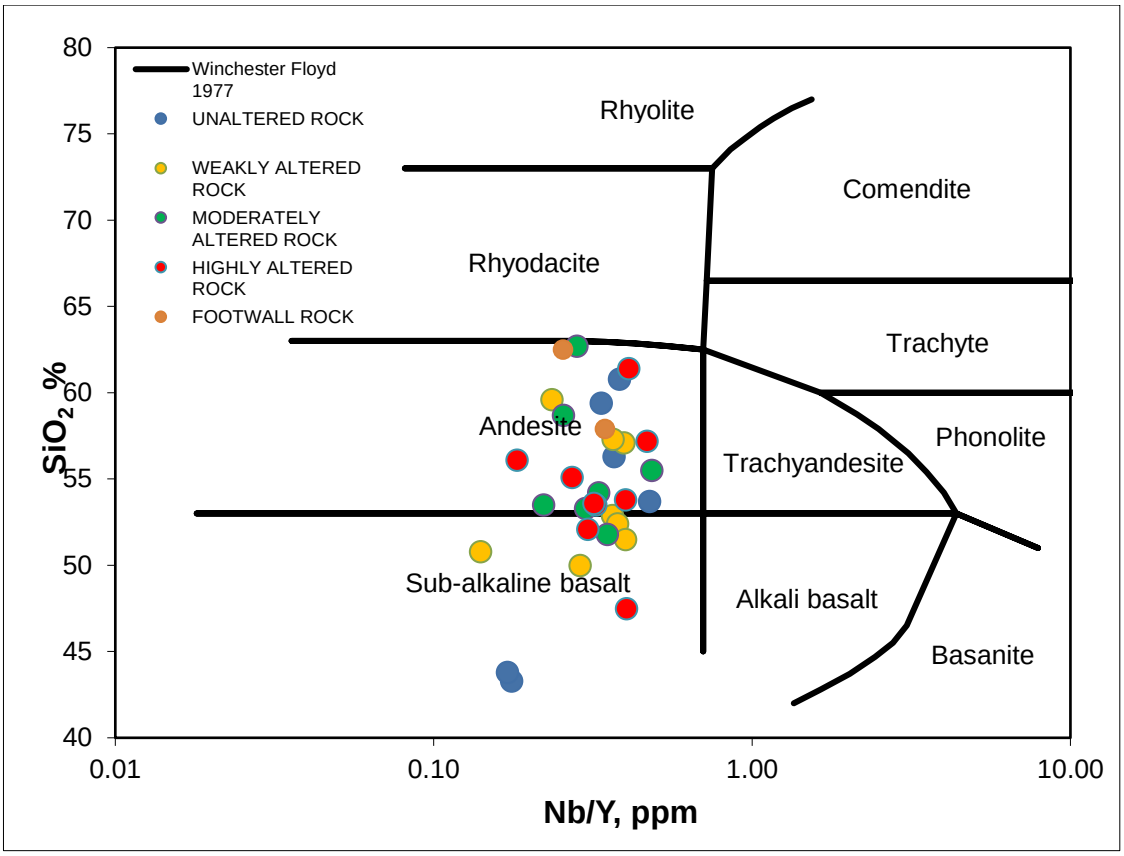

Fig. 4.14 Geochemical plot of SiO2 % versus Nb/Y showing classification of rocks in Akyem Mine gold deposit, (Winchester and Floyd, 1977).

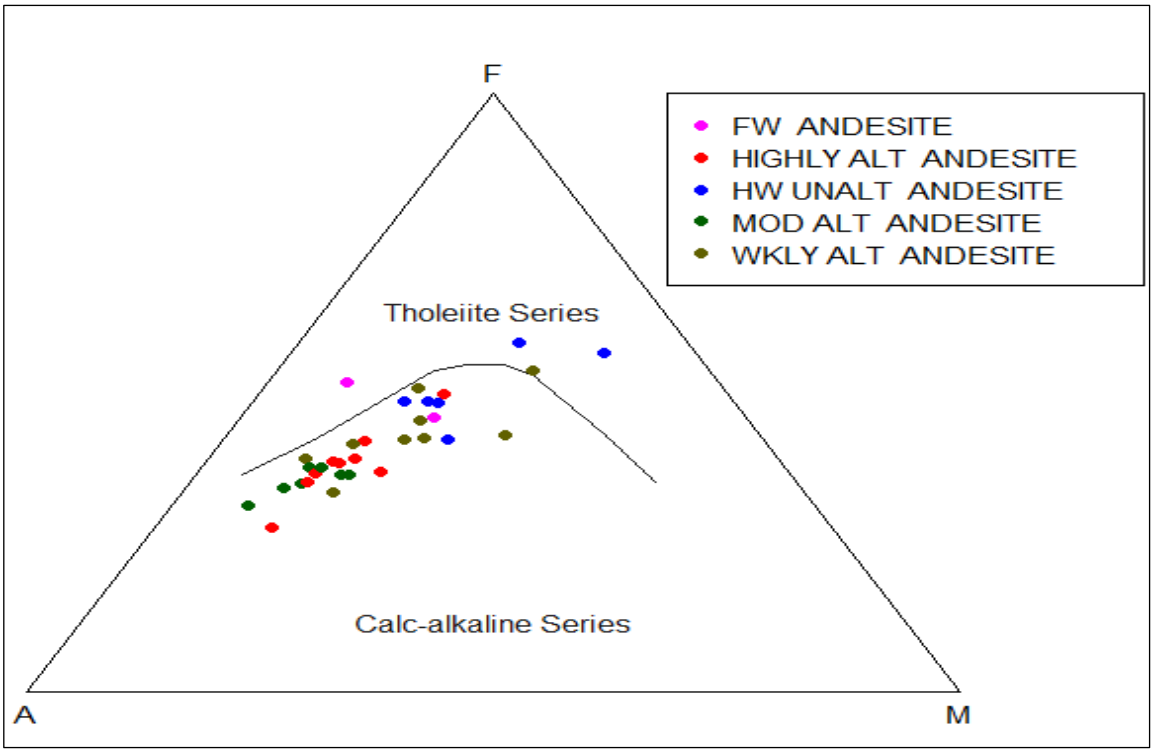

Fig. 4.15 AFM Diagram Showing Most of the Rocks in the Akyem Mine Gold Deposit Are Mainly Calc-Alkaline (Irvine and Baragar, 1971; Petro *et al*., 1979).

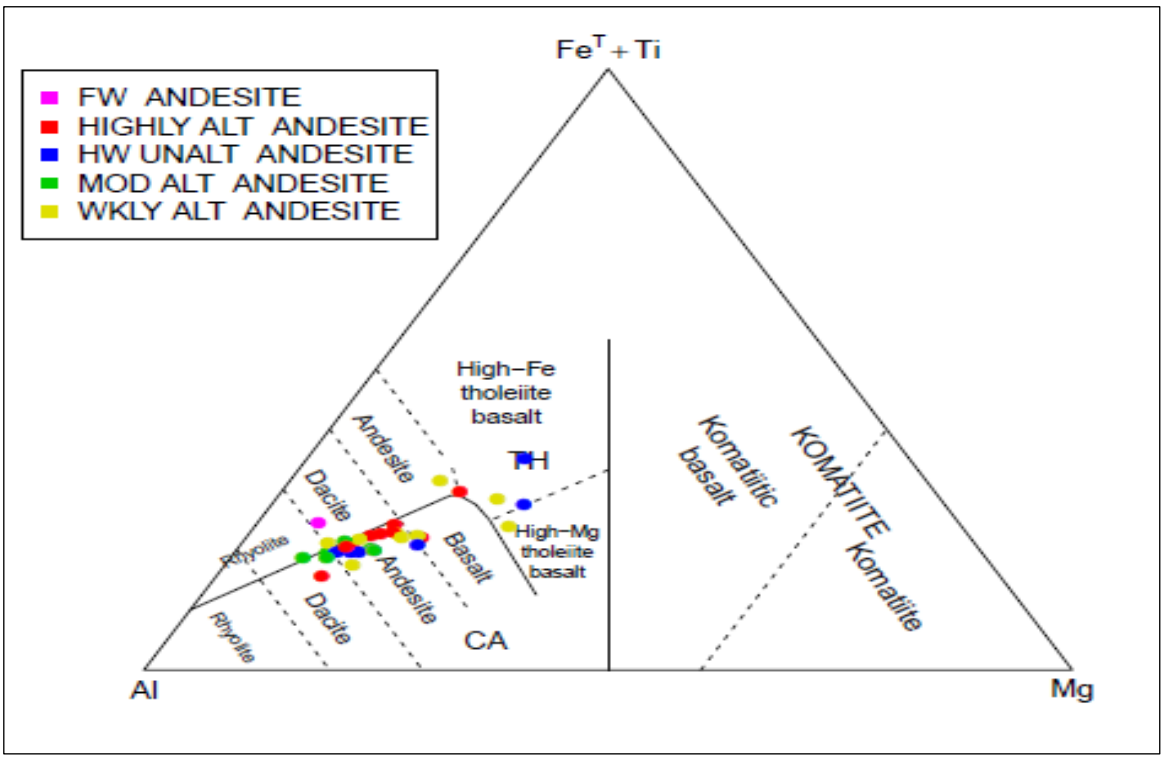

Fig. 4.16 Al-Fe+Ti-Mg Ternary Plot Showing the Rocks in Akyem Are Mainly Andesitic Basalts

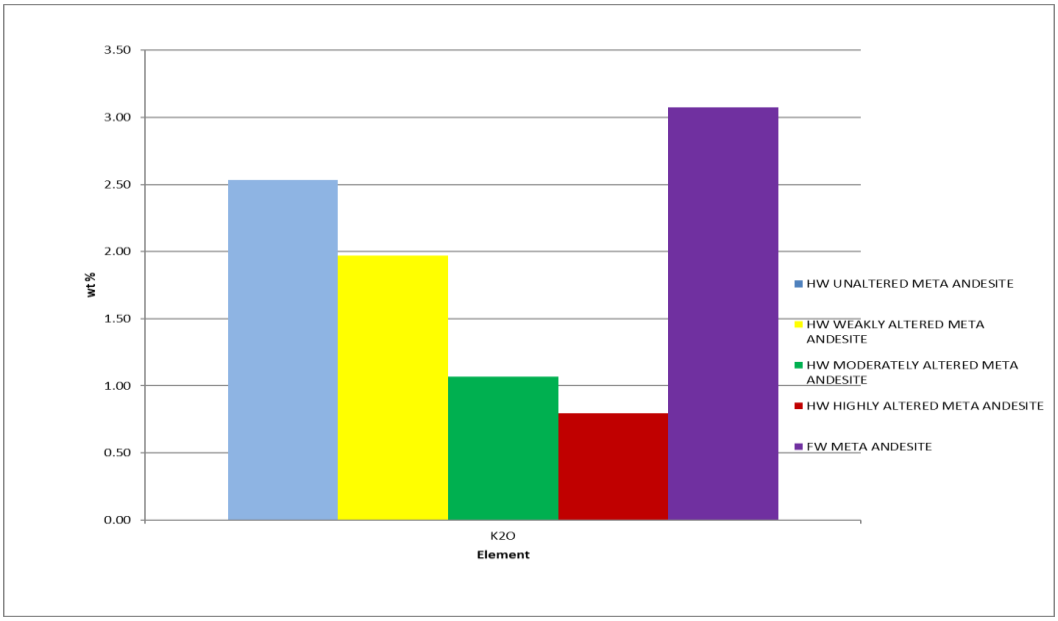

Fig. 4.17 Average wt. % of K_2O for Various Alteration Categories in Akyem Mine Deposit

The Unaltered hanging wall and footwall andesitic rocks plot in the chlorite-sericite, ankerite region (Ishikawa *et al.*, 1976). Weakly altered rocks are ankerite and dolomitic whilst moderate are highly altered by albite (Fig. 4.7).

Relationship between Ishikawa Alteration Index (AI) and (**a**) Na_2O and (**b**) K_2O for the Akyem rocks as well as TiO_2-Al_2O_3 binary plot of the unaltered and altered rocks (Figures 4.6-4.9)

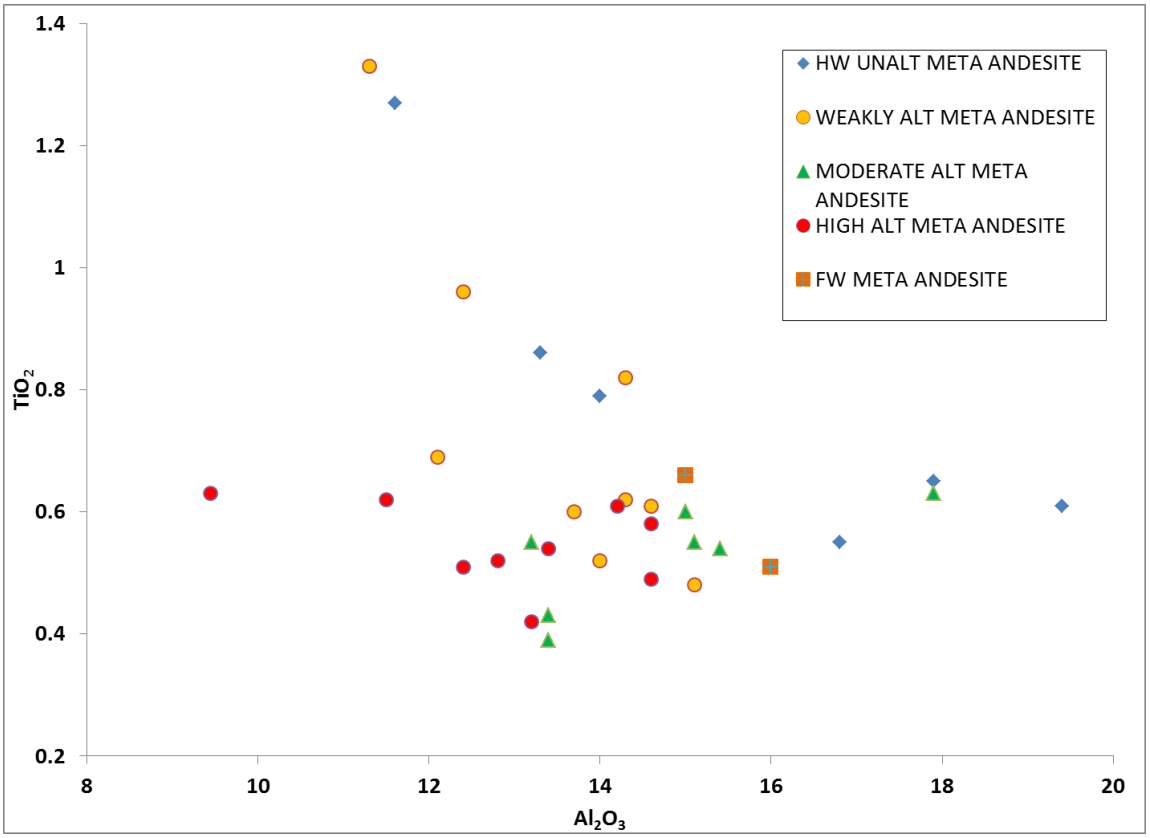

Fig. 4.18 TiO_2 – Al_2O_3 Binary Plot of Alteration Categories in the Akyem Mine Gold deposit

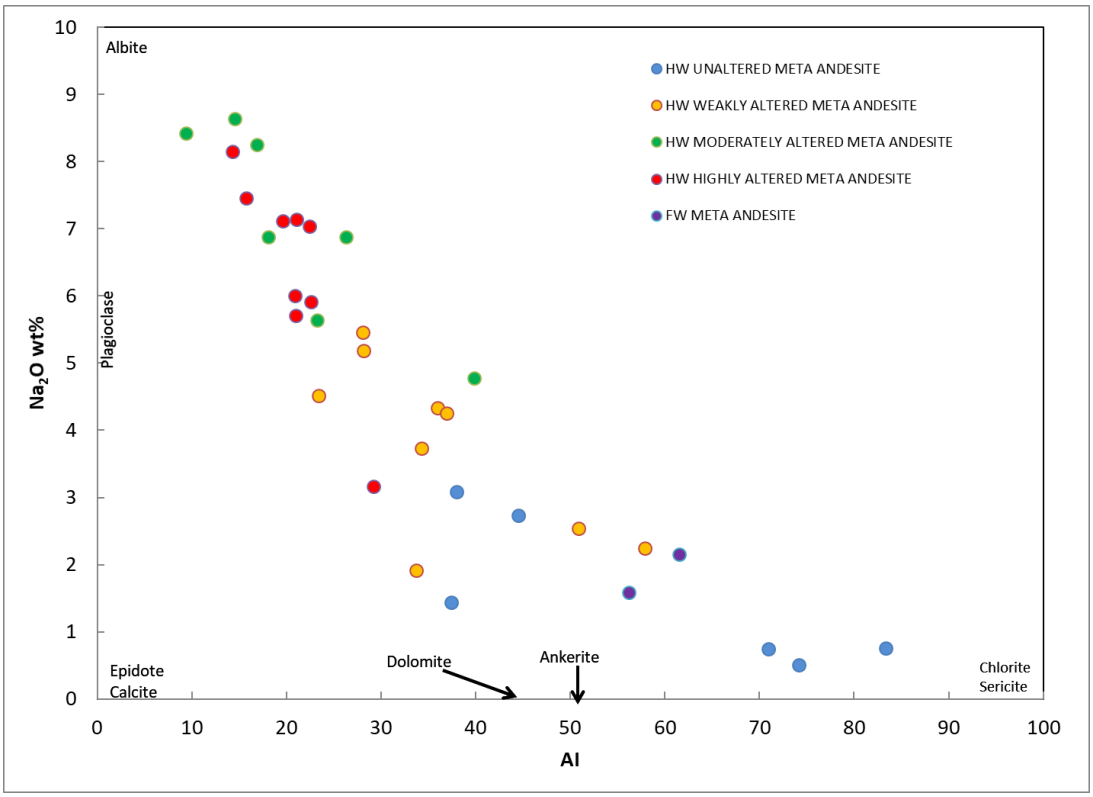

Fig. 4.19 Na_2O – AI Binary Plot of Alteration Categories (Ishikawa *et al.*, 1976).

The Ishikawa AI was devised to ratio the principal rock forming elements gained during chlorite and sericite alteration ($MgO + K_2O$) over the elements lost and gained ($Na_2O + CaO + MgO + K_2O$). The index varies from values of 20 to about 60 for unaltered rocks and between 50 and 100 for hydrothermally altered rocks, with an AI = 100 representing complete replacement of feldspars and glass by sericite and/or chlorite (Large *et al*., 2001).

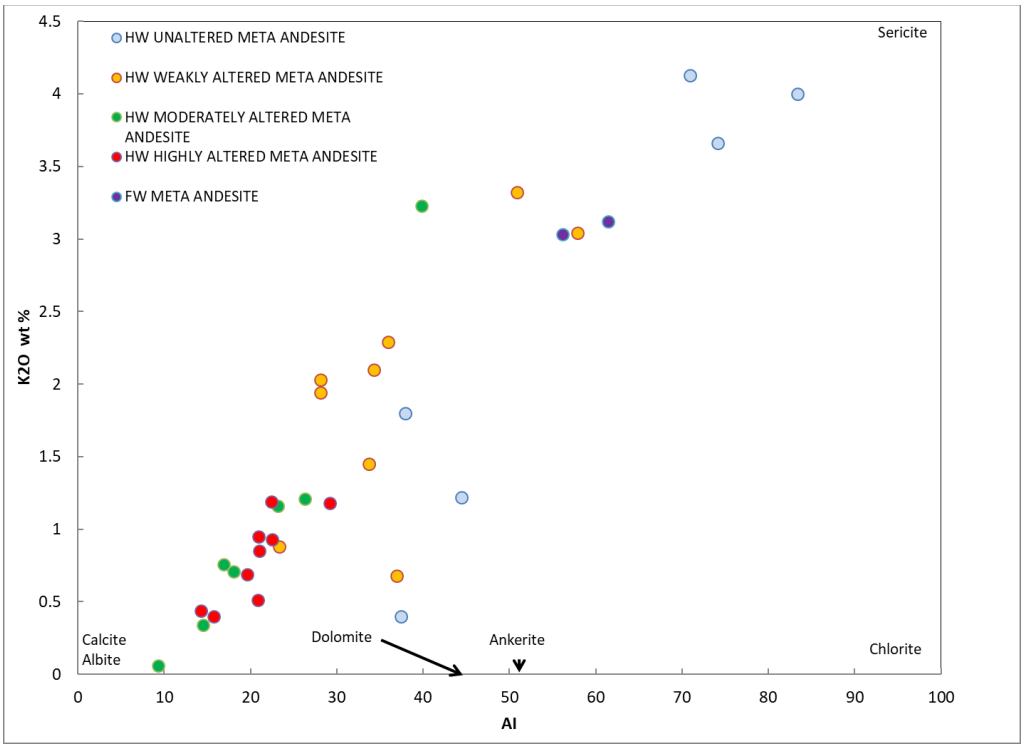

Fig. 4.20 K_2O – AI Binary Plot of Alteration Categories (Ishikawa *et al.*, 1976).

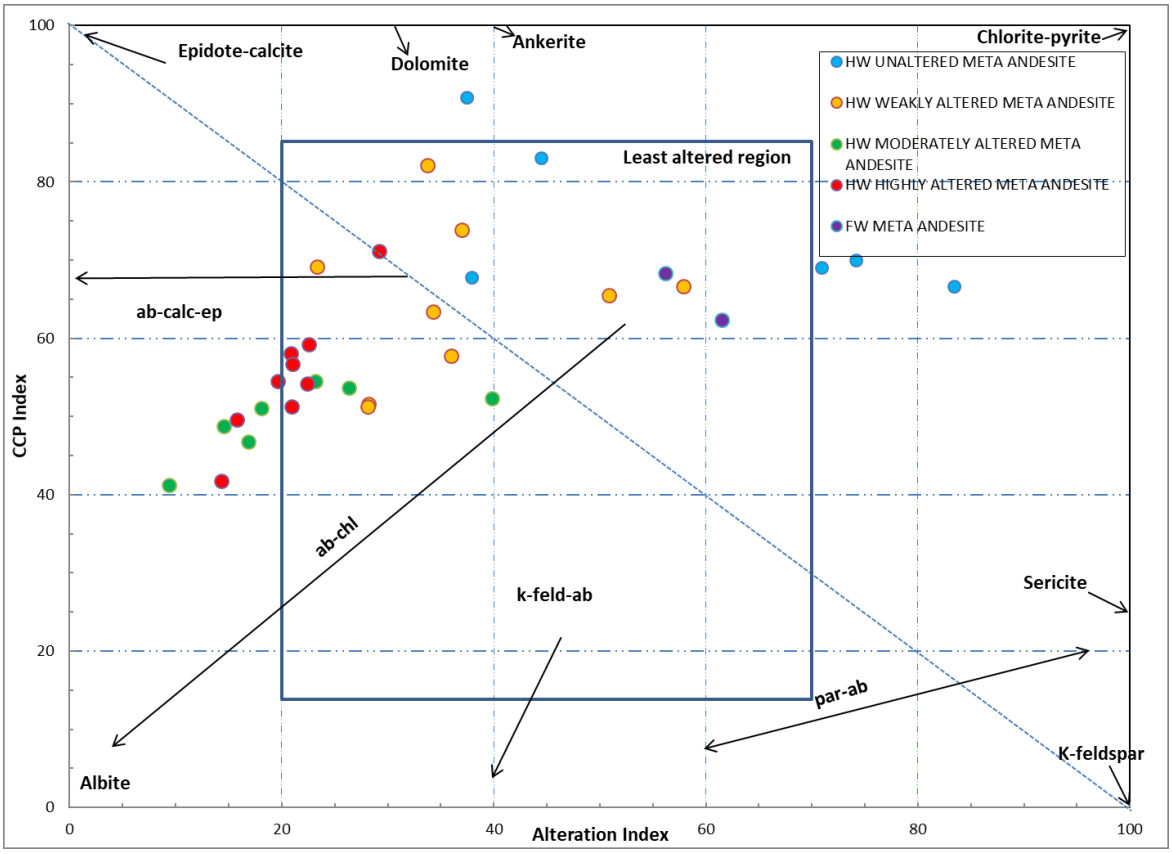

Fig. 4.21 Hydrothermal Alteration Types

CHAPTER 5

DISCUSSION

The rocks in the Akyem Mine gold deposit are fine to medium grained, weak to strongly foliated. Mineral compositions are dominantly made up of plagioclase, amphibole, chlorite and quartz with moderate sericite, epidote, dolomite, calcite and minor ore minerals such as pyrite, pyrrhotite, magnetite, arsenopyrite, gold and chalcopyrite (see Table 4.1). The rocks vary from amphibole-chlorite schist to quartz-chlorite schist. The presence of chlorite, sericite, epidote and carbonates is due to greenschist facies metamorphism (Allibone *et al*., 2002). There is relict fine grained bytownite (An_{32}) which suggests that the protolith could be a volcanic rock with primary minerals such as olivine, pyroxene, anorthite and amphibole. These primary minerals were probably altered to chlorite after olivine, epidote after anorthite (Miyashiro, 1961).

SiO_2 versus Nb/Y plot of the inferred volcanic protolith rocks on Winchester and Floyd (1977) classifies the rocks as andesite to sub-alkaline basalts (see Fig. 4.14). This classification is consistent with volcanic rocks in the Birimian (Leube *et al*., 1990). Metavolcanic rocks in the footwall and base of the hanging wall is classified as such by Atule, (2007).

Two generations of plagioclase occur. Plagioclae 1 which shows albite twinning with 40° extinction angle of bytownite composition (An_{40} – An_{52}) is probably replaced by porphyritic plagioclase (Plagioclase 2) of labradorite composition which overprints the shear.

Two generations of dolomite occur. Primary dolomite (Dolomite 1) probably replaced plagioclase 1 and secondary dolomite (Dolomite 2) replaced plagioclase 2. Plagioclase 2 is rich in inclusions of chlorite which suggests that it was probably formed after chloritisation. Dolomite 2 occur as veins and occasionally fill faults at high angle to the main shear. These veins are further overprinted by fine irregular chlorite (chlorite 2). The late irregular chlorite also overprints calcite.

Quartz occurs in three generations. Quartz 1 is fine grained, colourless, sheared, parallel to foliation, shows inclusion of sericite and overprinted by medium grained quartz 2 that was

introduced probably during shearing, (see Fig.4.2B). Quartz 3 occurs as patches and is recrystallised into coarser grains which show undulous extinction with irregular margins and appear as pinch and swell structures, (see Fig 4.5A). Sheared and recrystallised quartz form sutured margins and show quartz-rich shear zones alternating with amphibole, chlorite -rich zones or cleavages occur across the shear, (see Fig. 4.5A). These occur as patches and they are recrystallised into coarser grains which show undulous extinction with inclusions of quartz and sulphides.

The altered rocks in Akyem Mine gold deposit exhibit pervasive silicification, sulphidation, sericitisation, selective carbonatisation and albitisation. Allibone (2002; 2004) made similar observations in Birimian rocks in the Bogoso, Chirano and Obuasi area. These alterations were accompanied by pyrite, arsenopyrite, sericite, chlorite, quartz veinlets and ankerite both in the wall rock and mineralised zone at Obuasi and Prestea mines (Manu *et al.*, 2013).

Mineralisation at Akyem Mine gold deposit is associated with disseminated sulphides of pyrite, pyrrhotite, arsenopyrite, chalcopyrite, and chalcopyrite. Gold in the study area is more closely related to pyrite and arsenopyrite.

Gold is medium to fine grained. The fine grained version is overprinted by gangue and occurs along quartz veins and also as inclusion in pyrite (Fig. 4.7C). Fine grained gold (Au 1) is overprinted by pyrite which is altered to pyrrhotite (Fig.4.7B). Medium grained variety (Au 2) is pitted and filled with haematite, overprints alteration minerals and cut across quartz vein (Fig.4.7A).

Three varieties of pyrite occur; granular and euhedral pyrite (pyrite 1) is partially altered to pyrrhotite and an inclusion in gangue mineral that mark foliation. Fine anhedral pyrite (Pyrite 2) overprints foliation. It has an inclusion of gangue minerals (Fig. 4.8C). Later generation of pyrite (pyrite 3) is anhedral and occurs at the margins of pyrite 1 (Fig. 4.8D).Generations of pyrite are pyrite 2 and pyrite 3. This observation is also supported by Atule, 2007.

Pyrrhotite appears to be an alteration product of euhedral pyrite which overprints foliation (Fig. 3.9A). It is generally seen as alteration product of pyrite (see Fig. 4.9B)

Magnetite is granular to sub-angular and occur both along and across foliation and at the margins of pyrite or arsenopyrite, (see Fig. 4.10A). Magnetite is also a partial alteration product of pyrite and pyrrhotite (see Fig. 4.9B). Elsewhere it results from the break down of ankerite (see Fig. 4.10B). or from partial alteration of Arsenopyrite (see Fig. 4.9A).

Gold mineralisation at Akyem Mine deposit is associated with disseminated sulphides of pyrite, pyrrhotite, arsenopyrite, magnetite, chalcopyrite, haematite and chalcopyrite. The gold is more closely associated with fine anhedral pyrite and arsenopyrite.

Two varieties of arsenopyrite occur; Arsenopyrite 1 is very fine grained, sheared and elongated and partially altered to pyrrhotite or magnetite (see Fig. 4.9A). Arsenopyrite 2 is subhedral and occurs at the margins of coarse grained gold and sub euhedral pyrite, (see Fig. 4.8B). Arsenopyrite 2 is at low angle to foliation whilst Arsenopyrite 1 is parallel to foliation (see Fig. 4.9A). Arsenopyrite 2 is fine grained where as arsenopyrite 1 is very fine grained. Arsenopyrite is parallel or subparallel to foliation. Fine grained gold is disseminated and in association with very fine arsenopyrite. Similar associations have been recorded at Bogoso, Obuasi and Prestea Mines in the western flank of the Ashanti belt (Oberthur *et al*., 1997) (see Fig. 4.11B).

Chalcopyrite might have been introduced with of gold 2. It overprints foliation and has ring-like inclusions in carbonate (see Fig. 4.12B).

Table 5.1 Paragenetic Sequence of Rock Forming Minerals

Mineral		Genesis		
	1	2	3	4
Plagioclase	—	—	—	
Amphiboles		—	—	
Quartz		—	—	
Chlorite		—	—	
Dolomite		—	—	

Table 5.2 Paragenetic Sequence of Ore Forming Minerals

Minerals		Paragenesis		
	1	**2**	3	4
Gold			— —	
Pyrite		—	—	—
Pyrrhotite		—		
Magnetite		—	—	
Arsenopyrite		—	—	
Chalcopyrite			—	—

A plot of major oxides of the rock samples in the study area on the AFM diagram shows that the rocks are calc-alkaline with relatively rich total alkali contents coinciding with the extensional trend (see Fig. 4.15) (Irvine and Baragar, 1971; Petro *et al*., 1979).

Samples from the moderate to high alteration zones in Akyem mine deposit show strong Na_2O enrichment, and then reduces significantly in the weakly altered zone and is least in the unaltered hanging wall rocks (see Appendix. B1). This shows thatthe Na_2O enrichment is associated with gold mineralisation in Akyem mine. There is general enrichment of CaO in the hanging wall rocks compared with the footwall; however, the altered zones show higher concentration than the unaltered zones (see Appendix. B3). MgO weight percentage is highest in the unaltered hanging wall rocks and then reduces with increasing alteration towards the moderate alteration before a minor spike in the highly altered zone (Fig. B4).

Total FeO enrichment in the unaltered hanging wall units is very high but reduces in the altered zone and the footwall units (see Appendix B5). This prevailing trend in CaO, MgO and total FeO reflects the occurrence of carbonate alteration in the country rock is not related to gold mineralisation but probably due to metamorphism. This is because metamorphic minerals in the metavolcanic rocks in the Birimian are Mg and Fe-rich chlorite, sericite, titanite, with or without siderite and ankerite **(** Hirdes and Leube, 1989)

There is high K_2O wt % in the footwall and unaltered hanging wall rocks which decreases significantly with increasing alteration towards the highly altered rocks (see Fig. 4.16).

This depicts sericitisation with chlorite in the unaltered hanging wall and footwall and thus the gold bearing hydrothermal fluid was possibly not associated with sericitisation.

From Na_2O versus Altereation index (AI) plot, (see Fig. 4.19), the highly and moderately altered samples occur in the albite ($NaAlSi_3O_8$) region which is high in sodium. The least altered, unaltered and footwall rocks occur further away from the albite region and plot in the chlorite-sericite region. This further suggests that albitisation is associated with the ore forming hydrothermal fluid that in the Akyem Mine gold deposit.

In Fig. 4.20, the least altered, unaltered and footwall rock samples occur in high K_2O region (sericite alteration region) whilst the highly altered and moderately altered samples occurred in the calcite-albite region. This confirms that gold mineralisation in the Akyem mine area is albite related and not sericite. The presence of sericite may probably be as a result of metamorphism or may have come with an unmineralised hydrothermal fluid.

All the samples show that the unaltered hanging wall and footwall rocks plot in the chlorite-sericite and ankerite region (Ishikawa *et al*, 1976). Weakly altered rocks are ankeritic and dolomitic whilst moderate and highly altered varieties are albite rich (see Fig. 4.19). This is consistent with the alteration by Large *et al. (*2001) where weakly altered andesite samples plot in the dolomite-calcite-chlorite-albite alteration zone whilst samples from the high and moderately altered zone plot in the albite-calcite-epidote region (Fig. 4.21).

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1 Conclusions

The rocks in Akyem mine gold deposit are amphibole chlorite schist and quartz chlorite schist. Mineral compositions are dominantly made up of plagioclase, amphibole, chlorite and quartz with moderate sericite, epidote, dolomite and calcite. Their protoliths are probably andesite to sub alkaline basalts. They are fine to medium grained and show brittle or ductile deformation with metamorphism in the greenschist facies.

The altered rocks in Akyem Mine gold deposit exhibit pervasive silicification, sulphidation, sericitisation, carbonatisation and albitisation. Of all these alteration style, albitisation was mainly observed to be associated with gold mineralisation. Weakly altered rocks have alteration packages of dolomite-epidote-calcite-chlorite-ankerite and contain gold mineralisation between 0.2 g/t and 0.98 g/t whilst moderate to highly altered rocks are mineralised and characterised by silica-albite-epidote alteration package with gold grade above 0.98 g/t. Quartz veinlets and ankerite occur both in the wall rock and mineralised zone.

Gold mineralisation is associated with disseminated sulphides of pyrite, pyrrhotite, arsenopyrite, magnetite, chalcopyrite, haematite and chalcopyrite. The gold is more closely related to pyrite and arsenopyrite. Pyrite occurs in three varieties and arsenopyrite in two varieties. Fine grained gold 1 occur along quartz veins whilst gold 2 is medium grained and usually overprints quartz veins.

6.2 Recommendations

It is recommended that:

i. Since the rocks are altered and so makes mineral identification difficult. further work should employ electron microscope and microprobe analysis.
ii. The relationship between the various gangue minerals with respect to metamorphism should be studied in details.
iii. The relationship between the different alteration paragenesis and gold mineralisation should be studied.

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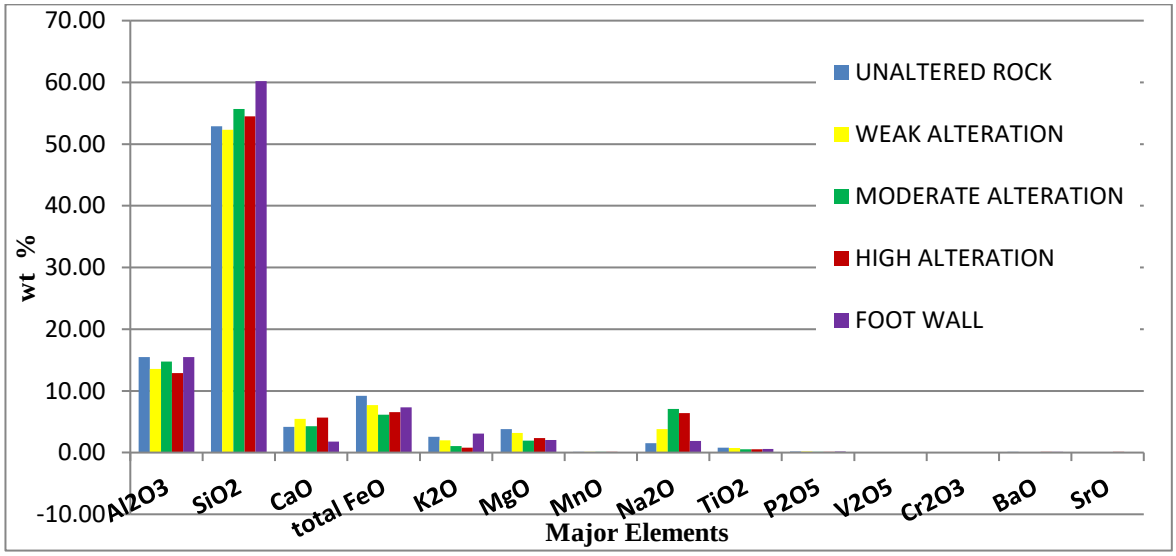
APPENDICES

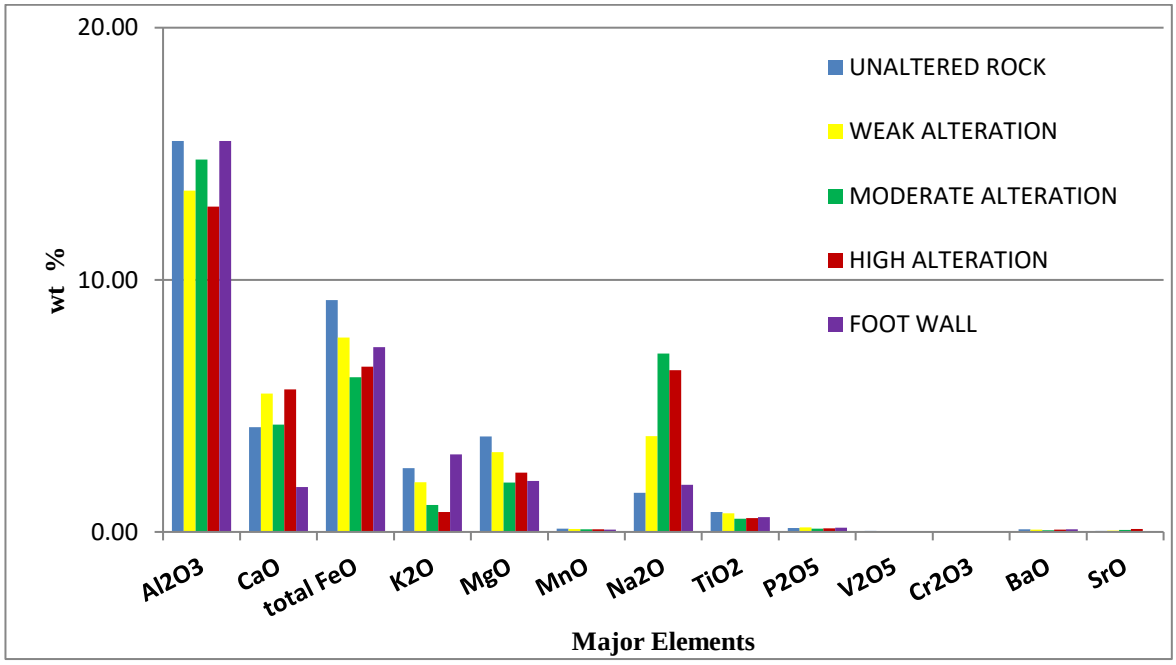
APPENDIX A

DISTRIBUTION OF MAJOR ELEMENTS FROM MINEALISED HANGING WALL AND UNMINERALISED FOOTWALL IN AKYEM MINE DEPOSIT



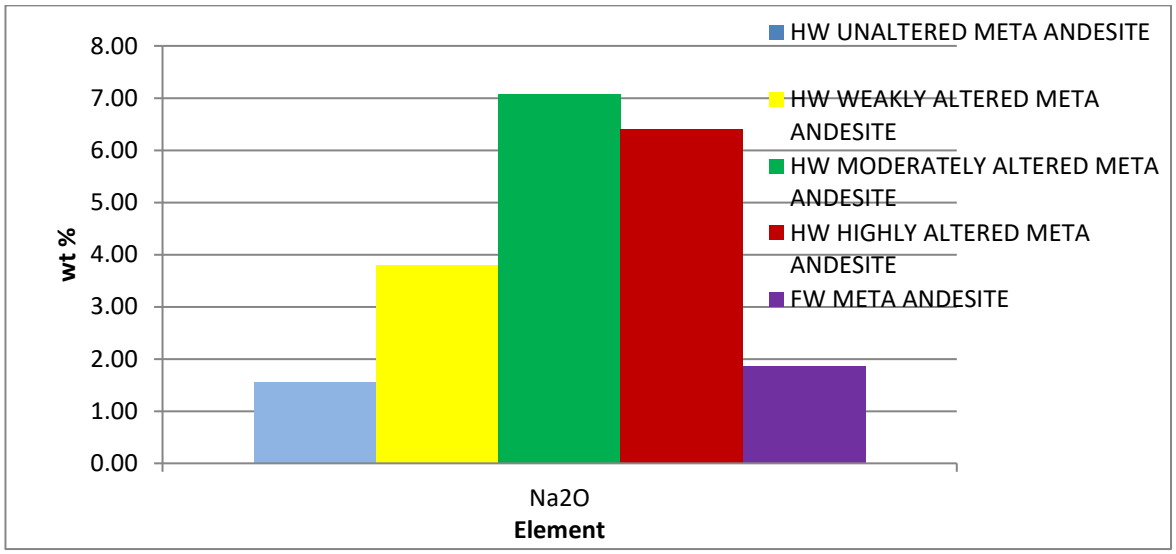
APPENDIX A2

DISTRIBUTION OF MAJOR ELEMENTS WITHOUT SILICA FROM MINEALISED HANGING WALL AND UNMINERALISED FOOTWALL ROCKS IN AKYEM MINE DEPOSIT



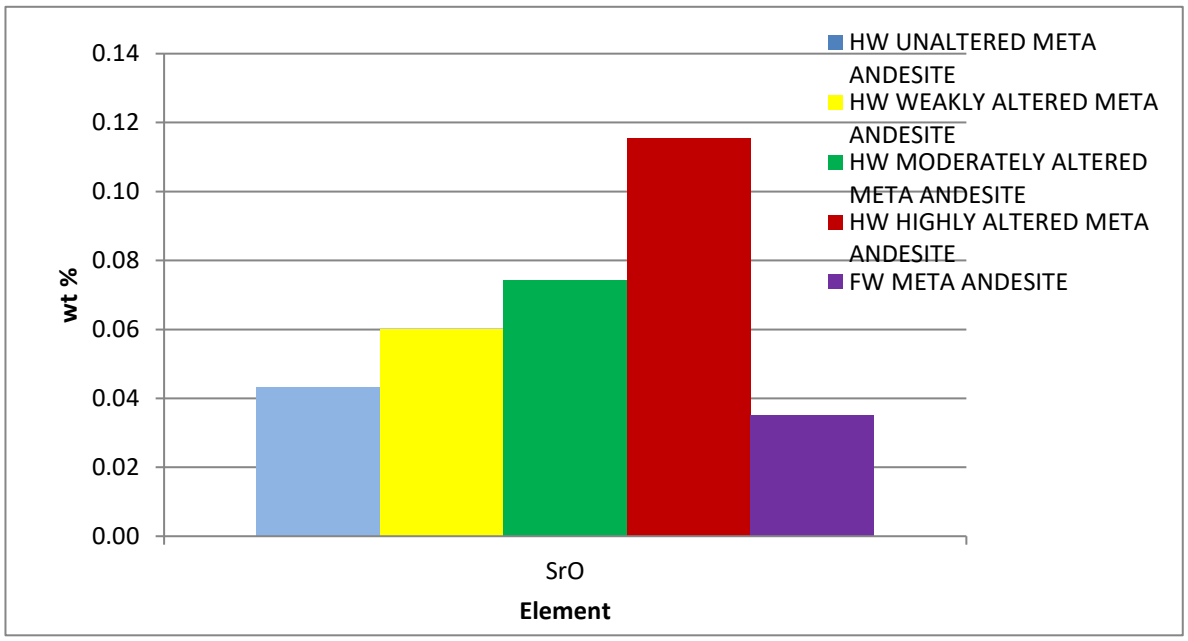
APPENDIX B1

PERCENTAGE WEIGHT OF Na_2O FROM MINEALISED HANGING WALL AND UNMINERALISED FOOTWALL ROCKS IN AKYEM MINE DEPOSIT



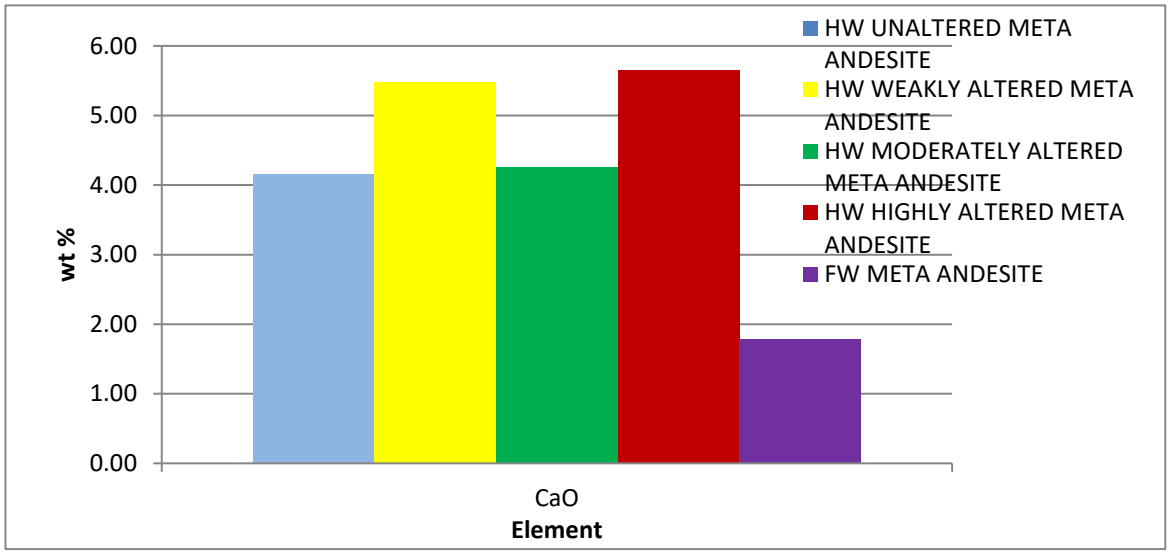
APPENDIX B2

PERCENTAGE WEIGHT OF SRO FROM MINEALISED HANGING WALL ROCKS AND UNMINERALISED FOOTWALL IN AKYEM MINE DEPOSIT



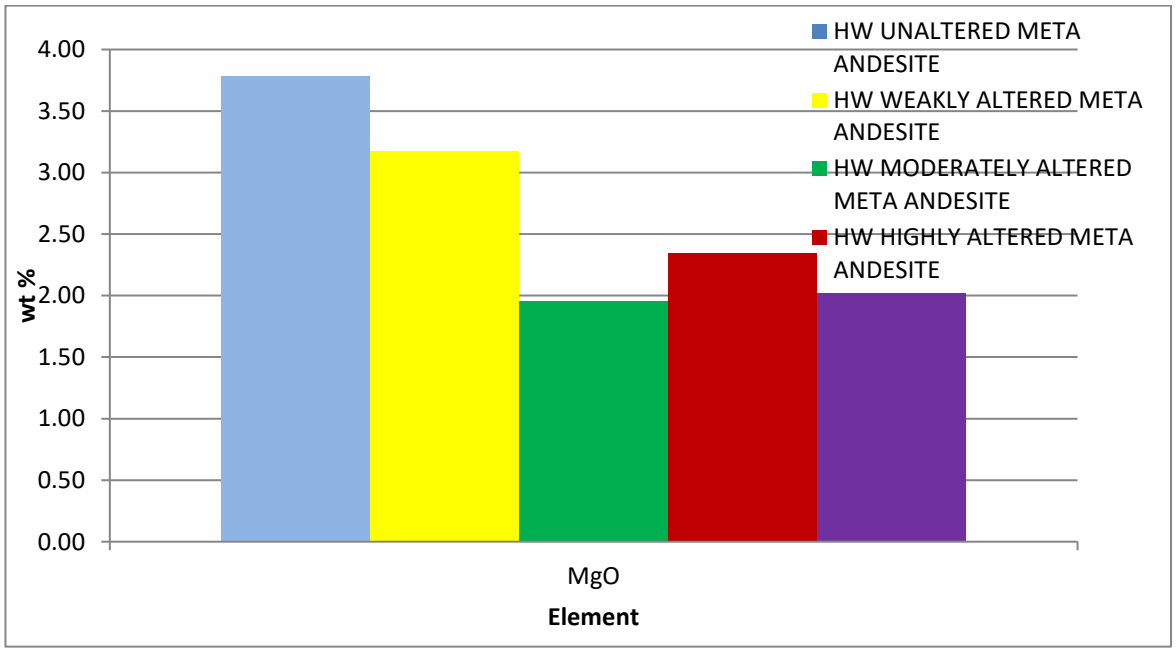
APPENDIX B3

PERCENTAGE WEIGHT OF CaO FROM MINEALISED HANGING WALL AND UNMINERALISED FOOTWALL ROCKS IN AKYEM MINE DEPOSIT



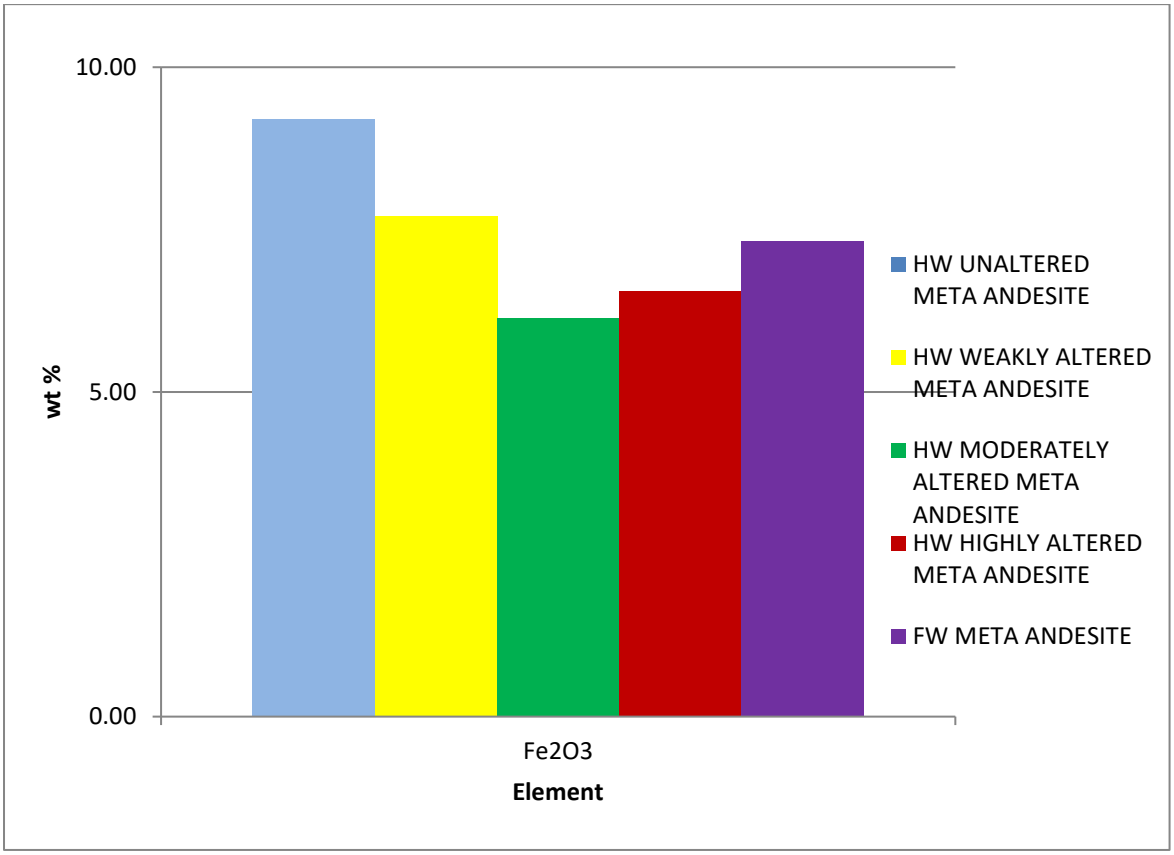
APPENDIX B4

PERCENTAGE WEIGHT OF MgO FROM MINEALISED HANGING WALL AND UNMINERALISED FOOTWALL ROCKS IN AKYEM MINE DEPOSIT



APPENDIX B5

PERCENTAGE WEIGHT OF Fe_2O_3 FROM MINEALISED HANGING WALL ROCKS AND UNMINERALISED FOOTWALL IN AKYEM MINE DEPOSIT



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