THE GEOLOGY OF THE MASSIVE SULPHIDE MINERALIZATION OF THE WIRE HILLS AREA, KENYA.

BY

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A thesis submitted in partial fulfilment for the degree of Master of Science (Geology) in the University of Nairobi.

Declaration

This thesis is my original work, and has not been presented for a degree in any other University.

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This thesis has been submitted for examination with our knowledge as University supervisors.

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ABSTRACT

A study of the Wire hills area and its relationship to the massive sulphide deposit associated with it is presented.

The geology of the Wire hills area varies from andesites through dacites to rhyolites associated with tuffs at the top. Cherts and banded ironstone are also associated with these rocks.

The study of drill cores has revealed that the Wire hills sulphide bodies occur in a sub-parallel manner striking to the north-west and dipping to the north-east at about 40°. The massive sulphide deposit shows effects of chloritization while the hanging wall rocks show silica enrichment. Sulphide veins are quite common in the footwall rocks.

The dominant minerals in the deposit are pyrite and pyrrhotite while chalcopyrite, arsenopyrite, sphalerite, gold and silver occur in minor amounts. Preliminary evaluation of the deposit indicates sulphide reserves of over 4 million tonnes.

Mineralogical and structural studies together with the chemical analysis indicate that the Archean massive sulphide deposit of the Wire hills is of volcanogenic-hydrothermal origin.

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CHAPTER 1

1 INTRODUCTION

1.1 Location

The Wire hills area is located in South Nyanza District, Nyanza Province about 90 km from Kisumu along the Kisumu-Kisii road and about 24 km from Kisii town (Fig.1). The main township in the study area is Oyugis which is located in the south-eastern part. The study area is about 140 sq. km and is bounded by the latitudes 0° 28' 36"S and 0° 28' 30"S and by longitudes 34° 40' 12"E and 34° 46' 12"E.

1.2 Physiography

Wire hills occupy the Central part of the study area. They are oriented approximately NW-SE and consist of several peaks. These hills form the highest topographic feature in the study area with the highest peak reaching 1663m above sea level. There are smaller hills to the east and north-eastern sections of the study area. In general, the area has an altitude of between 1260m and 1400m increasing southwards as one approaches the Kisii highlands. The drainage is generally good and the main rivers which drain the area include Awach, Owade and Nyandiwa. The rivers flow northwards and westwards due

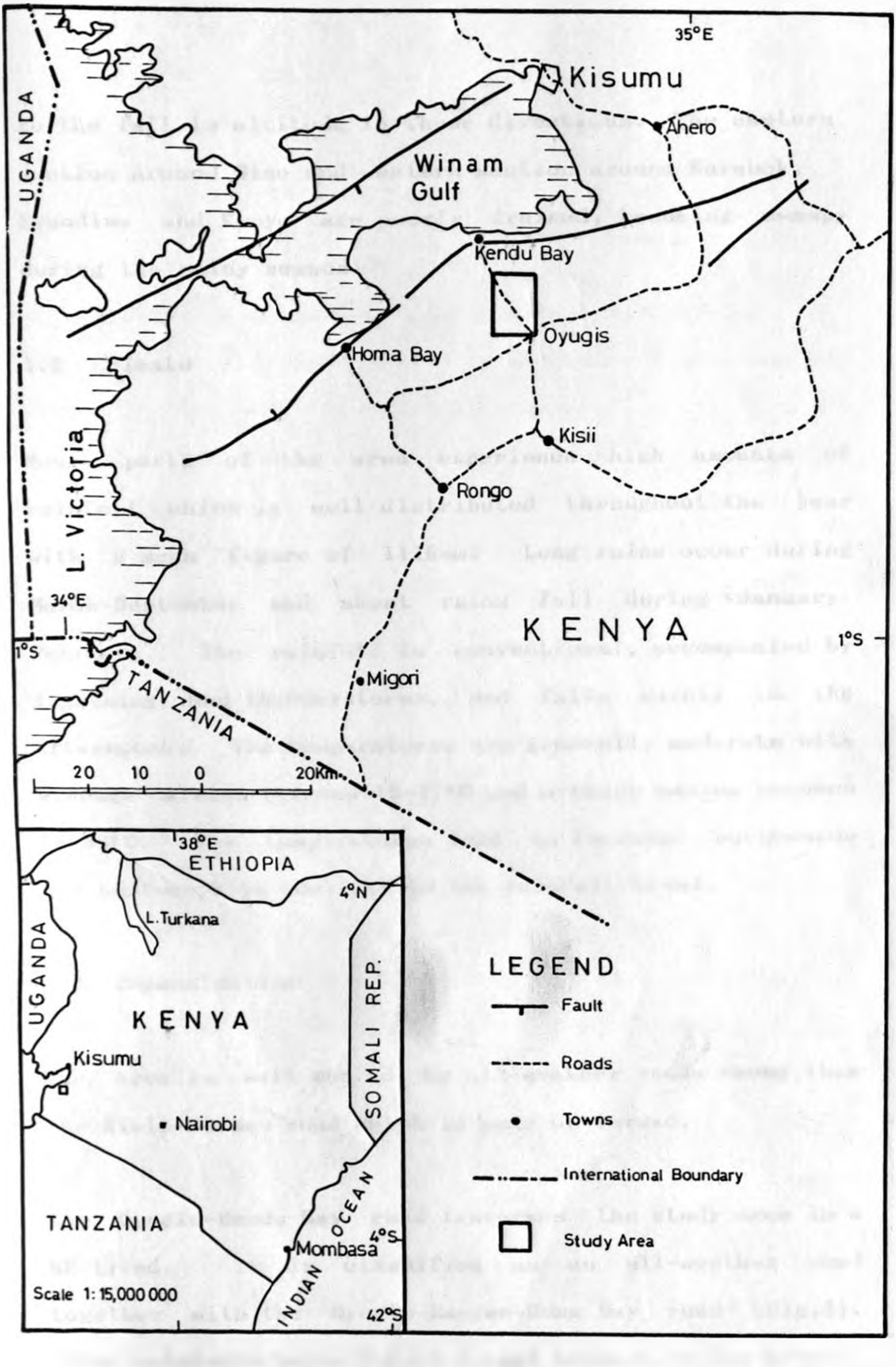


Fig. 1 THE MAPS SHOWING LOCATION OF STUDY AREA

to the fall in altitude in these directions. The eastern section around Sino and western section around Karabok, Nyandiwa and Kwoyo are poorly drained, becoming swampy during the rainy season.

1.3 Climate

Most parts of the area experience high amounts of rainfall which is well distributed throughout the year with a mean figure of 1116mm. Long rains occur during March-September and short rains fall during January-February. The rainfall is convectional, accompanied by lightning and thunderstorms, and falls mainly in the afternoons. The temperatures are generally moderate with average minima between 15-17°C and average maxima between 25-30°C. The temperatures tend to increase northwards and westwards in contrast to the rainfall trend.

1.4 Communication

The area is well served by all-weather roads among them the Kisii-Kisumu road which is made of tarmac.

The Oyugis-Kendu Bay road traverses the study area in a NE-trend. It is classified as an all-weather road together with the Oyugis-Rangwe-Homa Bay road (Fig.1). Other motorable paths form a closed network in the area.

1.5 Objectives of the Study

The objectives of the study were:

(a) To confirm the geology of the Wire hills area.

(b) To find out how the sulphide mineralization is related to the Wire hills rhyolitic dome.

(c) To study the paragenetic relationship between the sulphide minerals.

(d) To investigate the alterations associated with the sulphide deposit.

(e) To investigate the metal and mineral value of the deposit.

It is envisaged that the knowledge gained from this investigation will give more information concerning the genesis of the sulphide deposit and assist in further exploration of the sulphide mineral occurrences in the area. The work will also contribute new findings to the geology of the Nyanzian Group and its stratigraphy.

1.6 Previous Geological Work

Previous geological work in this area is reported by Saggerson (1952) to date back to 1909 when Coates examined the area south of Winam gulf. He studied the area between Oyugis and Kuja river and examined the mineralization of of the rocks of Wire hills and the sorrounding areas. One of his findings was that pyrite is a common mineral in the Nyanzian lavas though in small quantities. Coates (1909) also examined regions of gold and graphite occurrence but reported that they were not of economic value.

Other Geologists who studied the area as reported by Saggerson (1952) and Huddleston (1951) were: Oswald (1914), Coates (1930), Wayland (1931) and Kitson (1934). Oswald (1914) made a reconnaissance survey on the geology of the area between Lake Victoria and Kisii highlands. Coates (1930) reported on a graphite deposit occurring a few kilometres northeast of Wire hills, but commented unfavourably on it. Wayland (1931) did some reconnaissance geological mapping of western Kenya and described a traverse to the summit of Wire hills and surrounding areas. He reported traces of gold in quartz veins around the Wire hills. Kitson (1934) mapped the then Nyanza Province covering an area of about 25,900 sq. km which included the present Nyanza Province and Western Provinces. It is reported that he submitted his report in the form of traverse notes. In his report, he mentioned having visited the area around Oyugis township and indicated the presence of rhyolitic rocks.

Huddleston (1951) in his report on the geology of Kisii District covered a part of the study area. He noted the following:

(a) That the Wire hills are made up of rhyolitic rocks associated with tuffs and agglomerates.

(b) Minor developments of graphitic materials associated with fine grained mudstone, cherts and banded ironstone.

(c) Traces of gold, especially near the contacts between the Nyanzian lavas and granitic intrusives and also a copper ore boulder containing malachite and azurite along a stream valley in the area south of Oyugis township.

On the basis of these observations, he recommended further exploration of minerals in this area.

Saggerson (1952) carried out geological mapping of the then Kisumu District, which presently includes the whole of Kisumu District, large sections of Siaya and South Nyanza Districts and some parts of Western Province, all covering a total area of about 2900 sq. km. In his report, he has:

(a) Indicated that the geology of the area is dominated by the Nyanzian lavas and a few outcrops of sedimentary rocks and intrusives.

(b) Indicated the presence of pyrite veins within Nyanzian rhyolites and andesites and also traces of gold within banded iron formation.

(c) Suggested a stratigraphic succession for the Nyanzian volcanics to be as follows:

3. Rhyolites and dacites with banded ironstone and subordinate tuffs,

2. Andesites, Trachy-andesites and Dacites

1. Basalts with subordinate banded ironstone and tuffs.

He further suggested that this succession is thickest at Wire hill and could exceed 3000m.

Detailed exploration work in the area dates back to the late 1960's and 1970's when regional airborne geophysical surveys were carried out on the potential areas of western Kenya and the Wire hills were among the areas of special interest. In 1983, the Revolving Fund under the auspices of UNDP carried out a ground systematic follow-up of the airborne geophysical conductors. The geochemical work involved trenching and pedological sampling across the anomalies. Their trace element analysis revealed high copper values up to 2000ppm.

In most drill holes, massive pyrite-pyrrhotite bodies were intersected with occasional stringer mineralization of copper and silver. Geochemical assays of the sulphide deposit revealed maximum copper and silver values of 4.5%

CHAPTER 2

2 RESEARCH WORK METHODOLOGY

The following methods and techniques were used in carrying out the work:

2.1 Aerial Photography

Aerial photographs on a scale of 1:50,000 were used. Their interpretation indicated faults, lineaments, topographic variations and lithologic boundaries.

2.2 Geological Field Mapping

The aim of the exercise was to unravel the stratigraphic and structural history of the area. To accomplish these objectives, a geological field mapping was done on an area covering about 140 sq. km on a scale of 1:40,000. The traverses were conducted perpendicular to the strike of the major lithologic units, along river valleys, on hills and on raised grounds. Rock samples for petrographic and chemical analysis were collected. Structural measurements were done which included determination of strikes and dips of foliation surfaces and of joint trends for later structural interpretations.

and 93g/t respectively. The Revolving Fund recommended that further work be undertaken to define the extent and grade of mineralization. Further work was to include: Re-logging of the cores, further analysis of major elements from the cores, detailed geochemical work and geophysical survey, detailed geological mapping, structural analysis of the area and further core drilling to deeper levels.

Following the above recommendations, further exploration work was carried out in the Wire hills during the 1986 programme of the Revolving Fund. This involved detailed ground geophysical and geochemical work in an area of about 86 sq. km.

This work resulted in re-defining targets for the purpose of locating drill holes. Geochemical surveys involved trenching and soil sampling over anomalous zones for laboratory analysis. Drill holes were sited through the anomalies and in most cases massive sulphides were intersected. Based on the association of massive sulphides and acid volcanic rocks of Wire hills, they suggested that the geological setting could be a volcanogenic environment in which economic massive sulphide mineralization might be expected (A. Johnson, Personal Communication, 1987). However, they recommended further work to be done so as to determine the actual genesis of the massive sulphide deposit in addition to re-logging of the cores and analysis of the major elements.

2.3 Core Logging

Core logging was carried out on eighteen drill holes sunk in the area around Wire hills by the United Nations Revolving Fund for Natural Resources Exploration (UNRFNRE) team. The recovered cores are kept by the Ministry of Environment and Natural Resources at the Mines and Geological Department Nairobi. The logging was carried out so that the mineralization trend could be mapped and correlated and also to establish the lithostratigraphy of Wire hills.

2.4 Petrographic Study of Rocks

The study of rocks in thin section under the petrographic microscope was done to confirm and identify the lithological types and to investigate the host rock alteration products. The thin sections were made from rock samples collected during field mapping and also from the drill cores.

2.5 Ore Microscopy

This involved the study of polished sections made from massive sulphide samples collected from the drill cores. The ore microscopic examination was done to identify the sulphide minerals and establish their textures and the associated minerals.

2.6 X-Ray Diffraction Analysis (XRDA)

X-ray diffraction analysis was done to help identify unknown ore minerals and mineral products arising from hydrothermal alterations of the host rocks.

2.6.1 Powder Method

The X-ray Diffractometer used was a Philips Model No. PW 1710/00. The X-ray beam used was generated by a copper target CuK_α beam.

2.6.1.1 Theory

The basis of the XRD-analysis is on the Wuff-Bragg diffraction equation expressed as:

$n\lambda = 2d\sin\phi$ where n=integer
λ = X-ray wavelength
d = interplanar spacing
ϕ = Bragg angle

The use of the equation is based on the fact that the value of 'd' is unique to a particular mineral and if it is known in all possible directions, then the mineral can be characterised. The value of 'd' can therefore be obtained by finding 'λ' and ϕ. If the wavelength of the X-ray is set at a constant value, then 'd' will only depend on ϕ, for which the machine is set to determine.

The instrument was programmed such that the goniometer scans Bragg angles from 5° to 70° within which most minerals fall. The pulses from the diffractometer counter are traced on a chart recorder in form of diffractograms.

2.6.1.2 Sample Preparation

The samples were crushed and ground to fine powder of a size between 1μm and 10μm. Grinding to this size was done under acetone to prevent decomposition of sample during preparation. A slurry of powder was prepared in acetone on a microscope slide and as acetone evaporated, the powder settled and was left behind as a 'smear'.

2.6.1.3 Mineral Identification

The system used was that recommended by the International Centre for Diffraction Data and compiled by the Joint Committee on Powder Diffraction Standards (JCPDS). The JCPDS analyses are in two parts namely:

- JCPDS Diffraction file
- JCPDS Data book

The diffraction file is a search manual which is arranged such that the highest d-values are listed in a decreasing order corresponding to the intensity of peaks and possibilities given. The suspected mineral is thereafter looked up in the Powder Data book which has search cards of particular minerals with their detailed diffractometric descriptions.

The 2ø values obtained from the diffractometer chart were first converted into corresponding d-values using a conversion table. For the unknown minerals, the intensities were assigned 100 while the others were given relative values to it. The values were tabulated. The mineral with the d-value corresponding to that of the most intense peak was looked up in the JCPDS diffraction file and further confirmed by use of the JCPDS Powder Data book.

2.7 Atomic Absorption Spectrophotometry (AAS)

The Atomic Absorption Spetrophotometer used was a Varian Techtron AA6 model. The analytical method was used for whole rock assay to:

(a) Characterise various lavas in the study area
(b) Study the alteration patterns associated with mineralization.

2.7.1 Method

The instrument consists of a hollow-cathode lamp of element of choice, a gas source of which oxygen acetylene was used, a gas chamber where the liquid sample is aspirated to decompose the molecules to give atoms in the ground state, detector and readout system.

The theory of the analysis is that the lamp which is the light source emits a sharp line spectrum of the element to be determined which is passed through the atomic vapour. If an element similar to that of the lamp is present in atomised vapour, then the spectrum will be absorbed, a measure of which indicates the amount of the element present (McLaughlin, 1977).

2.7.2 Sample Preparation

The following procedure was carried out during the preparation of the samples of AAS analysis:

(a) Rock was pulverized and sieved and the 100 mesh fraction taken.

(b) 1 gram of sample was the thoroughly mixed with 5 grams of Na_2CO_3 as a flux in a platinum crucible and fused at 1000°C until a clear melt was obtained.

(c) The sample was then dissolved in 50ml 1:1 HCL solution.

(d) The sample was then diluted using distilled water to have the concentration within the calibrated range of the machine.

(e) The stardards for the machine calibration were prepared from 1000ppm stock solutions prepared from analytical grade chemicals.

2.8 X-Ray Fluorescence Analysis (XRFA)

The XRF analysis was carried out on the sulphide deposit for the investigation of their major and minor elements and on monominerallic samples of pyrite, arsenopyrite, chalcopyrite for their minor and major element content.

2.8.1 Fundamental Parameters Method (FPM).

The theory behind the method is discussed by Kinyua (1982) and Norrish (1977). For the excitation of characteristic fluorescence X-rays, a radioactive isotope source of Cd-109 was used and measured by Si (Li) detector. The above source is capable of exciting K-shells of elements from Calcium to Molybdenum and L-shells of heavy atoms upto Uranium. The use of fundamental parameters method made it possible for quantitative analysis to be carried out since the element concentration can be related to the size of area below the peak of the characteristic X-rays.

2.8.1.1 Sample preparation and analysis

Samples were crushed and thoroughly pulverised to particle size of less than 50 microns. A known mass of sample and starch or cellulose were mixed and thoroughly homogenized. Out of the mixture, pellets of mass between 0.1 gram and 0.2 gram were prepared. Starch or cellulose was used both as a binder and a dillutant to minimize enhancement effects. The pellets were excited for 2000 sec. each while the multi-element target plus sample and multielement target alone were excited for 500seconds each. This last stage was performed to correct for absorption effects. The result of XRF-Analysis are presented in chapter 5.

CHAPTER 3

GEOLOGY

3.1 General Geology

The Wire hills area lies within the rocks of the Nyanzian and Kavirondian Groups which are of Archaean age. These rocks together with the accompanying granites form a narrow strip of Archean rocks which extend from northwestern Tanzania to western Kenya and through into eastern Uganda (Figure 2). They exhibit low grade regional metamorphism of the greenschist facies.

The age of the rocks of the Nyanzian and Kavirondian Groups has been determined by radiometric techniques and the lowest accepted limit stands at about 2550Ma. Analysis by Rb-Sr dating for a rhyolite outcrop sampled at a locality about 2km. north of Oyugis town along the Owade river gave an age of about 2015 +/- 300Ma (Cahen and Snelling, 1966). The recent dating of hornblende from the Migori granite which intrudes rocks of the Nyanzian Group gave K-Ar age of 2530 +/-50Ma (Ogolla, 1984). It is however, considered that the history of the group extends back to at least 3100Ma (Sanders, 1964).

The geological succession of the Wire hills area is here

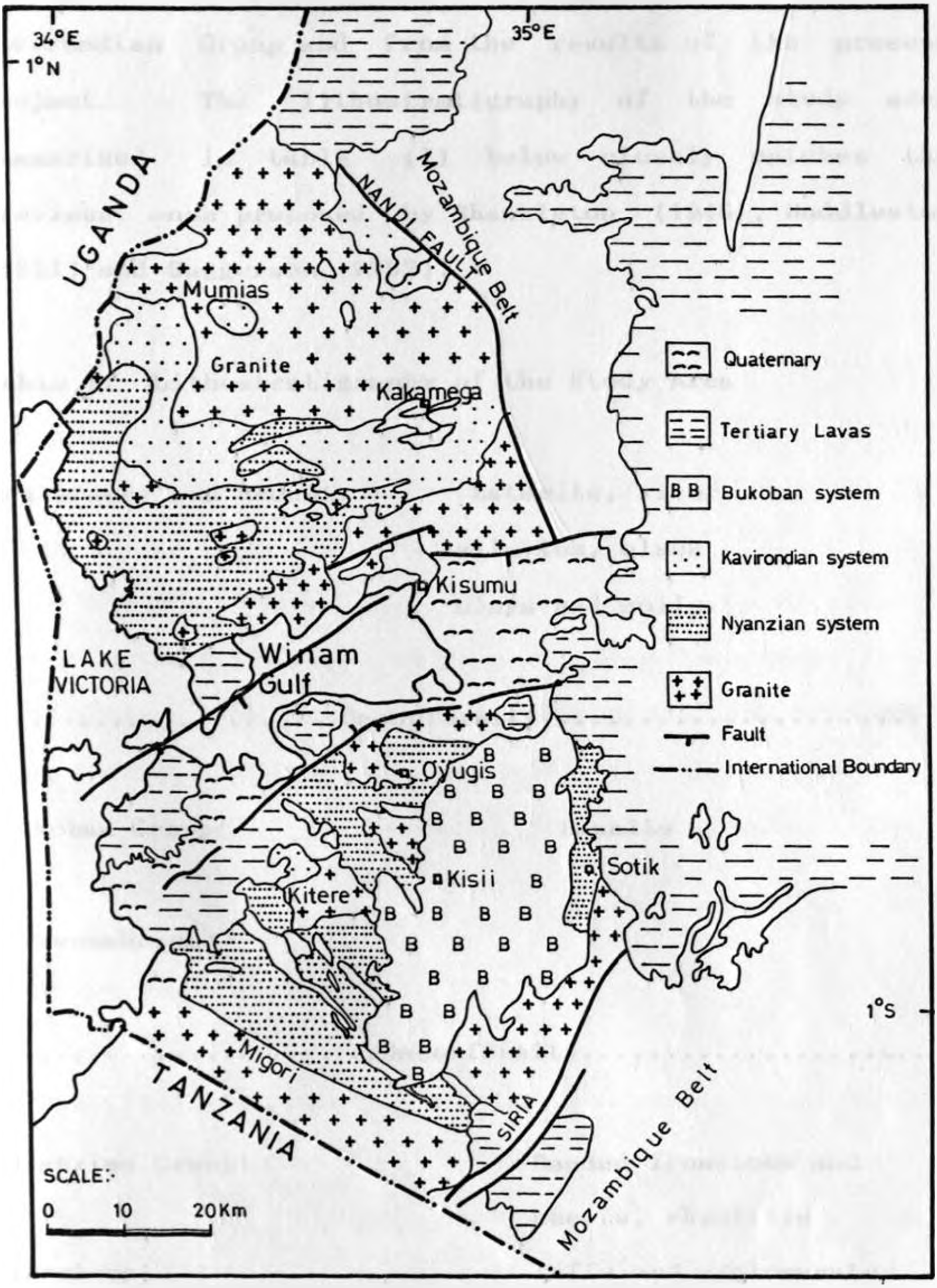


Fig. 2 MAP OF WESTERN KENYA GREENSTONE BELT AFTER SANDERS (1964)

attempted in light of the knowledge of the Nyanzian-Kavirondian Group and from the results of the present project. The lithostratigraphy of the study area summarised in table (1) below closely matches the previous ones proposed by Shackleton (1946), Huddleston (1951) and Saggerson (1952).

Table 1. Lithostratigraphy of the Study Area

Quaternary and Recent:	Laterite, river alluvium, black clays and soils.
......................Unconformity......................	
Bukoban Group: (Precambrian)	Basalts
......................Unconformity......................	
Nyanzian Group: (Archean)	-Banded ironstone and cherts, rhyolitic tuffs and agglomerates, rhyolites and flow brecciated rhyolite, -Dacites -Andesites
....	

Intrusives:	Minor quartz veins
Giant quartz veins	
(Precambrian)	Dolerites
	Granites and
	Diorites (Archean)

3.2 Detailed Geology of the Wire Hills Area

In the Wire Hills area, the geology is dominated by rocks of the Nyanzian Group which are both volcanic and sedimentary. Rocks of the Kavirondian and the Bukoban Groups are of minor occurrence while the intrusives are dominated by the Oyugis granite and quartz veins. The rocks are described in detail below.

3.2.1 The Nyanzian Group

The Nyanzian rocks that occur in the area include both volcanics and sediments. The volcanic rocks are represented by dacites, andesites, rhyolites and associated pyroclastics. The sedimentary rocks include banded ironstone and cherts.

3.2.1.1 Andesites

In the area, andesite outcrops are located about 7km northwest of Oyugis around Kosele and to the south of river Awach Kibuon. To the north and to the west, the andesites are bordered by dacites and rhyolites respectively.

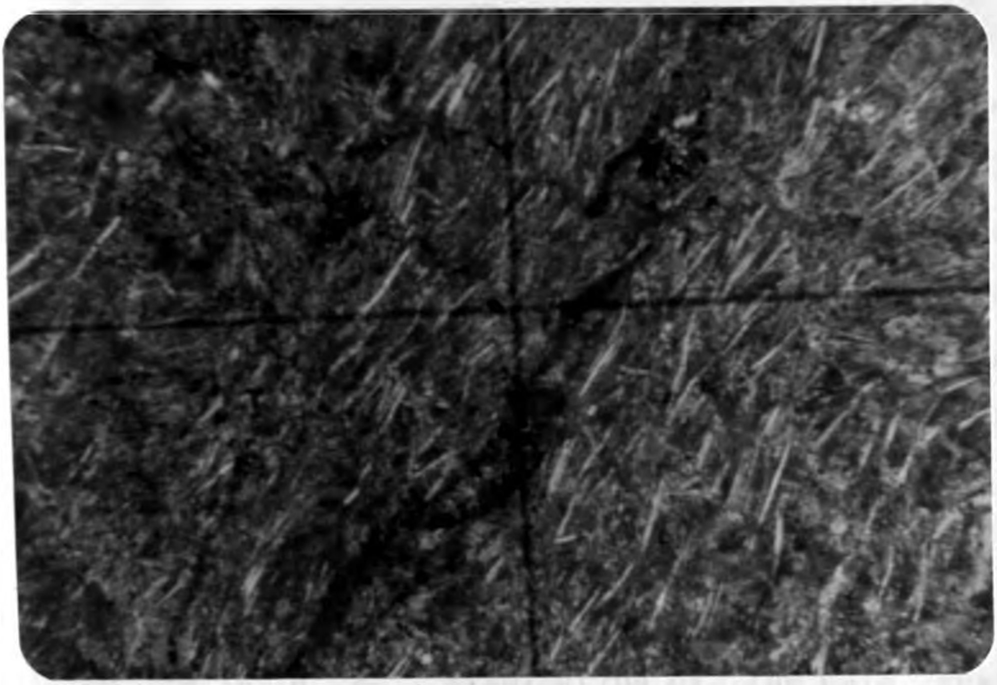
In the field, the rocks are bluish- green, fine grained dense and show variable degrees of alterations and deformations. In fresh or mildly deformed outcrops, the rocks are masssive but jointed. In strongly deformed zones, the andesites are highly sheared resulting in the development of schistosity in some outcrops. On weathering along such shear zones, the rocks break into thin slabs rich in iron oxides that have caused a reddish brown colouration on them. Magnetite is frequently associated with such weathering products. Quartz veining is prominent in the deformed zones and the veins are emplaced within deformed rocks concordant to their foliation planes.

In thin section, the major composing minerals include plagioclase, chlorite, augite, calcite and minor amounts of sericite and iron oxides. The texture in thin section is typically porphyritic, phenocrysts being mainly plagioclase feldspars and minor augite.

Flow texture is commonly present and is exhibited by crystallites of plagioclases and sanidine (Plate 1). The crystallites are elongated in a particular trend indicating the direction of lava flow. The matrix also contains the same composition as the phenocrysts together with the minerals listed above. The plagioclase is dominantly andesine having an extinction angle of between 15° and 25°. The andesine phenocrysts often show both polysynthetic albite and Carlsbad twinning patterns. Interpenetrative twins of andesine were noted in one specimen in which the twins enter each other at an angle of about 90°. Augite frequently occurs as disseminated phenocrysts typified by their high birefringence.

Quartz mainly occurs in the groundmass as a cryptocrystalline base as well as anhedral crystals. Some quartz also occurs as 'clots' and as micro-veins too. Hornblende is rare but when present, occurs as euhedral phenocrysts. Secondary minerals are very prominent in thin section and are represented by chlorite, sericite, calcite and iron oxides in the order of decreasing abundant.

Chlorite occurs as greenish weakly pleochroic scaly masses in plane polarised light (PPL). In crossed polars (XP), the mineral shows low birefringence characterised by colours of the first order orange. Chlorite shows good cleavages and extinction angle of less than 6°. Calcite commonly occurs and is determined by its characteristic



(XP,X20)

PLATE 1

Photomicrograph of andesite. Crystallites are of andesine and they show a flow texture.

twinning, rhombohedral cleavages, twinkling effect and by its high interference colours in XP. The mineral occurs in the groundmass in the form of grains, veins and as an alteration product of the calcic-minerals.

Sericite is a common alteration product of the silicate minerals. It occurs in the groundmass as small tabular flakes of high birefringence. Some sericite also occurs as disseminated flakes on feldspars. Iron oxides occur as dark and opaque minerals with irregular shapes and also as grains which are disseminated throughout the specimen.

Whole rock chemical assay of representative samples are tabulated in Table 2. Examination of the data reveal that the SiO_2 value falls within the andesite field which ranges from 52% to 64% (Hatch, 1984, Carmichael et al, 1974).

3.2.1.2. Dacites

The dacites occur in the southern part of the study area around Wire Hills forming a crescent shaped outcrop (Map). They are bounded to the west and south-west by the Oyugis granite and to the north by the rhyolites. To the south, the dacites are overlain by the Bukoban basalt.

In the field, the rocks are greyish to greenish grey fine grained, dense and occasionally flinty. The outcrops are

TABLE 2 WHOLE ROCK CHEMICAL ANALYSIS OF WIRE HILLS AREA ANDESITES (%)

OXIDE\ SPEC.NO.	146	147	163	166	179	63
SiO_2	59.21	59.49	57.57	59.34	58.19	60.58
TiO_2	0.75	0.83	0.92	1.25	1.50	1.17
Al_2O_3	14.17	13.23	15.12	14.17	16.06	14.17
Fe_2O_3	5.72	4.29	7.15	7.86	8.58	7.15
MnO	-	0.65	0.16	0.13	1.00	0.13
MgO	2.16	1.91	2.25	2.50	2.12	2.16
CaO	4.20	2.17	14.44	12.01	8.48	6.23
Na_2O	2.56	3.37	2.02	2.16	2.02	4.85
K_2O	3.37	2.41	0.24	0.36	0.84	1.08
P_2O_5	0.08	0.08	0.06	0.04	0.18	0.12
Total	92.58	88.43	99.93	99.82	97.47	97.63

generally lithologically inhomogenous being highly siliceous in some outcrops and tending to rhyolitic composition, while others are more mafic and approaching andesitic composition. On weathering the rocks become friable, yellowish or pale pinkish in colour and occasionally stained reddish by iron oxides. The rocks frequently have disseminations of pyrite in euhedral grains and also as millimetre thick veins. In altered zones, clear calcite and quartz grains are present as inclusions in vesicles. Quartz veining is common and some of the quartz veins are auriferous. In some outcrops, flow patterns are shown by vesicles which are straightened and elongated into rods, some of which are infilled with quartz.

In thin section, the texture is typically porphyritic and the phenocrysts often show flow patterns in which the crystallites are elongated in a preferred direction. The matrix is dominantly fine grained. The phenocrysts are mainly composed of plagioclase feldspars though the particular minerals could not be determined with much certainty due to the alteration which has masked the albite twinning patterns. The quartz comprise more than 40% of the rock. The other prominent minerals include 25% feldspars, 20% chlorite, 5% calcite, 5% sericite, 3% iron oxides and 2% epidote.

Quartz occurs in 'Pools' and as anhedral grains disseminated in the groundmass. The quartz 'pools' are inferred to represent vesicles which got infilled with silica.

Chlorite, calcite and epidote are secondary minerals formed as alteration products from the mafic minerals. The abundance of chlorite and epidote indicates that the primary mafic minerals were completely altered into the secondary minerals. Chlorite occurs in tabular crystals while calcite occurs mainly in the groundmass as small grains and veins.

The epidote occurs both as tiny grains and as disseminated rounded phenocrysts. The epidote is pale greenish in PPL and occurs in euhedral masses which in XP shows strong birefringence characterised by third order interference colours.

Iron oxides occur as opaque dark minerals disseminated throughout the specimen. Occasionally hematite occurs in boxworks structure while magnetite occurs as a replacement of the mafic minerals.

Sericite occurs in minor tabular flakes which often show a preffered orientation and are characterised by high interference colours in XP. Some sericite crystals occur as replacement of the feldspars.

Chemical analysis of the dacite are given in table 3. From the table, the results of silica (SiO_2) analysis falls in the range of 64-68% which is considered to be

TABLE 3 WHOLE ROCK CHEMICAL ANALYSIS OF WIRE HILLS AREA DACITES.(%)

OXIDE\SPEC.NO.	218	184	239
SiO_2	68.87	67.37	65.88
TiO_2	1.08	1.17	1.17
Al_2O_3	14.17	14.17	14.17
Fe_2O_3	5.72	5.72	6.43
MnO	0.13	1.00	0.13
MgO	0.53	0.46	1.41
CaO	3.48	3.57	7.40
Na_2O	4.72	5.32	3.64
K_2O	2.05	1.20	0.75
P_2O_5	0.06	0.06	0.14
Total(%)	100.81	100.04	101.12

the range for a dacitic rock (Hatch, 1984).

3.2.1.3 Rhyolites

The rhyolites form the dominant rock unit in the study area. The ryolites occupy the central and eastern sections, bounded by the andesites to the north west, dacites and granites to the south-west and overlain by the Bukoban basalts to the south east. They overlie the intermediate lavas and ironstone. The rhyolites have a maximum accumulation on the Wire hills where as a rock unit, they attain a thickness of more than 300m. Based on their macroscopic textures, the rhyolites can be subdivided into three sub-units. These subdivisions are: fine grained rhyolites, flow brecciated rhyolites and brecciated rhyolites.

(a) Fine Grained Rhyolites

Fine grained rhyolites are the most common among the rhyolitic rocks. The rocks are fine grained and flinty often breaking in a splintery manner producing sharp edges which are translucent to transparent. The rocks are highly siliceous varying in colour from creamy white to shades of green and light pink. Maroon coloured types have been noted in drillcores together with yellowish types. There is often a porphyritic variety intercalated within the fine grained type. The phenocrysts observable in outcrops are mainly clear quartz crystals in anhedral shapes measuring upto 2mm. The fine grained rhyolites often weather to a yellow or pale pinkish white friable rock, commonly stained to reddish colours by iron oxides. Fresh outcrops of this rock type have been noted on the western peaks of the Wire Hills and along Owade river. The rest of the occurrences are altered equivalents.

In thin section, the texture is weakly porphyritic in which the phenocrysts are embedded in a fine grained groundmass. The phenocrysts are mainly composed of euhedral sanidine crystals. The groundmass is mainly composed of fine grained quartz and feldspars together with sericite and iron oxides. The sanidine phenocrysts comprise less than 2% of the rock and occurs with hexagonal crystal outline. In total, the feldspars comprise about 40% of the rock.

The quartz phenocrysts occurs in euhedral dipyramidal shaped crystals while in the groundmass the quartz occurs in anhedral fine grained masses which comprise about 50% of the rock. Sericite occurs in very small scaly masses in the groundmass characterised by it's high interference colours in XP. Some sericite crystals occur as a replacement on the feldspar phenocrysts. Sericite comprises about 8% of the rock. Iron oxides frequently occur in fine grained units disseminated throughout the rock and constitute about 2% of the rock.

In the drill core samples, the fine grained rhyolites exhibit intense alterations with abundance of sericite and introduction of chlorite and calcite. These latter minerals are attributed to hydrothermal solutions which invaded the rock.

(b) Flow Brecciated Rhyolite

Occurrences of the flow brecciated rhyolite was mainly observed in drillcores recovered from the Wire hills area. The rhyolite stratigraphically underlies the tuffs and lapilli tuffs.

In hand specimen, the rock is fine grained, dense, siliceous and has well rounded fine grained rhyolitic clasts. The colour is commonly leucocratic with creamy white shades although greenish colours do occur due to chloritization, especially near the mineralized zones. The texture is agglomeratic and where there is alteration, the clasts tend to be the least altered.

In thin section, the rock is essentially composed of quartz and feldspars with minor occurrence of calcite, chlorite, sericite and accessory iron oxides. The texture in thin section is mainly fine grained but occasionally porphyritic units occur. Quartz occurs both as phenocrysts and as anhedral masses in the groundmass. The phenocrysts have a di-pyramidal crystal outline. The feldspar phenocrysts when present are mainly sanidine. The groundmass is composed of quartz, feldspar and the secondary minerals, namely; 10% sericite, 5% chlorite and 3% calcite. Quartz comprises more than 40% of the rock while feldspar comprises about 35% and iron oxides about 2%.

A distinctive feature of the flow brecciated rhyolite is the absence of a distinct boundary between the clasts and the matrix and also the continuity in mineral composition from the matrix to the clasts. The formation of the flow brecciated rhyolites has been postulated by among others Spence, 1975 and Spence and de Rosen-Spence, 1975.

The formation is thought to be as a result of autobrecciation which occurs when a rhyolitic lava flow into water. The interaction between the cold water and the hot lava results in chilling of the lava front which then solidifies earlier than the other parts of the lava. The chilled and solidified portions of the lava are then inco-operated into the lava giving it an agglomeratic outlook. The chilled and solidified lava is more aphanitic than the rest of the lava which solidify slowly.

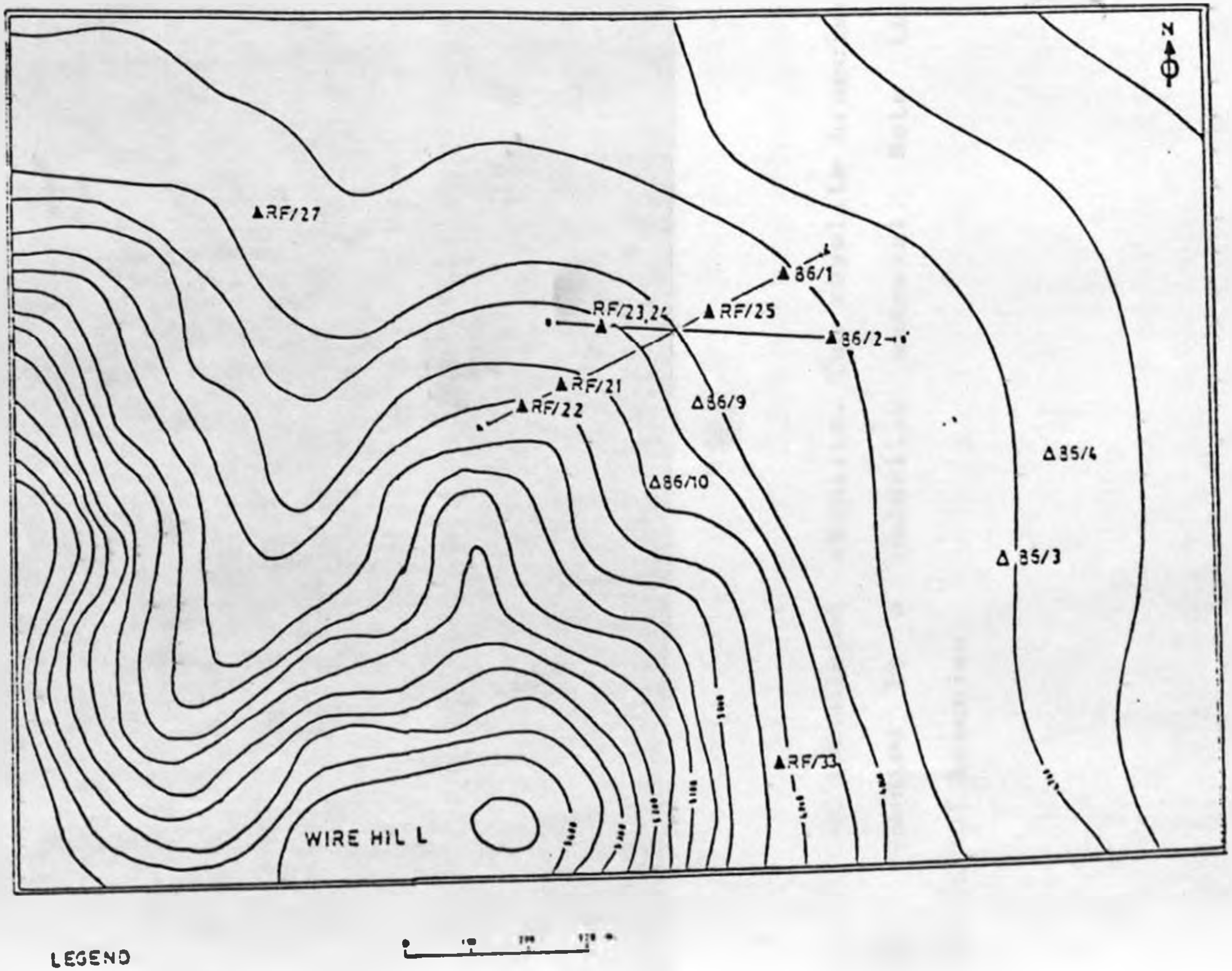
(c) Brecciated Rhyolite

The rock was only observed in the drillcores recovered from the Wire hills in the drillholes 86/1, 86/10, RF/22, RF/22 (Figure 3 and appendix). The rock unit occurs in the lower stratigraphic zones at depths exceeding 100m. In drillholes 86/1 and RF/22, the relative thickness of the rock unit averages about 20m. While in drillhole 86/10, a relative thickness of about 140m is present. The occurrence of the rock unit in drillhole RF/21 extends below the maximum drilled depth.

In hand specimen, the breccias vary in size from less than 5x5mm to 70x30mm. The breccias are generally leucocratic being yellowish but greyish green in some occurrences. In plate 2, the cementing material is greenish and fine grained but occasionally it has greenish fibre-like structures of chlorite. The breccias often show minimal displacement and in such specimens the opposing faces match and can fit perfectly well when moved closer to each other. The edges of the breccias are sharp but in most cases have been smoothened to varying extent. In thin section, the breccias are composed of fine grained rhyolites in which quartz and feldspars are the dominant minerals. Sericite is prominent but chlorite is in minor quantity comprising about 2% of the rock.

The occurrence of breccias have been noted in other countries where it is associated with volcanogenic massive sulphide deposits especially within the Canadian Archean greenstone belts. The formation of the breccias has been hypothesised by many geologists, among them

Fg 3 LOCATION MAP OF DRILLHOLES ON WIRE HILL



LEGEND

— 1100 — Contours (feet)

Drillholes

(a) ▲ Mineralised

(b) △ Non-Mineralised

•———• Baseline

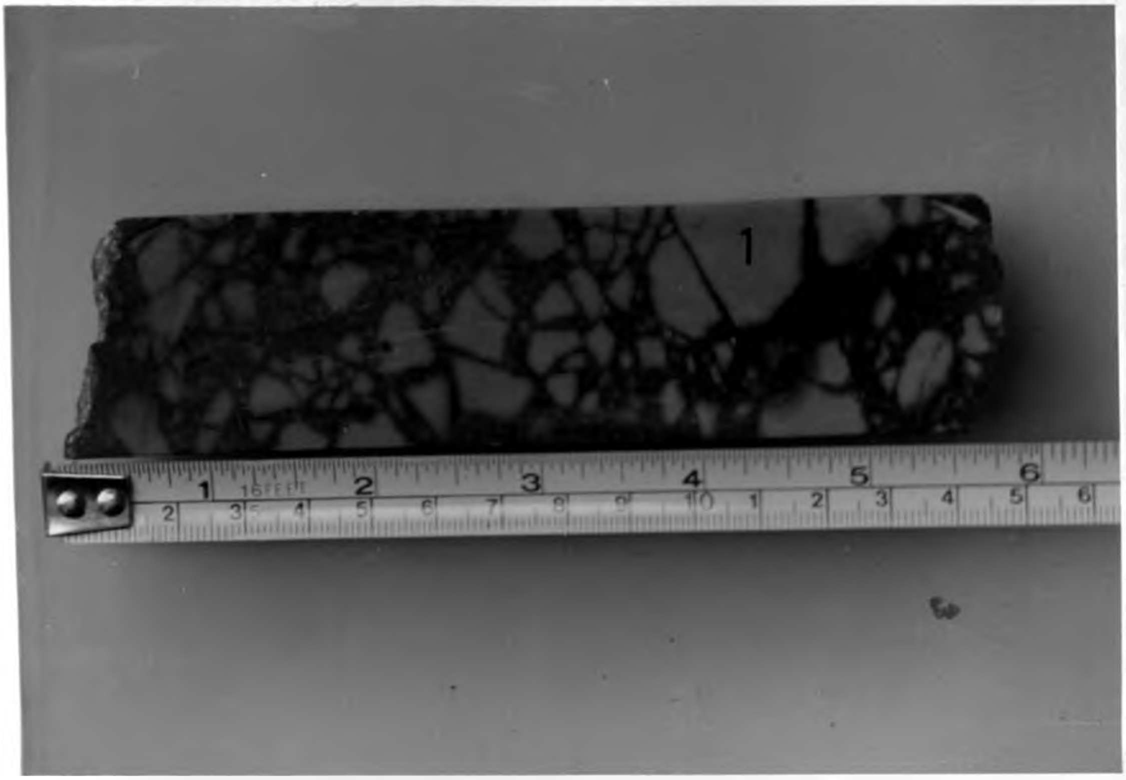


PLATE 2

Photograph of brecciated rhyolite. The rhyolite breccias (1) are cemented by a chloritic material. Note the smoothening of breccias

Mitcham, (1974) and Bryant, (1968). Some geologists, among them Bryant (1968), favour an intrusive origin while others favour explosive volcanism and yet others a tectonic model. Most studies reveal that the breccias form close to the vents of eruption and are a product of fracturing caused by the explosive activity of the volcanism.

For the case of the Wire hills breccias, a tectonic model is postulated because of the following reasons:

(a) While the rhyolite breccias elsewhere are associated with sulphide mineralization, these breccias of the Wire hills are non-mineralized except for the hydrothermal alteration which has affected the cementing material and also the breccias.

(b) The brecciated zones coincide with zones of faulting as revealed by geophysical surveys and

(c) In one case the unit is coincident with zones of displacement of the sulphide bodies (Fig. 13).

It can therefore be concluded that the breccias originated from fault movements. The faulting superceded sericitization which resulted in the rock attaining the yellowish colour. The openings which developed resulted in the migration of hydrothermal solution upward. This solution resulted in the smoothening of the sharp edges-of the breccias and deposition of chlorite within the space between the breccias. The direction of flow of the solutions is indicated by the growth of chlorite fibres which are elongated in the direction of flow.

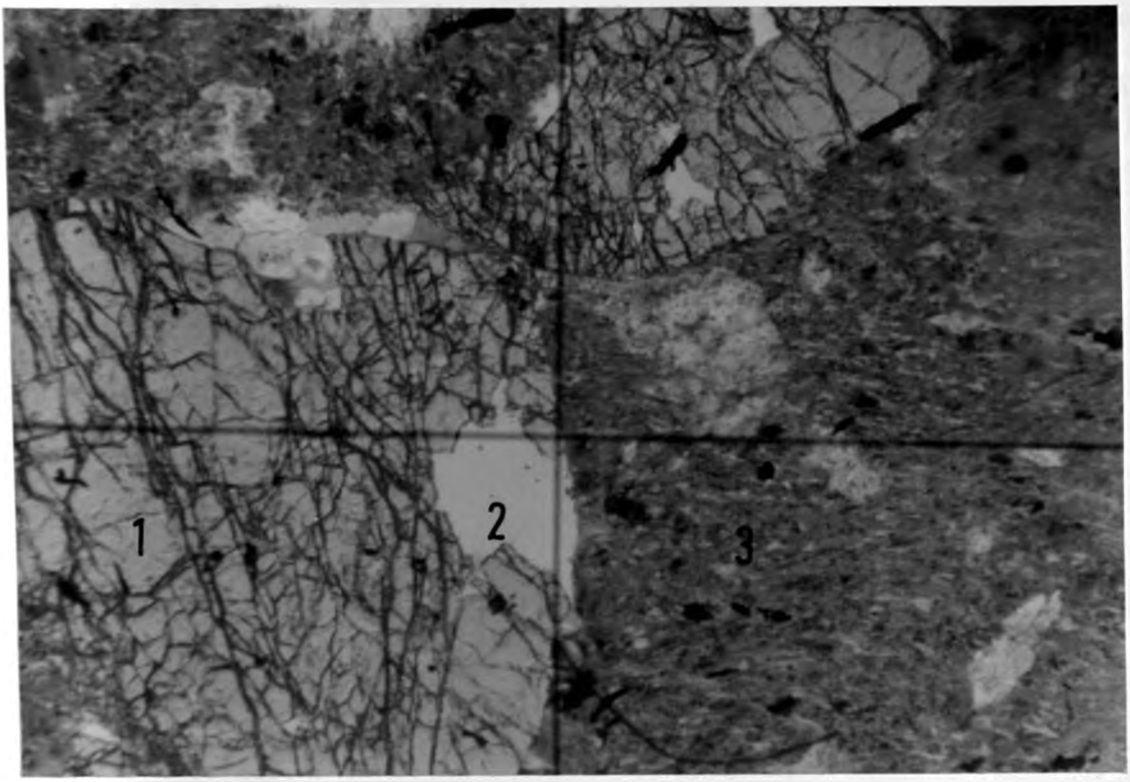
3.2.1.4 Garnetiferous Band

This rock unit occurs as a band which was noted in drillhole RF/21 at a depth of between 167m and 158m. The rock unit occurs between fine grained yellowish rhyolite and massive pyrrhotite ore which form the footwall rock.

In hand specimen, the rock is porphyritic with reddish brown almandine garnet being prominent and occurring in clusters in a fine grained dark green chloritised matrix.

In thin section, the texture is similarly porphyritic. The phenocrysts of almandine garnet comprises about 30% of the rock. The garnets occur in euhderal aggregates which show alot of fracturing, the space in between being infilled with quartz (Plate 3). Quartz comprises about 25% while chlorite accounts for about 40% of the rock. Iron oxides and other accessory minerals account for the remaining 5%. Quartz occurs in anhedral masses associated with the garnets and also as fine separate grains.

Chlorite occurs in green tabular and weakly pleochroic units while iron oxides occur as opaque minerals



(XP,X20)

PLATE 3

Photomicrograph of a garnetiferous rock. Garnets (1) are fractured and infilled with quartz (2) . The host rock (3) is highly chloritized for example as noted in the right hand side of the photomicrograph.

disseminated within the groundmass. The chlorite is a product of hydrothermal magnesian metasomatic alteration. This resulted in the complete alteration of the feldspars to chlorite due to the introduction of magnesium. This change resulted in the release of silica which is expressed in fractures in the garnets as quartz.

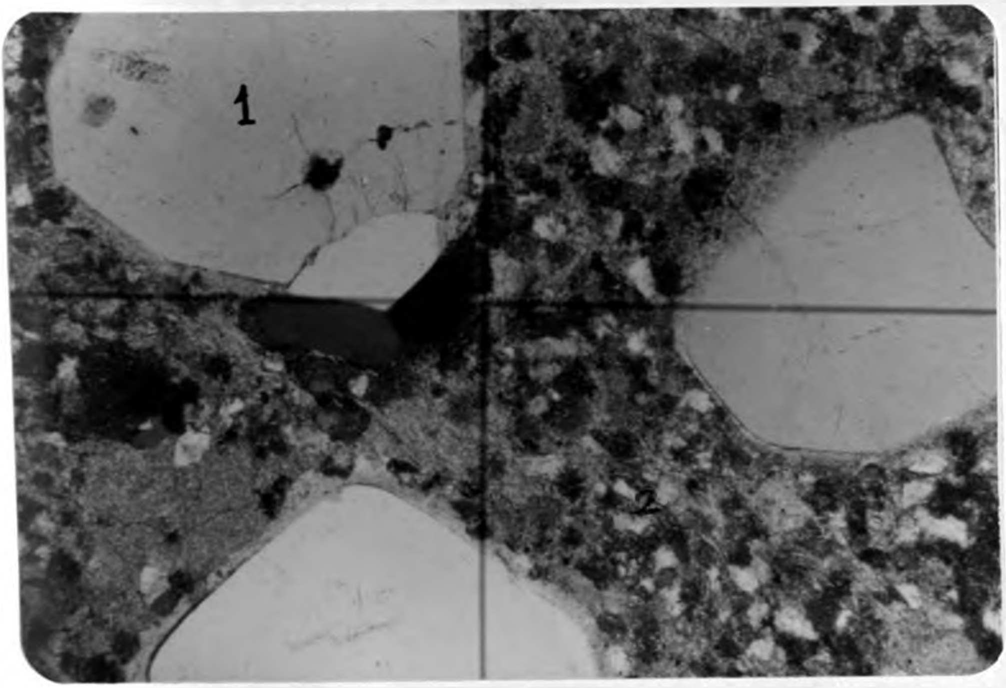
The presence of garnets in the rock possibly resulted from high temperature hydrothermal alteration of the aluminous rock. Since the rock is highly altered, it is suggested that the altered rock was a tuff. Tuffs were found, from the present study to be more susceptible to hydrothermal alterations.

3.2.1.5 Quartz Porphyry

A typical occurrence of this rock type is of limited exposure in the study area. However, the rock is prominent on Kisuri hills northeast of the main Wire hills. Here, due to its high resistance to weathering and erosion, the outcrop forms a high positive relief. The Kisuri chain of hills quartz porphyry is displaced by a fault that trends N60°E in the area just east of Nyalenda (Map). The rock is displaced to the south by a distance of about a kilometre.

In the field, the rock is massive, jointed, whitish to pale-greenish or pale-pinkish and strongly porphyritic. The phenocrysts are of euhedral clear quartz crystals with typical pyramidal terminations. The quartz crystals vary in size from about 1mm to 10mm, rarely exceeding 14mm. but on the average about 2mm in cross-section. The matrix is often medium to coarse grained and composed dominantly of quartz. In some of the outcrops, especially at the peak of the hill,the rock is scoriaceous in nature giving it a porous frothy appearance.

In thin section, the texture is porphyritic and the phenocrysts are embedded in a coarse grained matrix. The rock is composed of about 70% quartz, 25% sericite, 2% iron oxides and about 3% feldspars. The phenocrysts are mainly of hexagonal shaped quartz crystals (Plate 4). These crystals are occasionally fractured or cracked and the opened up spaces infilled with sericitic material. Feldspar occasionaly occurs as highly altered phenocrysts. Most parts of the feldspars are altered into sericite but the rectangular crystal outline and weak carlsbad twinning are occasionally preserved. The matrix is dominated by coarse granular aggregates of Quartz. The quartz grains of the matrix appear well rounded and of nearly uniform size. Surrounding the coarse grained quartz crystals are fine tabular aggregates of sericite. The abundance of sericite in the matrix possibly explains lack of feldspars in the matrix as they could have been completely altered into sericite. The iron oxides occur both as dark and reddish opaque minerals. The reddish colour which persists both in PPL



(XP, X20)

PLATE 4

Photomicrograph of quartz porphyry. Quartz phenocrysts (1) are embedded in a medium grained matrix.

and XP indicates the presence of haematite while the dark and opaque mineral in PPL and XP is possibly magnetite. The oxides occur as disseminated grains in the matrix.

The quartz porphyry is suggested to be of volcanic origin mainly because of the following reasons:

(a) No sharp contact exists between the quartz porphyry and the other volcanic rocks.

(b) The quartz porphyry grades laterally into the other extrusive rocks, notably the fine grained rhyolites away from their main occurrences.

(c) Vesicularity of the rock on top of Kisuri hill which though is of minor extent, suggests a sub-aerial type of volcanism.

(d) The abundance of columnar jointed outcrops on top of the Kisuri hill as most occurrences of this jointing pattern have only been observed in volcanic rocks.

3.2.1.6 Pyroclastic Rocks

The pyroclastic rocks are of relatively minor occurence in the Wire hills area. The rocks mainly occur as intercalations within the rhyolitic rocks, but results from the drillcores reveal that they often overlie the rhyolitic rocks. The rocks comprising the pyroclastic units include tuffs, crystal tuffs, lapilli tuffs and agglomerates.

(a) Tuffs, Crystal Tuffs and Lapilli Tuffs

These rocks are intimately associated with each other and with the rhyolitic rocks in which they occur both as intercalations and as an overlying unit. In outcrops, the tuffs are sometimes difficult to distinguish from the rhyolitic rocks especially when both rocks are weathered.

(i) Tuffs

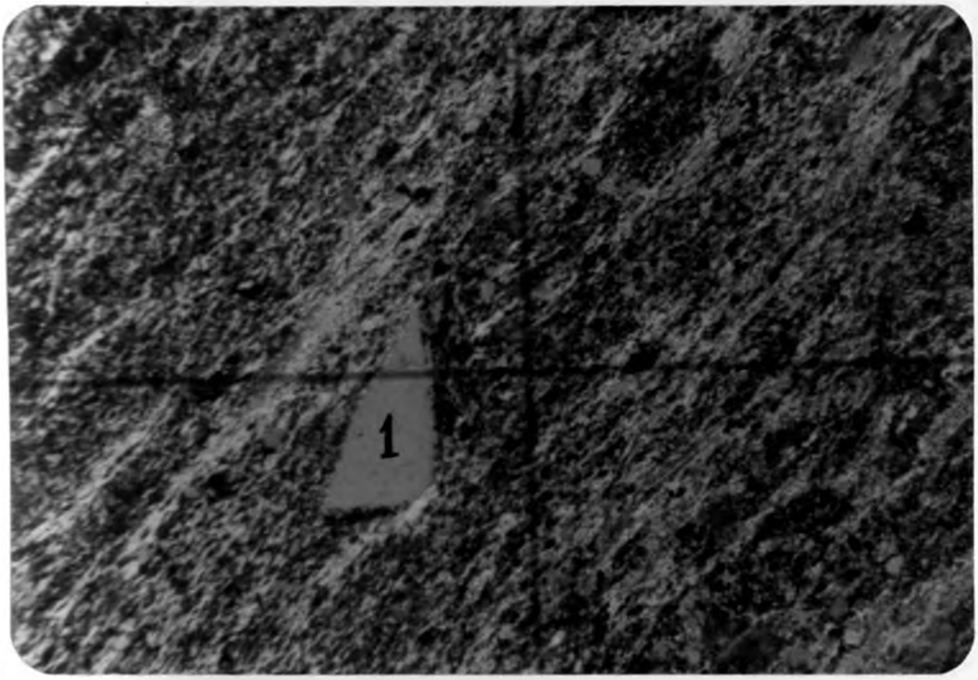
The tuffs occur in the northern and southern foot of the Wire hills. In the southern outcrop, the band is about 100-200m. thick and is sandwitched between the rhyolites. The rock is whitish pink, fine grained and weakly porphyritic with the development of a greasy texture. The northern outcrop is highly sheared to a schistose rock, but in places, to slates where individual folia can be cleaved off the rock with ease. This intense shearing has been made possible by the proximity to a fault zone which transects the Wire hills in a NNE trend. However, the overlying fine grained rhyolite is relatively underformed. The northern tuff outcrop is highly stained reddish by iron oxides which were possibly derived from the overlying banded iron formation.

In thin section, the tuffs are composed mainly of fine grained quartz crystals and also recrystallized quartz masses developed along the shear planes. The quartz comprises about 70% of the rock, the rest being, 20% iron oxides and 10% sericite. The dominant iron oxide is haematite which shows a reddish colour both in PPL and in XP. Sericite occurs in minor tabular flakes which are colourless in PPL but strongly birefringent in XP. Both sericite and the haematite grains show the effects of shear strain.

(ii) Crystal Tuffs

The occurrence of crystal tuffs were mainly noted in drillcores recovered from the Wire hills area. The rocks are frequently strongly sheared and altered. The effects of supergene alterations resulted in the formation of a whitish soft rock in which clay minerals are dominant. The hydrothermal hypogene alterations on the other hand resulted in the formation of a highly chloritised rock which tends to a chlorite schist.

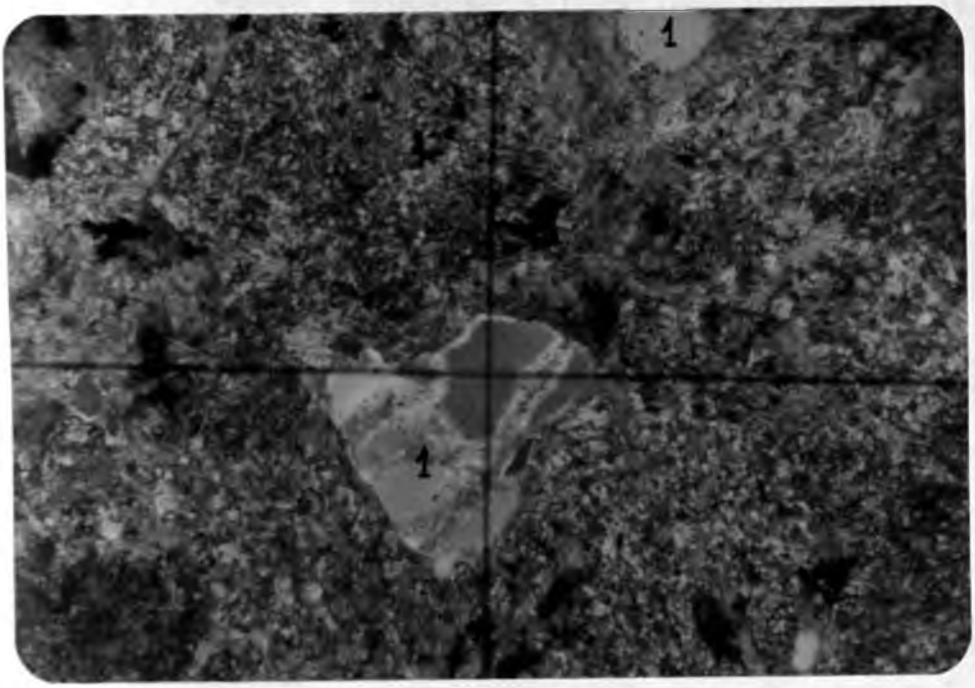
In thin section, the crystal tuffs are porphyritic and show the effects of shear strain. The mineral composition is dominated by quartz which comprises about 50% of the rock while sericite and/or chlorite comprise about 45%, the rest being iron oxides and other accessory minerals. The quartz occurs as euhedral crystals and as angular fragments disseminated in the rock (Plate 5). The quartz phenocrysts and fragments often show corrosion effects where the crystal in extreme cases, is reduced to shapeless wrecks (Plate 6). The matrix is generally fine



(XP, X20)

PLATE 5

Photomicrophgraph of crystal tuff showing quartz fragments and crystals (1) embedded in an altered and sheared matrix.



(XP, 20)

PLATE 6

Photomicrograph of crystal tuff showing the corrosion effects on the quartz crystals (1). The matrix has been altered to a chlorite and sericite rich rock.

grained but dominated by minute tabular crystals of sericite which are oriented parallel to each other (Plate 5). This indicates that the sericite crystals developed along the planes of weakness generated by the shear forces. Where hypogene alterations dominate, the amount of sericite is reduced with the introduction of chlorite and epidote.

(iii) Lapilli Tuffs

The lapilli tuffs were noted in drillcores and occasionally as small outcrops overlying rhyolitic rocks of the Wire hills.

The Lapilli tuff outcrops were often noted to grade laterally into agglomerates with which they are almost 6similar except for the size of the fragments. In the drillcores, the lapilli tuffs consists of lapilli-sized fragments which are commonly in the range of between 2mm and 5mm diameter (Plate 7). The matrix is usually fine grained and commonly altered to mica minerals which may be sericite or chlorite. The lapilli fragments are composed of rhyolitic and pumiceous rocks which are often sheared into conformable trends with the foliations. The shear effects have modified the shape of the fragments such that they bulge in the centre but are frayed at the ends. This could also be due to flight i.e. shape modified during the flight of the fragments (semi-molten).

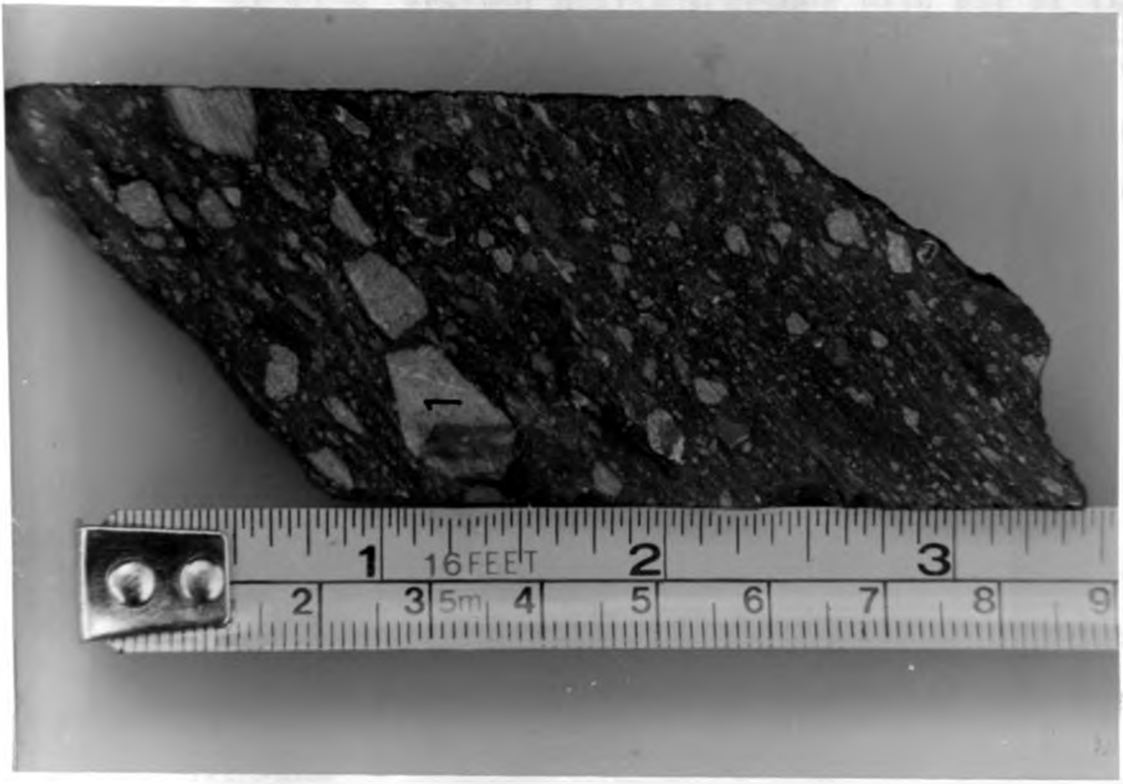


PLATE 7

Photomicrograph of lapilli tuff. The laplli fragments (1) are pumice while the cement (2) is fine grained consolidated ash.

In thin section, the rocks occasionally have crystals of quartz which are often corroded, but angular quartz fragments are also common. The cementing material is composed of fine grained quartz together with any of the following minerals; calcite, chlorite, sericite and iron oxides depending on the type and extent of alterations of the rock. The chlorite and the sericite occur in tabular and fibrous aggregates while the iron oxides occur in rounded grains disseminated in the specimen.

(b) Agglomerates

The agglomerates are of minor occurrence within the Wire hills area. Outcrops occur as patches on the Wire hills, along Owade river, in the south area of God Nyango hill and also along a seasonal river bed west of Sino kagola School (Map 1).

In the field, the agglomerates consist of rock fragments measuring upto 50x40cm. On the Wire hill, the outcrops are massive and the fragments do not show any alignment or shear effects (Plate 8). The fragments are composed of fine grained rhyolites which is also the composition of the cementing material. In the outcrop south of God Nyango hill, the fragments show flow/shear effects where the fragments point in a particular direction. The outcrop along the river valley west of Sino Kagola is about 30m. wide and more than 200m in length. The

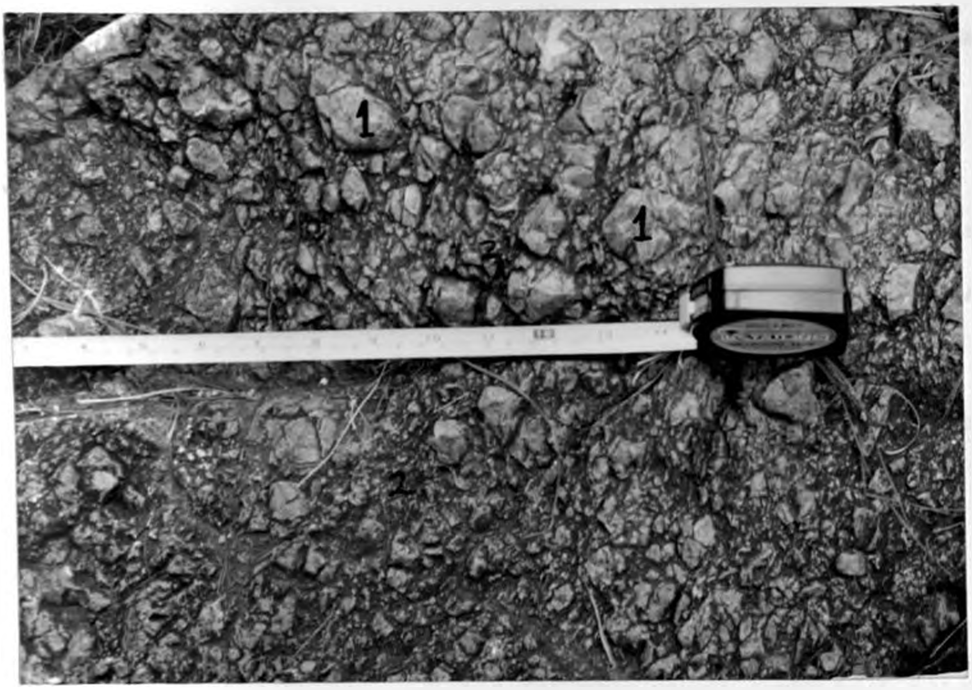


PLATE 8

Photomicrograph of an agglomerate outcrop. Both the fragments (1) and the cement are of rhyolitic composition.

agglomerate outcrop is strongly sheared, striking E-W and dipping 70° to the north. The fragments are sub-rounded and flattened, the flat surface being parallel to the strike. In this occurrence, the cementing material is relatively highly sheared and altered when compared to the fragments.

The presence of agglomerate indicates the existence of volcanic centres in the vicinity. From the structure of agglomerates on Wire hills as described above, it can be interprated that the volcanic vent is possibly close to the hill top.

3.2.1.7 Nyanzian Sedimentary Rocks.

(a) Banded Irostone

The banded ironstone is of common occurrence in the Wire hills area particularly where rhyolitic rocks outcrop. The ironstone overlies the rhyolites unconformably and in places it is overlain by the rhyolites or tuffs. The rocks are well distributed in the study area with typical occurrences on Pakla, God Nyango, Mithui and Wire hills (Map). The rock outcrops usually form areas of high relief due to their resistance to weathering and erosion caused by the abundance of chert in them.

In the field, the banded ironstone is highly fractured and occurs largely as floats such that the original banding patterns are rarely preserved. The larger boulders are also contorted and broken by smaller fractures and micro-faults. The ease with which the ironstone is fractured is attributed to the brittle nature of the rock due to the chert layers.

In hand specimen, banded ironstone typically occur as chert bands alternating with brownish-red iron rich bands composed mainly of haematite. The size of the bands are variable and a fairly well developed banding on Pakla hill shows cherty bands having a maximum thickness of 3cm alternating with bands of iron oxides of thickness in the range of 0.5cm to 1.5cm (Plate 9). The chert rich bands frequently contain microbands of reddish iron oxides. Similarly iron rich bands do occasionaly contain microbands of chert layers in the order of 1-2mm in thickness. In thin section, the cherty layers consist of microcrystalline quartz which occurs in rounded or spherical shapes forming a continous mass throughout the specimen. Under crossed nicols it shows a finely speckled and twinkling apearance. Inclusions of coarse crystals of quartz do occur and appear to be a product of recrystallization. Microbanding is evidenced in thin section where thin bands of iron rich layers occur within the microcrystalline mass.

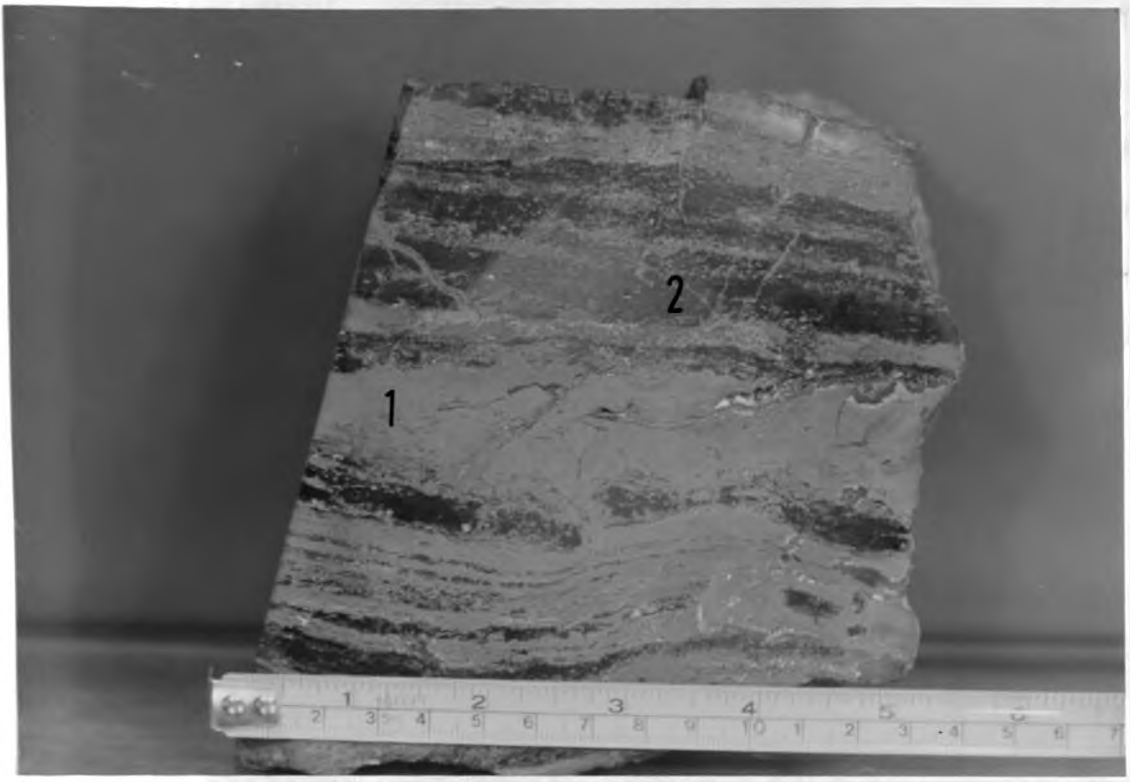


PLATE 9

The photograph is of banded ironstone collected from Pakla hill. The iron-rich bands (1) alternate with cherty bands (2).

(b) White Chert

The white chert occurs in a single outcrop on the second highest peak of the Wire hills. The rock is white, massive, frequently jointed and fractured. The outcrop has a diametre of about 30m and attains a maximum thickness of about a metre. The chert is very fine grained, non-banded and brittle. It breaks in a splintery manner producing sharp edges which are nearly transparent. The chert is not mineralized with pyrite as opposed to the other cherts which are associated with ironstone outcrops. The chert overlies the pinkish, fine grained rhyolites of the Wire hills.

In thin section, the chert consists of microcrystalline aggregates of quartz observable in crossed polars. Inclusions of coarsely recrystallized quartz commonly occurs within this rock unit.

The presence of the chert at the top of the Wire hill is indicative of the fact that this area was once a marine sedimentary basin. The conditions must have been quiet which made it possible for silica to be precipitated as colloids. The area was thereafter subjected to uplift which generated weathering and erosional processes. Chert being very resistant to these processes remained as a capping.

3.2.2 The Kavirondian Group

The Kavirondian sediments are rare within the study area. The rocks are only represented by an outcrop of sandstone. The sandstone forms a small isolated exposure on the mid-slope of Mawira ridge behind Oyugis town. The outcrop is about 10m thick and is underlain by weathered dacites and overlain by the porphyritic basalt of Bukoban age. The rock is medium to fine grained and shows good bedding structures. The beds dip gently to the south with magnitudes of between 10° and 25° . This contrasts with the general direction of the Nyanzian rocks which dip at high angles to the north-east . The difference in the dip direction and magnitude indicates that a strong angular uncomformity exists between the Kavirondian sedimentary unit and the underlying Nyanzian rocks.

In thin section, the rock consists of more than 50% quartz, 2% feldspars, 30% clay minerals and about 18% iron oxides. The quartz occurs as round grains embedded in a fine grained groundmass. Quartz crystals are rare but when present they occur in a tabular form with a size comparable to that of the rounded quartz grains. Iron oxides and clay minerals form the major component of the groundmass. the clay minerals are dominated by sericite, kaolinite and minor chlorite. The iron oxides are dominantly reddish haematite but magnetite also occurs as disseminated rounded grains.

3.2.3 The Bukoban Group

The Bukoban rocks are similarly of minor occurrence in the study area but typically occur capping the Mawira ridge behind Oyugis town. The Bukoban rocks are represented by an outcrop of porphyritic basalt. The basalt occurs overlying the Nyanzian dacites, and in part the Kavirondian sandstones and the Oyugis granite.

In hand specimen, the rock is bluish-green, fine to medium grained and weakly porphyritic. The phenocrysts are mainly feldspars which occur as tabular crystals reaching about 7mm long. The other phenocrysts are of dark green augite. Some outcrops are amygdaloidal with the structures assuming spheroidal shapes which vary in size from 1mm to 5mm. The quartz that occupies the amygdules occurs in two forms,namely: Coarse crystals of quartz typical of growth in an open space and microcrystalline quartz typical of deposition of silica from a colloidal solution. Pyrite and quartz veins are common in the Bukoban basalt.

In thin section, the basalt is composed of the following minerals; oligoclase, augite, sericite epidote and chlorite. The plagioclase occurs as phenocrysts and as felted small crystal laths in the matrix. The feldspar frequently shows alterations to sericite while the mafic minerals alter to chlorite and epidote. Augite occurs both as phenocrysts and as disseminated crystals within the matrix. From the succession determined for Nyanzian and Kavirondian Groups by Huddleston, (1951), the basalt overlies the Kavirondian and Nyanzian rocks with an uncomformity. Huddleston, (1951), also divided the rocks of the Bukoban Group into Lower, Middle and Upper Groups within the Kisii series. From the present study, it can be inferred that the porphyritic basalt belongs to the Lower Group of the Kisii series. The occurrence represents a remnant of an extensive basalt outcrop now eroded forming an outlier.

3.2.4. Quaternary and Recent Deposits

These deposits include all the superficial materials found in the study area which include mainly soils and laterites.

(a) Laterites

The laterites are widespread and occur as a reddish brown, coarse grained and porous mappable rock unit. The rock caps most of the other rock types with the exception of giant quartz veins and cherts. Large deposits of a thickness exceeding 10m are frequently present on the rhyolites from which they are mined as a raw material for road and building construction. During the present study it was noted that laterites developed on andesites, dacites and granites are of smaller magnitude and of thickness of less than a metre.

(b) Soils

Under this categorisation are include gravels, alluvium, swamp deposits and residual soils.

Alluvium and gravels are present along river beds and are well developed along the beds of major rivers in the study area. Among the residual soils, the most common is the reddish-brown volcanic type which is commonly found overlying the rhyolites as a product of weathering. Andesites and dacites commonly weather to black cotton soils but in the area around Oyugis, the dacites weather to reddish soil. Therefore, the black colouration observed is mainly due to the presence of organic matter since these rocks mainly occupy the low swampy grounds.

Great thickness of the black cotton soil however occur in swamps irrespective of the type of the underlying rock. The granitic rocks frequently yield coarse grained sandy light yellow brown soils. The granitic soils due to the high content of quartz are used as a raw material for road construction and building purposes.

In general, the rocks are commonly deeply weathered to depths exceeding 10m. In some places except on hill tops where the soil cover is thin or lacking.

3.2.5 Intrusives

The major intrusive rocks are granites and quartz diorites while the minor intrusive units include dolerite dykes and quartz veins. The major intrusives outcrop in the western and south western sections of the study area while the minor intrusives occur through-out the area. The various forms of the intrusive rocks are discussed below.

3.2.5.1 The Oyugis Granite

This is the major intrusive body within the study area. It outcrops in the area south-west of Kosele and west of Mawira ridge.
In the field, the granite outcrops are easily identified by their large fragmentary boulders that stand out in the generally low altitude.

In hand specimen, the rock is coarse grained, leucocratic with white and pink feldspars in a leucocratic matrix speckled with greenish patches of mafic minerals. The rock occasionally has dark green xenoliths which are mainly composed of hornblende. The xenoliths measure upto 5cm in length. The granite is frequently mineralized with pyrite which occurs as disseminited euhedral crystals and as minor veins.

In thin section, the granite shows the presence of both K-feldspars and Na-feldspars in variable proportions. The texture is porphyritic in which these feldspars form phenocrysts. The main Na-feldspar identified is oligoclase which is also the dominant feldspar and accounts for about 40% of the rock. The oligoclase shows the characteristic lamellae twinning patterns but appear cloudy due to secondary alterations. The K-feldspar present is orthoclase which comprises about 30% of the rock. The orthoclase crystals rarely show the characteristic Carlsbad twinning patterns which are masked to varying degrees by the alterations to sericite and kaolinite.

The samples collected from near the contact zone between the granite and the intermediate rocks, namely, dacites and andesites, have higher amounts of plagioclases compared to those collected further inside the granitic field. This is due to Na-K chemical transfer between the two lithologies during the intrusion of the granite.

Quartz which is the second dominant mineral after the feldspars constitute about 20% of the rock. It mainly occurs in anhedral masses that mainly infill the interstices between the other coarse crystals. Hornblende is present in a minor quantity making about 6% of the rock. The mineral is often altered to chlorite and magnetite which together make upto 4% of the rock.

The age of the Oyugis granite is suggested to be post-Nyanzian but pre-Bukoban based on the observation of the present study. During the field mapping it was observed that the Bukoban basalt overlies the granite at a quarry behind Oyugis (Plate 10). The basalt was found to have inclusions of granite, rhyolites and dacites together with some quartzitic pebbles. These lithic fragments are sub-rounded to angular in shape indicating minimal abrasion from the time of release from the parent rock. These xenoliths commonly occur within 4m from the contact between the basalt and the granite. However, no age relationship was established between the Oyugis granite and the Kavirondian sandstone.

3.2.5.2 Quartz Diorite

The rock occurs in the area located about 2km south of Kosele market and it forms the outer margin of the Oyugis granite in contact with the andesites and the dacites. The prefix quartz is added to the name diorite to signify the high amount of quartz than is otherwise present in a typical diorite.

This intrusive body is characterized by large bouldery outcrops which are resistant to weathering and erosion. The quartz diorite is greenish in colour, medium to coarse grained in texture but occasionally porphyritic in which case the white phenocrysts give the rock a spotted appearance. Hornblende is frequently present as small

PLATE 10

A photograph showing the contact between the Bukoban basalt (1) and the Oyugis granite (2). The contact is shown by the arrow in the photograph.

tabular dark green crystals and pyrite is a common accessory primary sulphide mineral.

In thin section, the rock is composed of about 10% quartz, 70% andesine, 8% hornblende, 2% enstatite, 5% augite and the secondary minerals, chlorite, sericite, magnetite and calcite account for about 5% of the rock. Andesine occurs as phenocrysts. These phenocrysts frequently show mild to intense degrees of alterations in which sericite and kaolinite are formed thus masking to a variable extent, the twinning pattern. The hornblende, enstatite and augite similary occur as phenocrysts which are commonly altered to chlorite and magnetite. The magnetite occurs in octagonal crystals which are associated with the chloritized zones. Quartz occurs in euhedral masses which infill the interstices between the phenocrysts and occasionally in pools which represent secondary recrystallization.

3.2.5.3 Dolerite Dykes

The dykes occur in isolated outcrops in the Wire hills area (Map 1). Typical occurrences are found in the areas around Kosele market where a dyke intrudes the andesites, 2km east of Oyugis town where another dyke intrudes the dacites and on Mawira ridge where also another dyke intrudes the Bukoban basalt.

In the field, the dykes occur as linear features having a positive relief due to their resistance to weathering and erosion. Where the outcrops are not massive, the trend of the dykes are characterised by large bouldery fragmentary units arranged in a manner describing the trend of the dyke. The sizes of the dykes vary from a width of between 1m and 20m but the length occasionally extends to about 100m.

In hand specimen, the dolerite dykes are medium to coarse grained and compact. They are greenish in colour but often speckled dark by the mafic minerals which are largely hornblende. Pyrite occurs both as a primary and a secondary minerals forming disseminations and veins respectively.

In thin section, the texture is porphyritic and the phenocrysts are emplaced in a medium grained matrix. The mineral composition of the dyke include; 30% hornblende, 2% augite, 60% plagioclase feldspars, 5% quartz, and the remaining 3% as secondary minerals; chlorite, sericite and magnetite. In some dykes, augite forms an important constituent and may account for over 10% of the rock at the expense of horblende. Hornblende is the main mineral that constitutes the phenocrysts but euhedral prismatic feldspar crystals also occur. The composition of the matrix is dominated by crystallites of feldspars which also occur in small tabular crystals. Small disseminated grains of augite are often present.

The age of the dolerite dykes is suggested to be post-Bukoban. This conclusion is reached from the observation that the dykes intrude both the Nyanzian and the Bukoban rocks. However, some dykes may be pre-Bukoban especially those observed within the Nyanzian rocks. The intrusion was structure controlled in that the trend of the dykes coincide with the joint pattern in the Wire hills area.

3.2.5.4 Quartz Veins

The quartz veins are sub-divided into two: Giant Quartz veins and minor quartz veins. The giant types have widths of upto 100m and lengths exceeding a kilometre while the minor veins measure upto 0.5m by 5m in size. These quartz veins are described below.

(a) The Giant Quartz Veins

Two outcrops occur in the study area, one just behing the Oyugis town and nearly parallel to the Oyugis-Kisii road while the other lies in the area about 2km north of Kwoyo School (Map 1). The quartz vein at the Oyugis town trends N40° E while the other trends N70° E.

he veins are composed exclusively of coarsely crystalline white quartz. The structure of the giant veins is such that they are pervaded by minor quartz veins measuring about 5cm or less in width (Plate 11).

PLATE 11

Photograph showing the the structure of the giant quartz vein. Later quartz veins and veinlets intrude the giant quartz vein as can be observed in the central zone of the photomicrograph. The pencil measures about 18 cm. in length.

The orientation of the minor quartz veins within the giant quartz vein is such that they lie parallel to the trend of the giant quartz vein (Figure 4). The whole rock frequently contain acicular quartz crystals developed in open spaces. In thin section, the rocks are composed of euhedral crystals of quartz which occurs in interlocking aggregates.

From the observation of the structure of the giant quartz veins, the mode of formation is suggested to have involved the injection of silicic fluids until the veins attained their present size.

(b) Minor Quartz Veins

Minor quartz veins occur in most parts of the study area but are more prominent in the strongly sheared zones. The areas of occurrences include the northern section of the study area, around Mithui hill and to the east around Nyandiwa School.

The quartz viens are typically white with coarse crystals of quartz prominently developed but in a few occurrences the veins are composed of non-crystalline quartz. The veins are composed of non-crystalline quartz. The veins occur in two sets: NE-SW and NW-SE trends (Figure 5). The latter set of quartz veins are more prominent and are associated with the strongly sheared zones. The NE-SW

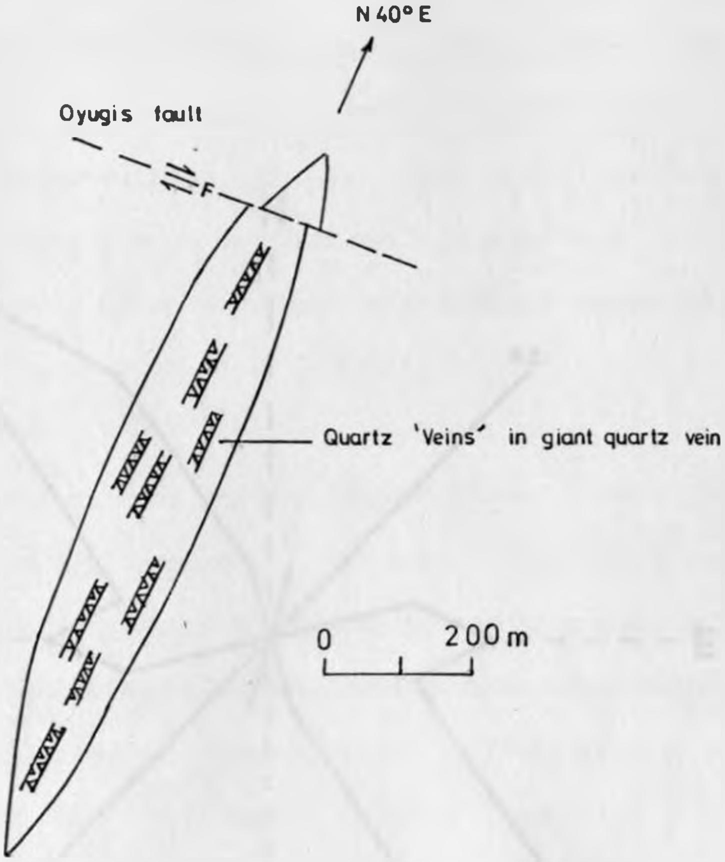


Fig 4 DIAGRAM SHOWING THE STRUCTURE OF THE OYUGIS GIANT QUARTZ VEIN.

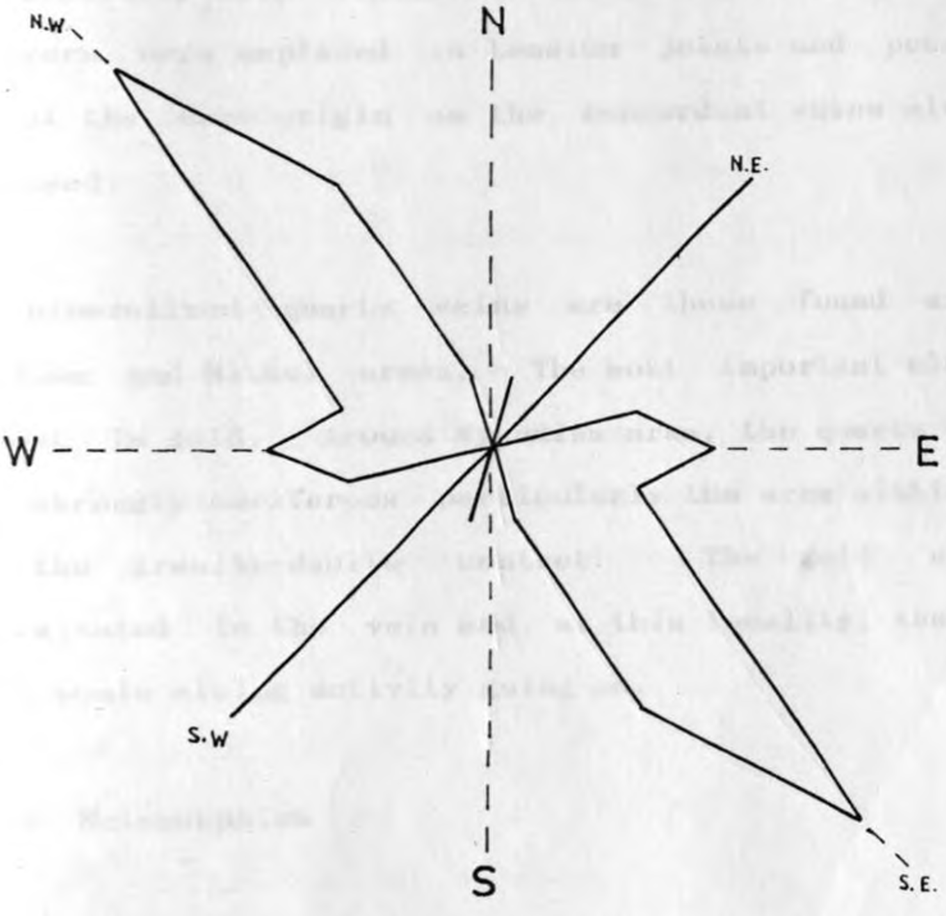


Fig. 5 Rose Diagram for Trend of Veins (whole area)

Scale: 38 readings

trending quartz veins are inferred to have originated from the process of remobilization of silica and alterations of the feldspars as a result of metamorphism that accompanied the deformation. x The other set of quartz veins that trend in a NE-SW direction are minor and generally have widths of less than a centimere. The stringers were emplaced in tension joints and possibly are of the same origin as the concordant veins already discussed.

The mineralized quartz veins are those found around Nyandiwa and Mithui areas. The most important element present is gold. Around Nyandiwa area, the quartz veins are strongly auriferous particularly the area within 2km of the granite-dacite contact. The gold occurs disseminated in the vein and at this locality, there is small scale mining activity going on.

3.2.6 Metamorphism

The type of metamorphic change noted in the area is due to regional metomorphism which has affected most rocks. The grade of metamorphism is of the greenschist facies. This low grade metamorphism affected most rocks of the greenstone belt in the western Kenya Archean belt (Shackleton, 1946; Huddleston, 1951 and Saggerson, 1952). Saggerson, (1952), postulates that the metamorphism is due to the intense folding and faulting to which the rocks were subjected prior to the Bukoban times. This could also be true in the study area as a lot of shearing and faulting was noted during the field mapping. The degree is generally low, becoming phyllitic in the rhyolites and the associated tuffs as well as in the other volcanic rocks. In some areas, notably along river Onger (Map) in the north within the andesite field and also to the north east within the rhyolites, a high degree of shearing is evident due to the proximity of fault zones. The andesites and the rhyolites are altered to schists. The low grade regional metamorphism is characterised by development of the following minerals; chlorite, epidote, sericite, actinolite and pervasive silicification. Epidote is common in the intermediate rocks forming minor veins and bright green patches. The effect of chlorite formation modifies the colour of the rocks to pale-green.

3.2.7 Metasomatism

3.2.7.1 Processes of Metasomatism

The effect of metasomatism are mainly observed in drill holes sunk in the Wire hills area. However, a 20m band of epidotized rock was observed close to the contact between the granite and the dacites. The alterations noted within the drill cores are associated with the sulphide mineralization of the Wire hills.

The alterations are of hydrothermal origin and are distinctly developed in the mineralized zones of the rhyolitic pile. The alterations typically involve the following processes: Chloritization, sericitization, silicification, carbonatization, decarbonatization and supergene alterations. Most of the alterations accompanied the mineralization process. The degree of the alterations vary such that in extreme cases the original rock is difficult to identify precisely. Quartz and feldspars, the most common minerals in the rhyolitic rocks, frequently show the effect of hydrothermal alterations. Crystals of feldspars show alteration to sericite while quartz phenocryst shows variable degrees of corrosion corresponding to the extent of alteration of the rock.

(a) Sericitization

Sericite is a common alteration product associated with mineralization though not as prominently developed as chlorite. The mineral occurs in small tabular flakes which in PPL are colourless with a low relief in balsam, but high birefringence in XP. Where sericite is the dominant alteration product, the rock attains a yellowish appearance as was noted in rhyolites.

Sericitization is considered to be the initial process that occurs before mineralization (Roberts, 1978). The process occurs in an acidic environment and involves the introduction of the hydroxyl (OH-) group into the aluminosilicates, mainly alkali feldspars.

The reaction leading to the formation of sericite from a K-feldspar is given as (Roberts and Reardon, 1978):

$$KAlSi_3O_8 + OH^- \text{------->} KAl_3Si_3O_{10}(OH)_2 + SiO_2$$

The silica released is expressed in silicification.

(b) Chloritization

Chlorite is strongly developed in the footwall rocks in the mineralized zones and more so in the tuffs. In the highly altered tuffs, the chlorite develops as green fibrous aggregates which are oriented parallel to the shear planes. The rhyolites being more silicic and compact, are resistant to the alterations and hence show mild chloritization. However, a brecciated rhyolite unit described earlier (section 3.2.1.3 (c)) shows intense chloritization of the matrix material but only mild chloritization of the breccias. The edges of the breccias are however, corroded and rounded due to the invading hydrothermal solutions. In extreme cases, the rock attains a deep greenish black colour and a fine to medium grained texture. The rock so formed can be referred to as massive chlorite or chlorite schist when the rock is sheared into a schistose unit. These terms are invoked for cases where the chlorite content of the rock exceeds 75%.

An X-Ray Diffractometric (XRD) analysis of chlorite samples indicates the presence of clinochlore as the dominant chlorite species (Table 4). The adopted formula of the mineral derived from the analysis is as follows:

$(Mg, Fe, Al)_6\ (Si,Al)_4\ O_{10}\ (OH)_8$. (JCPD data book, 1984)

In thin section, the mineral occurs in deep green flaky weakly pleochroic masses in PPL but in XP it shows a weak birefringence often with an oblique extinction.

The chloritization process has been suggested to supercede sericitization (Roberts, and Reardon, 1978). The reactions involve the addition of magnesium and iron to the aluminosilicates with the production of chlorite. The main target minerals in the rhyolitic rocks are the feldspars and sericite.

Table 4: XRD-DATA FOR CHLORITE

REFLECTION	D-SPACING M	INTENSITY %
001	14.2550	13
002	7.1382	100
003	4.7201	28
004	3.5479	91
005	3.1976	15
005	2.8313	15

(c) Carbonatization

The process of carbonatization resulted in the formation of calcite as the main carbonate mineral. Calcite is a common mineral in the chloritised zones and here it occurs both as disseminated grains and as minor veins. Some of these calcite veins are associated with sulphide minerals, notably arsenopyrite, chalcopyrite and pyrite. The confirmation of the identity of the carbonate mineral was done by the use of XRD-analysis (Table 5).

The strong relationship between calcite and the formation of the sulphide minerals shows that they are of the same origin. The carbonate was therefore also contained in the mineralizing hydrothermal solutions.

Table 5: XRD DATA FOR CALCITE

Reflection	D-Spacing m	Intensity %
001	3.8835	8
002	3.0482	100
003	2.8578	8
004	2.5082	13
005	2.2925	22
006	1.1035	21
007	1.9180	93
008	1.8806	29

(d) Decarbonalization

Decarbonalization process is expressed by the occurrence of a carbonaceous material within fractures in the rhyolite. The material is soft, dark and has a typical graphitic streak. An X-ray diffractometer pattern indicates that the unit is not graphitic but consists of a solid, non crystalline carbon. The material was intersected by the drill holes 86/7 and 86/8 at a depth of 160m and 150m respectively (Appendix).

Correlation of these two drillholes indicate that the carbonaceous material occupies a fracture zone which steeply dips to the east. Within this fracture, the material also coats rhyolitic fragments and is also associated with minor chlorite grains. The presence of chlorite within this material was revealed by the XRD analysis.

This carbonaceous material is unlikely to be of sedimentary or organic origin when it's mode of occurrence within the rhyolite is considered. Organic carbon usually occurs in sedimentary rocks as stratified units and not as veins as observed in this case. A sedimentary origin is also discarded due to to the absence of sedimentary rocks associated with it.

However, several occurrences of bituminous carbon veins have been noted in igneous rocks and in or near veins containing metallic sulphides (Krauskopf, 1967). Krauskopf (1967), postulates an igneous origin for such carbon veins. He suggests that the carbon is juvenile in origin, having originated from the earth's interior.

Hutchinson (1982), however, proposed a model, which is also favoured by the present study. The model involves the decarbonatization of carbon dioxide by ferrous silicates to produce carbon. The reaction is expressed by the following equation:

CO_2 + Fe-Silicates = Magnetite + Carbon + SiO_2

The Carbon dioxide is contained in the hydrothermal solution that was in contact with the rock. The process described above accompanies the conventional hydrothermal cycle which also results in the precipitation of the metallic sulphides which are associated with the carbon veins. It is suggested that the explacement of the carbonaceous vein was fracture controlled, the openings providing the channelways for the transport of the hydrothermal fluids which also contained the generated carbon.

(e) Silicification

The process involves the enrichment of rocks by silica which is deposited as quartz. Within the mineralized zones of the Wire hills, silica enrichment is pronounced in the footwall and hanging wall rocks. Such alteration patterns have been noted in other massive sulphide deposits of the world (Matsukuma and Horikoshi, 1970; Sangster, 1972; Franklin, 1975; Boyle 1976; Roberts and Reardon, 1978). In the Wire hills, silicification is expressed in the footwall rocks as quartz veins while in the hanging wall rocks it involved pervasive quartz enrichment.

The source of silica is thought to be contributed to a large extent by the processes of chloritization and sericitization (Roberts and Reardon, 1978; Riverin, 1980). Boyle (1976), however, suggested that it is a product of replacement reaction. The liberated silica was then transported upwards as a component of the hydrothermal solutions. Where cracks and fractures were present, the silica was precipitated to form the quartz veins. More intense silicification is observed in the tuffs, crystal tuffs and lapilli tuffs. This fact is attributed to the porous nature of these rocks which make it possible for circulation of the silica enriched hydrothermal solutions to occur. The rocks, in extreme cases appear as cherty units in which the occurrence of the pumiceous fragments is diagnostic as to their original nature.

3.2.7.2 The Geochemistry of Altered Rocks

Ten representive rock samples were taken from relatively unaltered and variably hydrothermally altered sections from the drillcores and analysed by standard chemical methods employing Atomic Absorption Spectrophotometer (AAS) (Table 6). By examination of the data in table 6, it is apparent that the hydrothermal alteration process is attributed, to varying degrees to the changes in amounts of MgO, SiO_2, CaO, and to a lesser extent TiO_2 and P_2O_5. The chemical gains and losses during the hydrothermal alteration are represented by the ternary diagrams discussed below.

For the system SiO_2 - CaO - MgO, (Figure 6) relatively fresh rhyolites plot nearer the apex of the triangle indicating low CaO and MgO values but with progressive increase in the degree of alteration, the values of CaO and MgO increase while that of SiO_2 decreases. The product of alteration becomes more Mg-rich and is expressed in the formation of chlorite. However, the increase in calcium outstrips the increase in magnesium . In the system SiO_2-Fe_2O_3-MgO the plots indicate a similar trend when the behaviour of SiO_2 is considered (Figure 7). The silica (SiO_2) is depleted while MgO and Fe_2O_3 are enriched with the progress in alteration. During the process, relatively more iron is inco-operated in the product than magnesium as indicated by the ternary

TABLE 6 AAS ANALYSIS OF WHOLE ROCK SAMPLES (% wt)OF

OXIDE\SPEC.NO.	1 125	2 3.18	3 10.6	4 1.28
SiO2	77.71	75.80	78.35	70.47
TiO2	-	0.25	-	0.42
Al2O3	12.29	10.40	12.29	13.23
Fe2O3	0.82	0.79	0.82	2.00
MnO	-	-	-	0.07
MgO	0.04	0.22	0.10	0.56
CaO	0.06	0.51	0.24	2.97
Na2O	0.70	1.94	4.21	1.13
K2O	8.67	1.69	1.81	2.89
P2O5	-	-	-	0.04
Total	100.29	91.60	97.82	93.78

FRESH AND ALTERED ROCKS

5	6	7	8	9	10
10.11	5.21	9.5	5.14	4.3	25.7
60.98	55.20	53.47	50.17	43.97	37.37
0.54	0.84	0.88	1.04	0.79	0.96
12.29	13.23	14.18	13.23	14.18	10.40
14.29	15.00	10.00	23.58	10.72	27.15
0.52	0.20	0.52	0.32	0.13	0.84
1.86	2.09	1.46	2.35	5.80	3.25
3.71	2.27	6.61	0.49	8.64	8.85
2.16	2.70	1.78	0.70	3.13	1.24
0.72	4.10	2.65	2.77	0.41	1.57
0.04	0.06	0.13	0.10	0.06	0.10
97.11	95.69	91.68	94.75	87.87	91.73

Table 6 - Explanation

Tern.Diag Ref.	Spec.Ref.	Lithology and sample point
1	125	Rhyolite outcrop from Wire hill
2	3.18	Rhyolite from ddh 86/3 at 240m
3	10.16	Rhyolite from ddh 86/10 at 130m
4	1.28	Altered rhyolitic tuff from ddh 86/1 at 165m.
5	10.11	Chloritized rhyolite from ddh 86/10 at 250m.
6	5.21	Chloritized rhyolite from ddh 86/5 at 190m.
7	9.5	Altered rhyolite from ddh 86/9 at 140m.
8	5.14	Chloritized rhyolitic tuff from ddh 86/5 at 110m.
9	4.3	Chloritized rhyolitic tuff from ddh 86/4 at 130m.
10	25.7	Chloritized rhyolitic tuff from ddh Rf/25 at 170m.

NB. Numbers used in the first column correspond to those in the ternary diagrams, (figures 6, 7, 8 & 9)

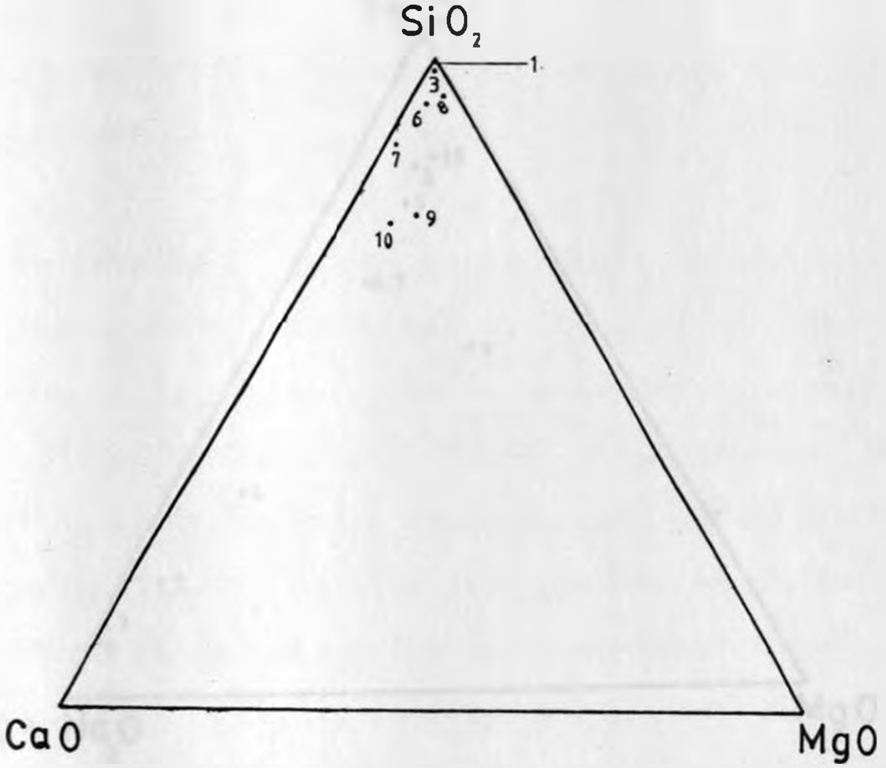


Fig.6 Ternary Diagram for SiO_2—CaO—MgO System.

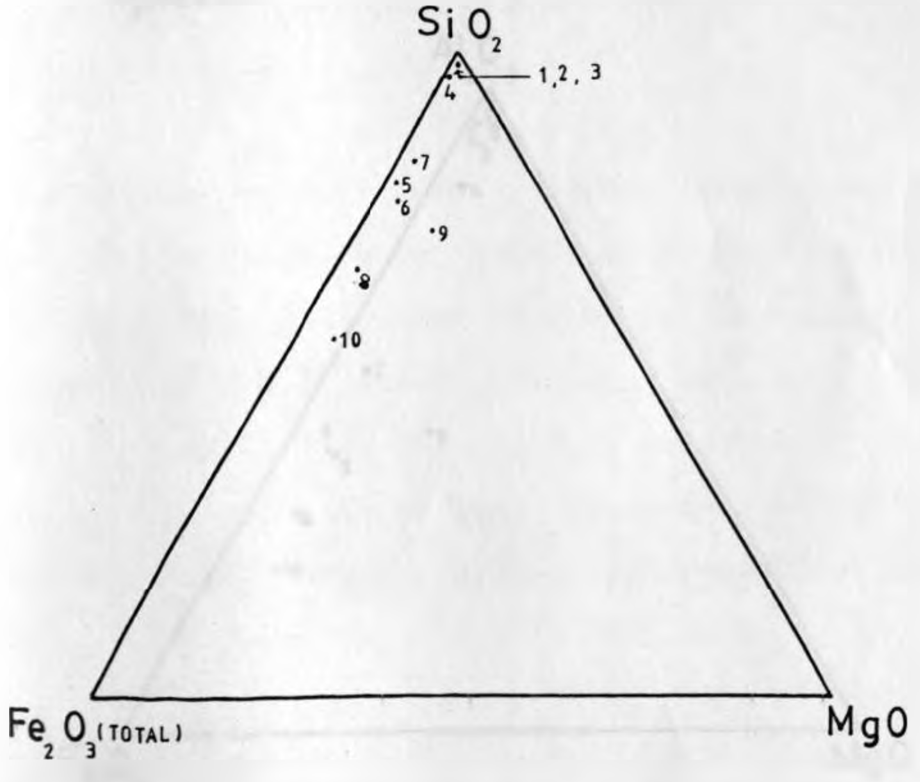


Fig. 7 Ternary Diagram for SiO_2—Fe_2O_3—MgO System.

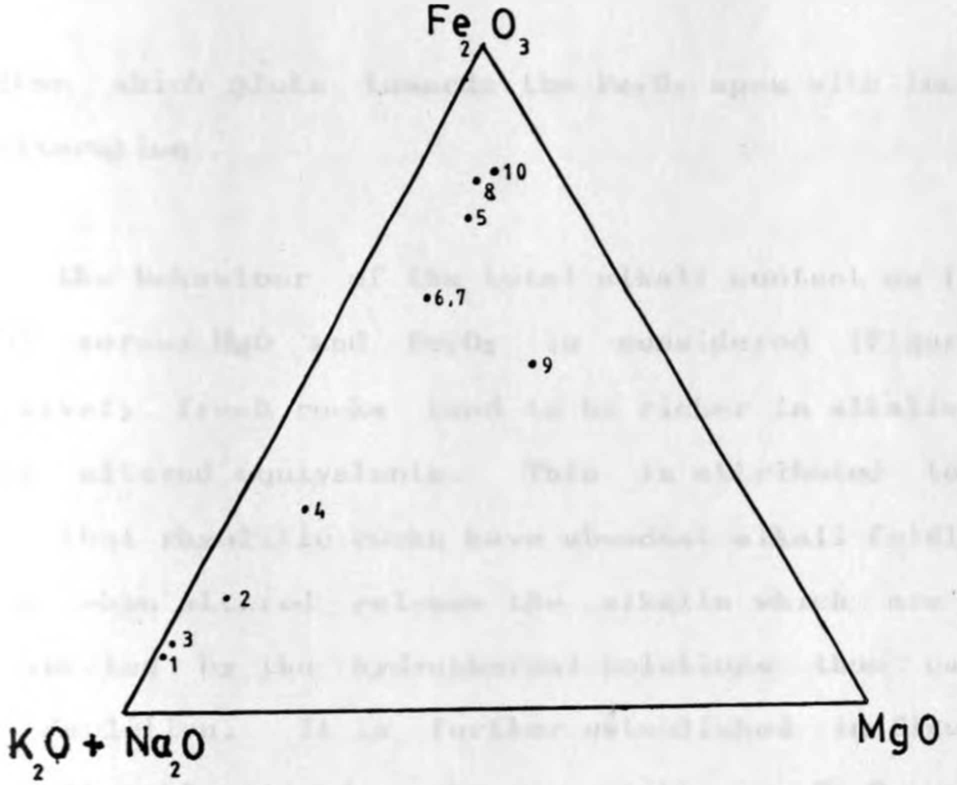


Fig. 8 Ternary Diagram for Fe_2O_3—(K_2O+Na_2O)—MgO System.

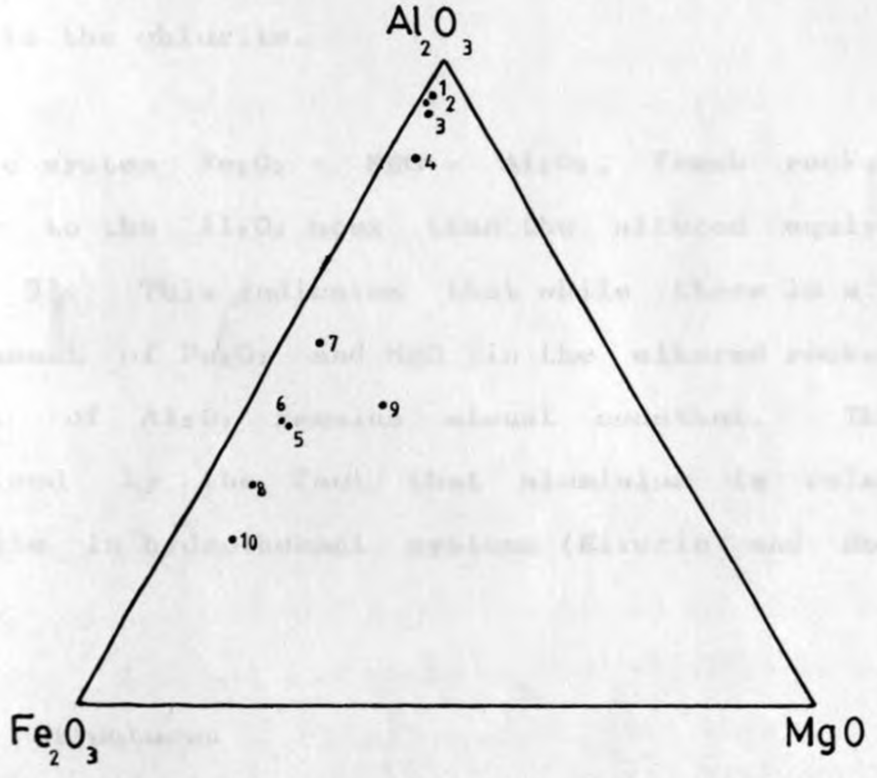


Fig 9 Ternary Diagram for Al_2O_3—Fe_2O_3—MgO System

diagram which plots towards the Fe_2O_3 apex with increase in alteration.

When the behaviour of the total alkali content as (K_2O + Na_2O) versus MgO and Fe_2O_3 is considered (Figure 8) relatively fresh rocks tend to be richer in alkalis than their altered equivalents. This is attributed to the fact that rhyolitic rocks have abundant alkali feldlspars which when altered release the alkalis which are then transported by the hydrothermal solutions thus causing the depletion. It is further established in figure 8 that the chloritised rocks are richer in Fe_2O_3 and MgO than those altered but not chloritised. This indicates that the main source of iron and magnesium in the altered rocks is the chlorite.

In the system Fe_2O_3 - MgO - Al_2O_3, fresh rocks plot closer to the Al_2O_3 apex than the altered equivalents (Fig. 9). This indicates that while there is a strong enrichment of Fe_2O_3 and MgO in the altered rocks, the amount of Al_2O_3 remains almost constant. This is explained by the fact that aluminium is relatively immobile in hydrothermal systems (Riverin and Hodgson, 1980).

3.2.8 Structures

The geological structures described in this chapter are divided into two, namely: Major and minor structures.

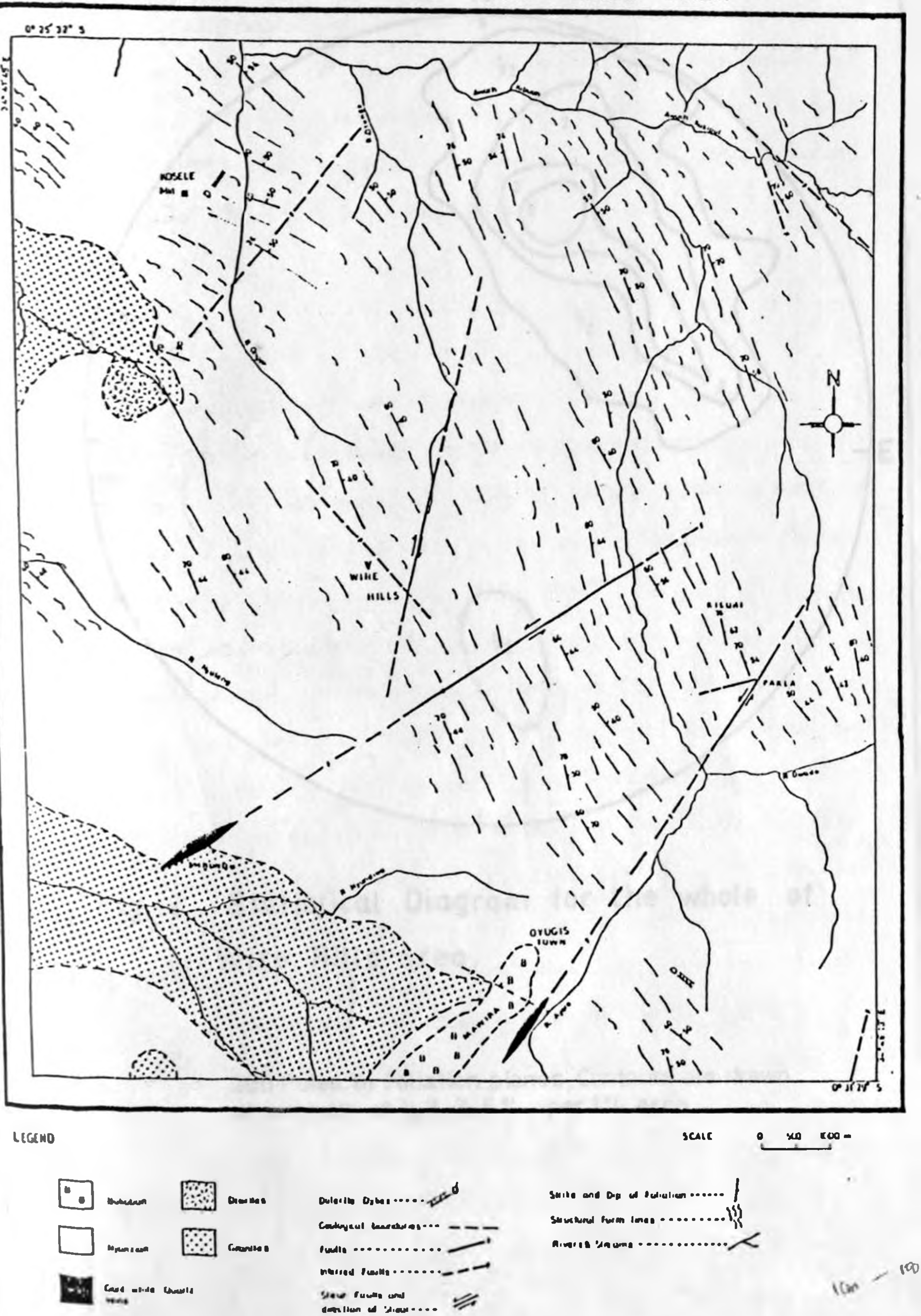
The minor structures include foliation, minor folds and joints while the major structures include regional folds and faults.

3.2.8.1 Major Structures

The structural map of the whole of the Wire hills area shows the strike of the foliations to be dominantly in the NW-SE trend though there are some deviations from this trend (Fig. 10). In the area around Kosele, there is a deviation from the general strike direction to a WNW-ESE direction. This change in attitude of the foliations could be due to a monoclinal flexure or shear fault with an axis in the NE-trend (Fig. 10).

According to Saggerson (1952), a major synclinorium axis passes through the northern limit of the study area and pitches to the south east. During the study, a plot of the foliation data on an equal area stereonet (Fig. 11) does not, however indicate the presence of a fold precisely. This observation is made from the fact that most data plot as a single cluster in the NE - quadrant of the steronet. However, this could be representing just one limb of the synclinorium proposed by Saggerson (1952). However, the presence of a possible synclinorium is supported by the presence of congruent minor anticlinal and synclinal folds, for example, an anticline was noted that plunges to SE near Kosele market.

Fig. 10 STRUCTURAL MAP OF THE WIRE HILLS AREA



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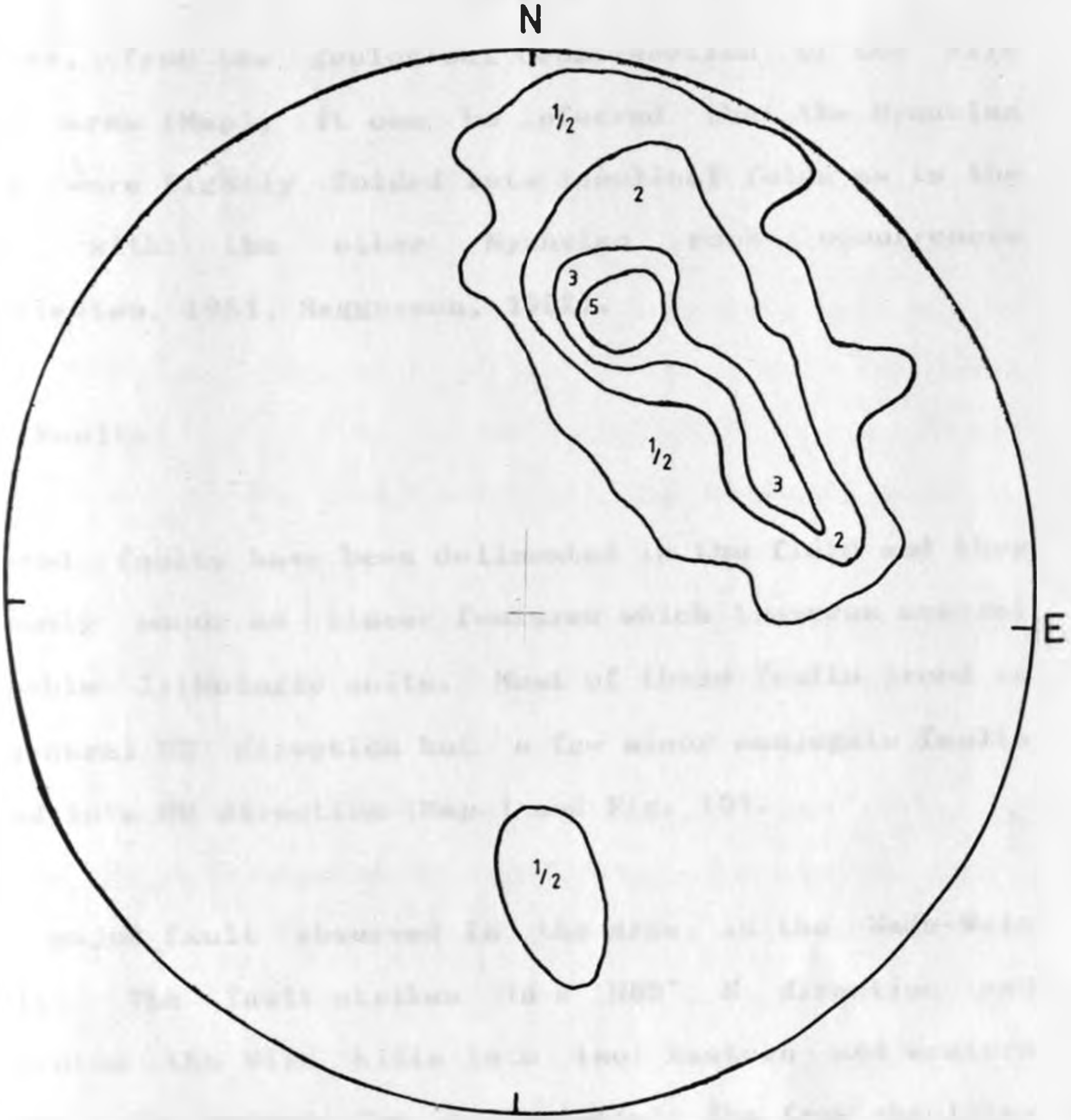


Fig. 11 Statistical Diagram for the whole of Wire Hills area.

206 Poles to Foliation planes, Contours are drawn at intervals of ½, 2, 3, 5 % per 1 % area

However, from the geological cross-section of the Wire hills area (Map), it can be inferred that the Nyanzian rocks were tightly folded into isoclinal folds as is the case with the other Nyanzian rock occurrences (Huddleston, 1951; Saggerson, 1952).

(b) Faults

Several faults have been delineated in the field and they commonly occur as linear features which traverse several mappable lithologic units. Most of these faults trend in a general NE direction but a few minor conjugate faults trend in a NW direction (Map 1 and Fig. 10).

The major fault observed in the area is the Wadh-Welo fault. The fault strikes in a N60° E direction and separates the Wire hills into two: Eastern and western hills. It extends for approximately 7km from rhyolites in the north through quartz porphyry and dacites and ends at the dacite-granite contact in the south. The fault resulted in the displacement of the quartz porphyry and a similar displacement of about a kilometre is noted at the rhyolite - dacite contact. The trend of the fault is coincident with the trend of the Mirondo giant white quartz vein and within the fault zone are emplaced the Nyandiwa auriferous quartz veins. It can therefore be concluded that these quartz veins owe their existence to the Wadh-Welo fault.

The Pakla fault is present in the south eastern part of the study area. It strikes in a N50° E direction and extends from just beyond the Pakla hill in the north to behind the Oyugis town in the south, a distance of about 7km. The fault has displaced the ironstone band on the Pakla hill by a distance of more than 100m. The fault zone on the Palka hill is well indicated by a strong brecciation of the ironstone band. The detached breccias and fragments have been cemented by the iron oxides released by the breakdown of the ironstone to form ferrocrete. In the south, the trend of the fault zone coincides almost exactly with the trend of the Oyugis giant quartz vein. The eastern edge of the vein is incised by a stream which most likely follows the fault line as it flows northwards. From these observations, it can therefore be inferred again that the Oyugis giant quartz vein was also emplaced in an opening created by the Palka faulting.

The Nyaingu faults occur in the area lying to the north of the Nyaingu hills, in the NE section of the study area. The faults trend generally in a NW direction, and the flow direction of river Awach to some extent is controlled by the strike of the faults. These faults have caused severe ductile deformation of the rocks in this area such that in extreme cases, the original rhyolitic rocks are sheared into slates.

River Onger fault zone trends about 10° E and occurs in the area east of the Kosele market. The fault line extends for more than 4km. This zone is characterised by strong shearing in the andesitic rocks and the Onger river flows along the strike of the fault. The fault has caused a change in the foliation trends, the fault line being the axis of the deviation (Fig. 10).

Two other faults occur at the Wire hills. One fault strikes in a N25°E and divides the two highest peaks of the Wire hills by a distance of about 500m. The other fault is minor and strikes in a N35°W. The two faults meet on the Wire hill and the angle between the two fault-trends is about 60°. From the value of the angle, it is inferred that the faults form a conjugate pattern and hence were formed at the same time.

A minor fault occurs in the southern part of Oyugis town and will be referred to as the Oyugis fault. The inferred extent of the fault is about 2km. It cuts across the northern portion of the Oyugis giant quartz vein and it trends in a NW-SE direction with a northerly dip. Fracturing and mylonitisation is observable along the fault zone especially where the fault transects the Bukoban basalt of the Mawira ridge. The age of the Oyugis fault is suggested to be post-Bukoban since it affects both the Nyanzian and the Bukoban rocks.

3.2.8.2 Minor Structures

(a) Foliation

Foliation is one of the most common geological structures in the Wire hill area. It is prominently developed in the Nyanzian volcanics. The foliation arises from planar features caused by folding in the project area.

The foliation measurements reveal that the regional structural trend in the Wire hills area is in the NW-SE direction (Fig. 10). The strike of the regional foliation, in general is between N60°W and N70°W but readings between N20°W and N40°W are occasionally recorded. The dip of this foliation is to the NE and ranges between 40° and 70° but sometimes may be as high as 80°.

(b) Minor folds

Minor folds are common in the highly deformed areas, especially to the north of Wire hills. These folds mainly occur in the andesites and rhyolites and are generally tight but some are open. The open folds are either anticlinal or synclinal in nature. A minor anticlinal fold near Kosele occurs within the andesite and it has a wavelength of about 3m and an amplitude of about 2m. The fold plunges to the SE. Other minor folds occur to the NE of the project area around Nyaingu hill.

These minor folds are nearly symmetrical and occur as synclines and anticlines which are highly jointed and occasionally micro-faulted. The Nyaingu minor folds have a wavelength of about 2m and an amplitude of about 0.4m. These minor folds of the Nyaingu area were produced by severe deformation that also culminated into faulting which are common in that area.

(c) Joints

Joint development is a very common feature within the Wire hills area and affects nearly all lithologic units. Two types of joints were noted in the study area, namely tectonic and columnar joints.

(i) Tectonic Joints

The tectonic joints comprise longitudinal and cross-joints. The former type of joints trend in a NW-SE direction and conform to the strike direction of the foliations. The cross-joints or transverse joints trend in a NE-SW direction and perpendicular to the strike direction of the foliaiton surface.

Longitudinal joints are more prominent in the Wire hills area as indicated by the rose diagram of jointing pattern (Fig. 11). The cross-joints defines a distinct planar feature which is frequently vertical but occasionally dip in the NW or SE directions. These opposite dip directions define a conjugate joint pattern in which the joint sets have a common strike direction. Oblique joints do occur and have trends in the NNE-SSW and NNW-SSE directions (Fig. 12). They are of minor development compared to the two other joint sets described above.

Sheet joints are common in the area around Nyaingu hill. The joint occur as horizontal planar features within the deformed rhyolites. They are associated with the folds in this area and hence have a common tectonic origin.

The longitudinal joints were formed along the planes of weakness developed as a result of the foliation of the rocks while the cross-joints were formed by tensional forces that acted perpendicular to the direction of compression.

The orientations of the veins and the joints exactly coincide (Figs. 12 & 5). Inference can be made that the veins were emplaced along joint planes. Prominent veins in the NW direction indicate that the joints were more well developed in this trend and so was the subsequent widening of the gaps.

In contrast, the NE trending veins are fewer, longer and thinner, indicating that a little widening accompanied the formation of these joints.

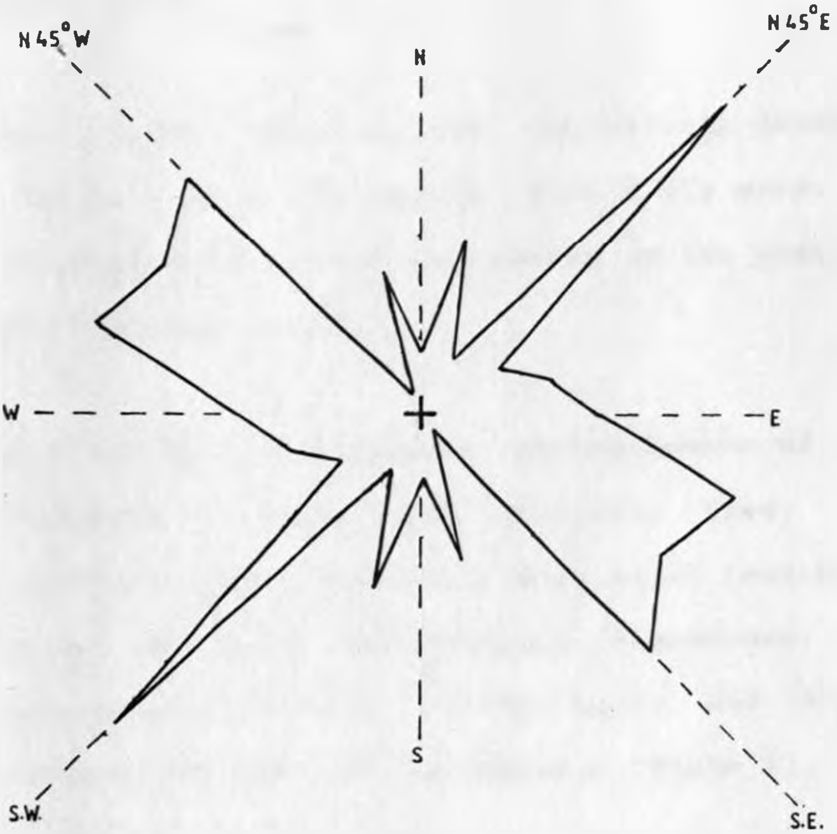


Fig.12 Orientation Diagram of all Joints from Wire Hills area.

A rose-diagram for 150 joint readings from the whole of wire hills area

(ii) Columnar Joints

Well formed columnar jointing was exclusively developed on Kisuri hill out of the entire Wire hills area. The columnar jointed blocks occur dominantly on the peak area of the quartz porphyry hill.

The columnar jointed blocks have varied number of faces ranging from four to eight but frequently five. The faces of the polyhedra frequently have equal lengths but in some cases the faces have unequal dimensions. The blocks measure approximately 50-60cm aside and dip at angles of between 70° and 80° to the west (Plate 12).

Columnar jointing develops as a result of tension that arises from the decrease in volume which occurs due to cooling of the rock. In classical examples, the columns are mostly hexagonal in shape since the tensional forces that develop are equal in all directions.

However, the development of unequal and varied number of faces in the quartz porphyry indicates that the tensional forces that were developed were unequal, being stronger in some directions than others. The occurrence of the columnar joints on Kisuri hill attests to the extrusive origin of the quartz porphyry since most of these joints develop in volcanic rocks.

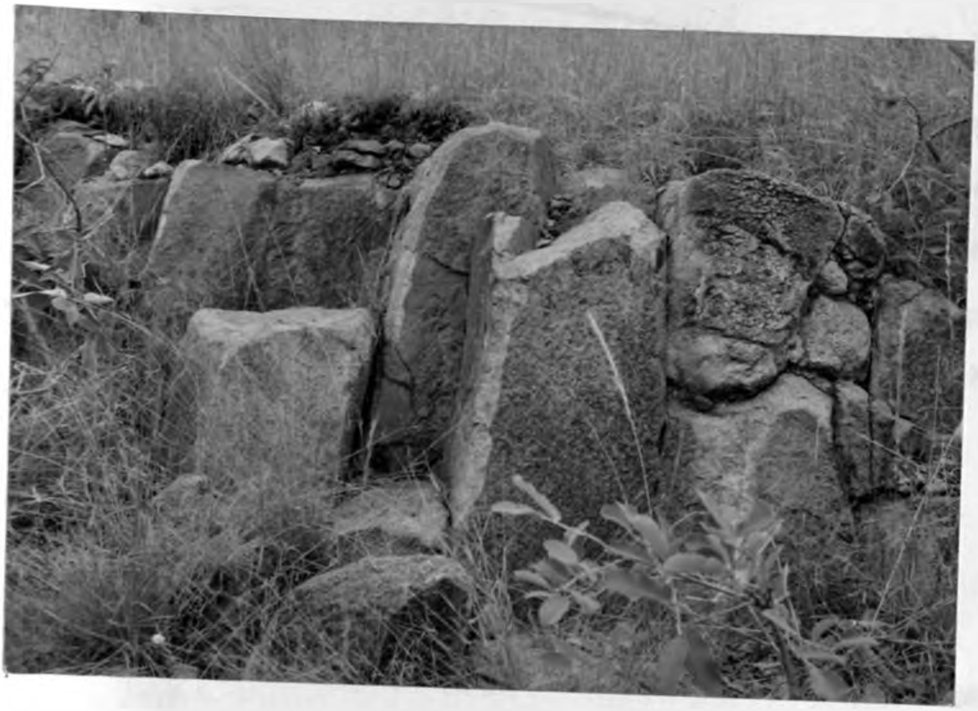


PLATE 12

A photomicrograph showing columnar jointing in quartz porphyry of the Kisuri hills.

CHAPTER 4

SULPHIDE MINERALIZATION

The Wire hills sulphide deposit occurs in the northern flank of the main Wire hill. The evidence of mineralization was revealed by exploratory diamond drilling in the area following geophysical surveys carried out in the area during the 1970's. The sulphide deposit localised in the area between the Wire and God Nyango hills.

4.1 Morphology of the Sulphide Bodies

The Wire hills sulphide deposit consists of two sulphide bodies which lie nearly parallel to each other but tend to converge at deeper levels.

The mineralization occurred within the moderately sheared and altered volcanic rocks and their pyroclastic equivalents. These sulphide bodies are found in the lower zones of the pyroclastic rocks close to the contact with the underlying rhyolites and dip at angles of between 40° and 50° to the NE. They are conformable to the foliations of the host rocks (Figs. 13&14).

The sulphide bodies vary in thickness from a few metres to more than 30m. They are often interlayered with

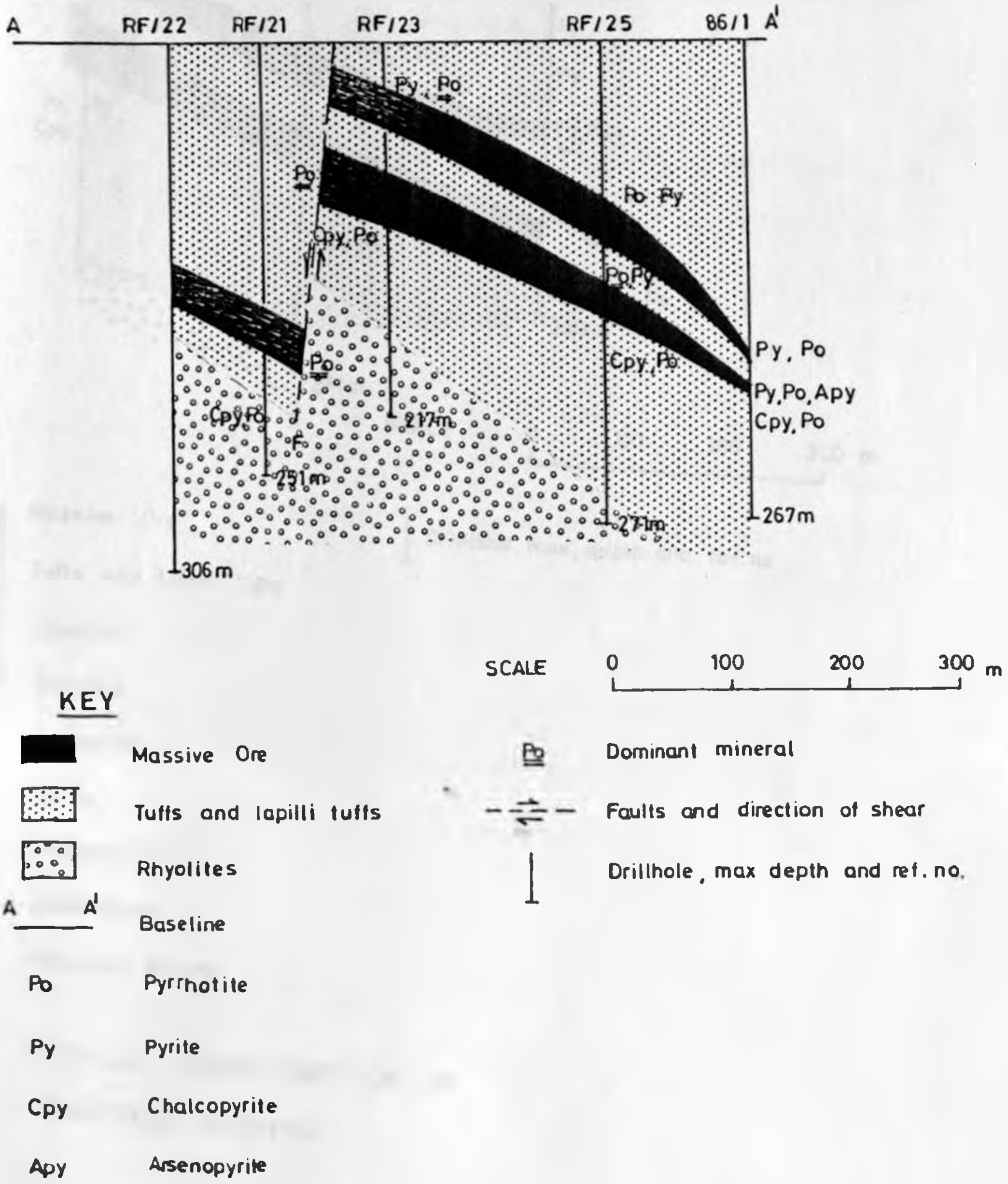
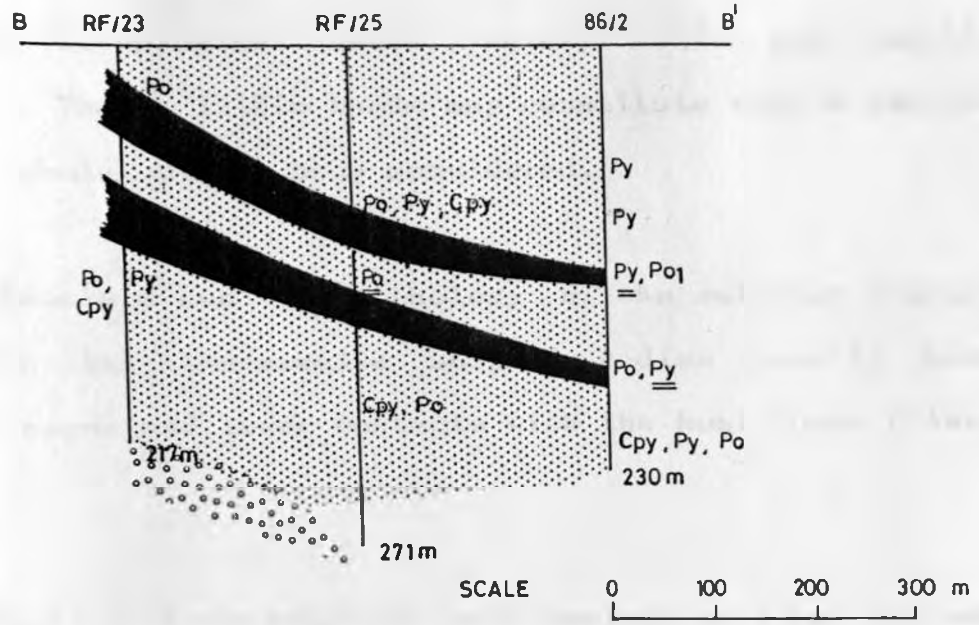


Fig 13 VERTICAL CROSS-SECTION OF SULPHIDE BODIES



KEY

■	Massive Ore
▨	Tuffs and Lapilli tuffs
°	Rhyolites
B—B'	Baseline
Po	Pyrrhotite
Py	Pyrite
Cpy	Chalcopyrite
Apy	Arsenopyrite
Po (double underlined)	Dominant mineral
⊥	Drillhole, max. depth and ref. no

Fig 14 VERTICAL CROSS-SECTION OF SULPHIDE BODIES

altered lithological units, mainly tuffs and lapilli tuffs. These lithic bands may constitute upto a quarter of the whole sulpide body considered.

The structure and the lithology of the sulphide deposit is such that the massive sulphide bodies usually have sharp upper and lower contacts with the host rocks (Plate 13).

The footwall rock-sulphide body contact is a bit diffuse due to the high intensity of chloritization which affected the rocks. The sulphide bodies are frequently underlain and overlain by chert or cherty tuff which thereafter grades into the other lithic units. Petrographic studies reveal that the cherts have a sedimentary origin, possibly precipitated from a colloidal solution.

After the sulphide deposition, the rocks were subjected to tectonic processes. This is evidenced by the faulting and displacement of the sulphide bodies (Fig. 13).

Along the drillcores, the fault zones are indicated by the highly brecciated host rocks. These post-mineralization faults resulted in the displacement of the sulphide bodies with a downthrow of about 90m to the south. The type of displacement which occurred indicates that the fault is normal since the downthrow is in the direction of the hade of the fault. These fault zones

PLATE 13

A photograph of drill cores showing the tuff - pyrhotite contact. Tuff is white and pyrhotite is brownish-grey in the photograph. Note the very sharp contact between the two zones.

are non-mineralized but show moderate to high degree of alteration with the formation of chlorite in the cementing material of the breccias.

The mineralization is such that in the upper levels, the sulphide minerals are frequently disseminated in a cherty base but becomes massive in the middle levels and then tapers to the lower levels. However, mineral zonation is not well developed but chalcopyrite is more prominent in the stringer zone than in the massive sulphide zones. A summary of the characteristics of the sulphide mineralization is given in table 7.

4.2 Textures of the Sulphide Bodies

Macroscopic and microscopic examination of the sulphide bodies has revealed the following textures: Massive, banded, veined, disseminated, brecciated and colloidal. These textures are discussed below.

4.2.1. Massive Sulphide Bodies

The sulphide bodies referred to as massive contain more than 80% sulphide minerals which are evenly distributed throughout the rock. The major composing minerals are pyrite and pyrrhotite while chalcopyrite and sphalerite are minor.

TABLE 7 SUMMARY OF THE CHARACTERISTIC FEATURES OF THE WIRE HILLS SULPHIDE DEPOSIT

DDH NO.	INCLINATION (DEG)	DRILL DEPTH (m)	INTERVAL OF BODIES	THICKNESS OF BODIES	MINERAL %	TOTAL THICKNESS	CHARACTERISTICS
86/1	61.5	265	175-182	7	50	11	Pyrite-Pyrrhotite
			226-230	4	30		Chalcopyrite,Pyrite,Arsenopyrite
86/2	61	230	81-87	6	20	34	Banded Pyrite
			103-106	3	20		Disseminated Pyrite
			122-128	6	30		Disseminated Pyrite ,Pyrrhotite minor.
			168-187	19	80		Massive Pyrite
86/8		312	126-136	10	40	10	Brecciated Pyrite ore
86/9		218	76-79	3	30	13	Layered Pyrite
			91-99	8	50		Weakly banded Pyrite
			121-123	2	50		Banded Pyrite
RF/21	45	251	166-189	23	90	30	Massive Pyrrhotite
			221-228	7	10		Disseminated Pyrite,Pyrrhotite,Chalcopyrite
RF/23	45	217	89-121	32	50	45	Massive Pyrrhotite
			129-142	13	50		Massive Pyrrhotite,Chalcopyrite minor.
RF/25	60	271	96-114	18	70	35	Massive Pyrrhotite
			139-156	17	60		Massive Pyrrhotite
RF/27	55	255	53-67	14	30	20	Layered Pyrite
			103-109	6	60		Disseminated Pyrite
RF/33	60	288	53-93	40	90	49	Massive Pyrite
			102-111	9	80		Massive Pyrrhotite ,Pyrite minor.

(a) Massive Pyrite Body

Pyrite comprises more than 90% of the body and occurs frequently in fine granular aggregates, which under the microscope are well formed crystals. The pyrite is occasionally associated with other sulphide minerals which occur in minor amounts such as chalcopyrite. One specimen of massive pyrite body has coarse grained pyrite crystals enclosed within the fine grained pyrite zone (Plate 14). The coarse crystals are interprated to be a second generation pyrite which crystallized from an iron and sulphur rich solution that was entrapped between the formed minerals. This solution cooled slowly resulting into coarse-grained pyrite.

(b) Massive Pyrrhotite Body

The body consists of fine grained pyrrhotite as the main sulphide mineral while chalcopyrite and pyrite occur in the minor sulphide minerals. Pyrrhotite comprises about 80% of the body while pyrite and chalcopyrite often comprise less than 5%. The other associated minerals are quartz and chlorite.

4.2.2. Banded Pyrite Body

The banded pyrite body consists of pyrite rich bands

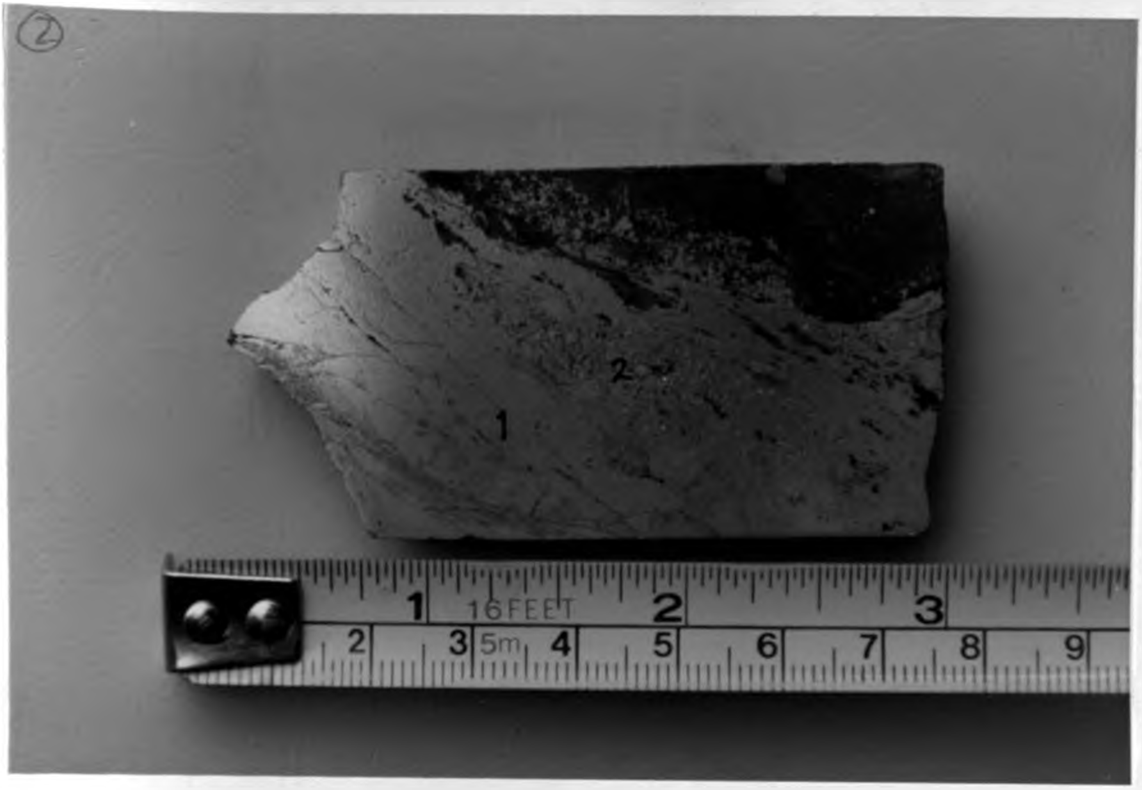


PLATE 14

Massive pyrite body. The body shows two generations of pyrite; fine grained (1) and coarse grained (2). The dark zone is cherty host rock interlayered with cherty bands (Plate 15 and 16). The pyrite rich bands consist of fine grained pyrite. The bands are occasionally folded, especially those that occur at the basal section of the body (Plate 16). In the specimen, a unique feature is observed at the fold crest where pyrrhotite lenses occupy the zone between the pyrite bands. The occurrence of the pyrrhotite at this position is inferred to mean that the mineral is of later generation and the mineralizing solution was pushed under pressure through openings created by the deformation.

4.2.3. Veined Sulphide Bodies

Veined sulphide bodies consist of the following: Chalcopyrite-pyrite, pyrite- arsenopyrite and pyrite-pyrrhotite. The mineralized veins and stringers are common in the footwall rocks but rarely do they occur in the hanging wall. The sulphide minerals are associated with the intensely chloritised zones of the host rock, a fact which indicates that the mineralization and the alteration processes occurred simultaneously.

(a) Veined Pyrite-chalcopyrite Body

The composition of the vein is dominated by pyrite which occupies the central region of the vein while chalcopyrite forms the outer margin (Plate 17).

This observation indicates that the mineralizing solution contained sufficient quantities of copper, iron and

PLATE 15

Banded pyrite body. The creamy-white bands (1) are pyrite and the dark grey zones (2) are composed of chert.

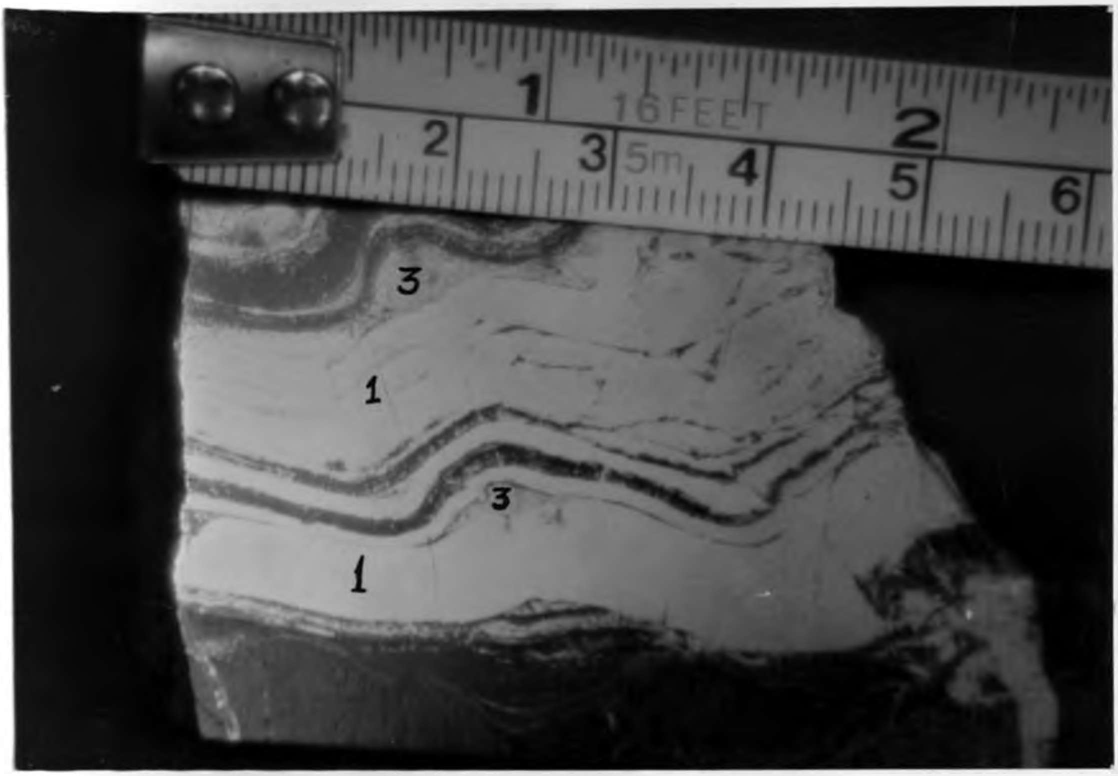


PLATE 16

Folded banded pyrite body Pyrite rich bands (1) alternate with dark grey cherty bands (2). The concave side of the fold crests are mineralized with pyrrhotite (3).

PLATE 17

A type of veined pyrite body. Pyrite layers (1) alternate with silicified tuff layers (2).

sulphur to precipitate the sulphide minerals. Chalcopyrite was precipitated first and the residual solution being richer in iron but poorer in copper, deposited pyrite. The host rock is highly silicified and this indicates that the silicification process preceeded the mineralization process.

(b) Veined Pyrite Body

The veined pyrite body consists of thin layers of pyrite alternating with silicified tuff (Plate 18). The host rock is mildly altered to greenish colour while pyrite occurs in fine to medium grained aggregates. The mineralized veins vary in size from about 1mm to 1cm in thickness while the silicified bands attain a thickness of upto 2cm. The host rock has disseminated pyrite grains which are occasionally cubic in shape and attain a size of about a millimetre across.

(c) Veined Arsenopyrite Body

The mineral, arsenopyrite, occurs almost exclusively in the footwall rocks in the form of veins. The mineral often occurs in euhedral shiny silvery-grey crystals in association with quartz and calcite.

(d) Veined Pyrite-Pyrrhotite Body

The vein deposit often occurs in the footwall rocks in

PLATE 18

Veined pyrite - chalcopyrite body. Pyrite (1) occupies the central zone and in it's margin is a zone rich in chalcopyrite (2). The host rock is cherty and appears as the dark grey zone in the photograph.

the form of stringers and minor veins. The minerals forming this type of deposit are usually fine grained and are occasionally associated with chalcopyrite.

4.2.4 Disseminated Sulphide Bodies

The disseminated bodies consist of sulphide minerals sparsely distributed within the host rock. The common minerals comprising the disseminated bodies include; pyrite, chalcopyrite and pyrrhotite. They often occur in combinations of two or more.

(a) Disseminated Pyrite Body

The disseminated pyrite body consists of pyrite cubes of dimensions between 1mm and 4mm scattered within a cherty tuff (Plate 19). Another disseminated pyrite body similarly occurs in drill hole RF/27 where well developed euhedral pyrite crystals are emplaced in a tuffaceous matrix. The occurrence of these euhedral pyrite crystals indicate that the crystals grew in a soft tuffacious rock which allowed for unobstructed growth. The environment of formation was possibly within a porous tuff unit and the pyrite crystals were deposited from hydrothermal solutions. The intensity of silicification indicates that the solution contained abundant silica as well.

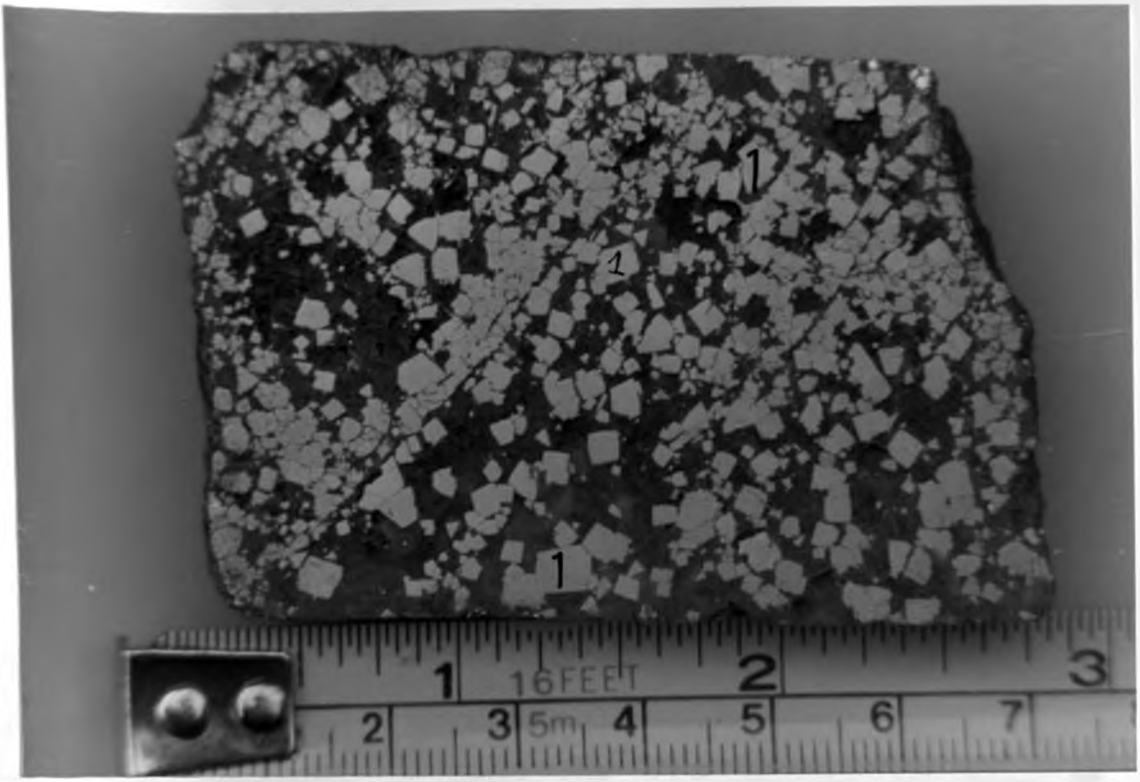


PLATE 19

Disseminated pyrite body. Pyrite appears as the euhedral creamy-white crystals (1). The host rock is cherty tuff.

(b) Disseminated Pyrite - Pyrrhotite Body

The body consists of disseminated pyrite crystals in a pyrrhotite rich base. Sulphide minerals constitute about 50% of the rock out of which the pyrrhotite value is about 40% and pyrite 10% (Plate 20). The pyrite crystals measure between 0.1mm and 3mm in size and occur within fine grained pyrrhotite though some also occur in the cherty matrix. Chalcopyrite is occasionally disseminated in the pyrrhotite.

(c) Disseminated Chalcopyrite - Pyrite Body

The body consists of about 47% chalcopyrite and about 3% pyrite (Plate 21). The gangue minerals include cherty quartz and chlorite. Chalcopyrite occurs in felted anhedral masses in which euhedral pyrite crystals are disseminated. Some of the pyrite crystals contain chalcopyrite as inclusions. These inclusions are observed both in macroscopic and microscopic scales. From this observation, it can be postulated that pyrite is a later mineral and during the process of its formation, it enclosed some of the earlier formed chalcopyrite.

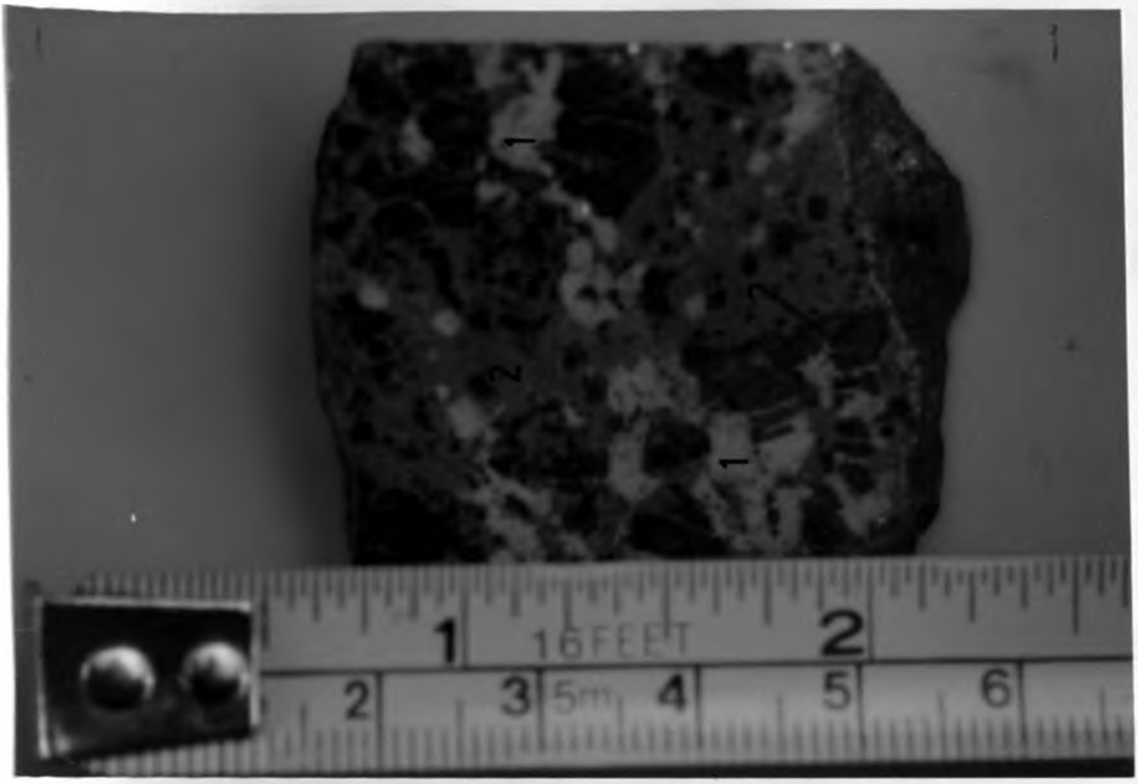


PLATE 20

Disseminated pyrite-pyrrhotite body. Pyrite appears as the creamy-white zones (1) and pyrrhotite the dark brown zones (2). The cherty host rock appears as the dark zones.

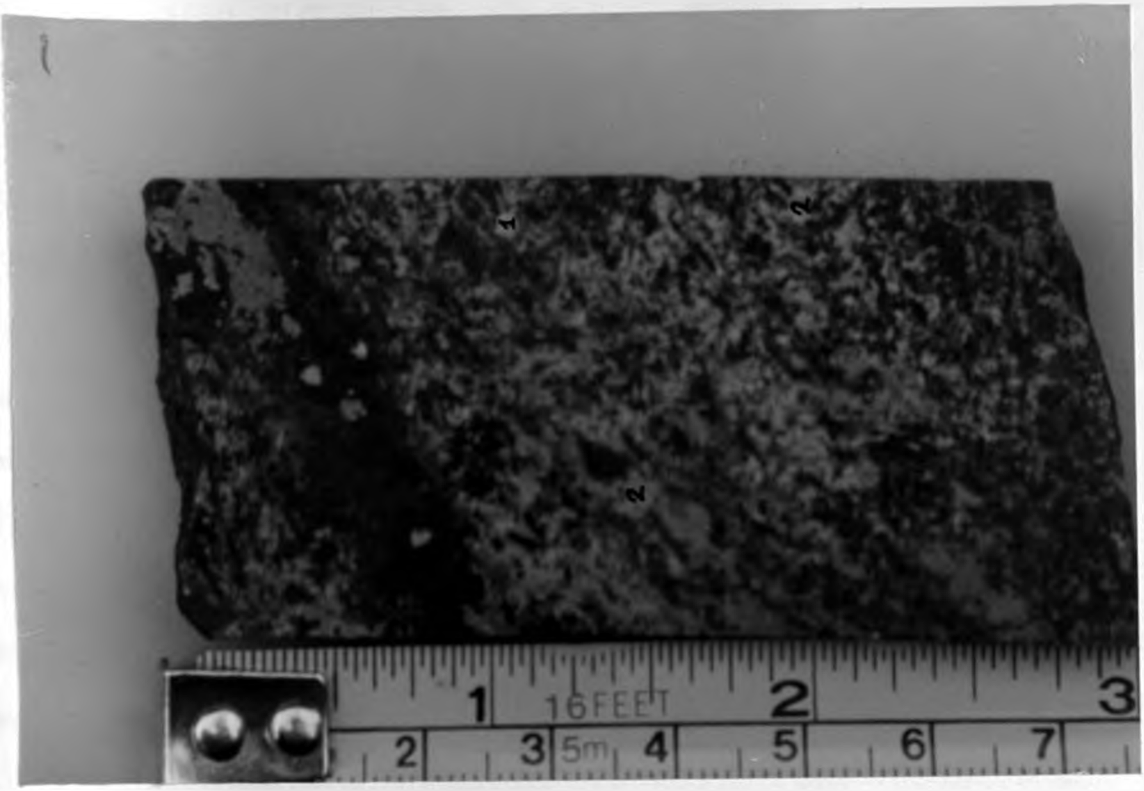


PLATE 21

Disseminated pyrite-chalcopyrite body. Greyish patches (1) are pyrite while chalcopyrite occurs as the yellowish masses (2). The dark zone is silicified and chrolitized host rock.

4.2.5 Brecciated Pyrite Body

Two forms of brecciated pyrite bodies occur, one in which pyrite forms the breccia while in the other, pyrite forms the matrix as well. The first type of body consists of pyrite fragments which are subrounded and vary in size from about a millimetre to 10 mm in diametre. The cement is dark, grey cherty material. From the structure of the body, it is suggested that brecciation resulted in abrasion of the fragments with the formation of the rounded grains. The cementing chert was deposited from the silica rich fluids that flowed through the open spaces after brecciation of the body.

The other form of brecciated sulphide body observed occurs in a lapilli tuff unit. In some zones, the lapilli fragments are cemented by pyrite but in most zones, pyrite also forms fragmentary concentrations (Plate 22). These pyrite fragments are inferred from a textural characteristic, to be of replacement origin. The replaced materials are lapilli fragments which were originally pumice. Such a replacement texture can be observed in plate 23 where the pyrite is preferentially localized within pumice fragments. This preferential concentration of pyrite was favoured by the porous and permeable nature of pumice. This condition allowed for the accumulation of mineralization solution in the

PLATE 22

Brecciated pyrite body. Yellowish patches are pyrite (1) while lapilli fragments are light-grey (2).

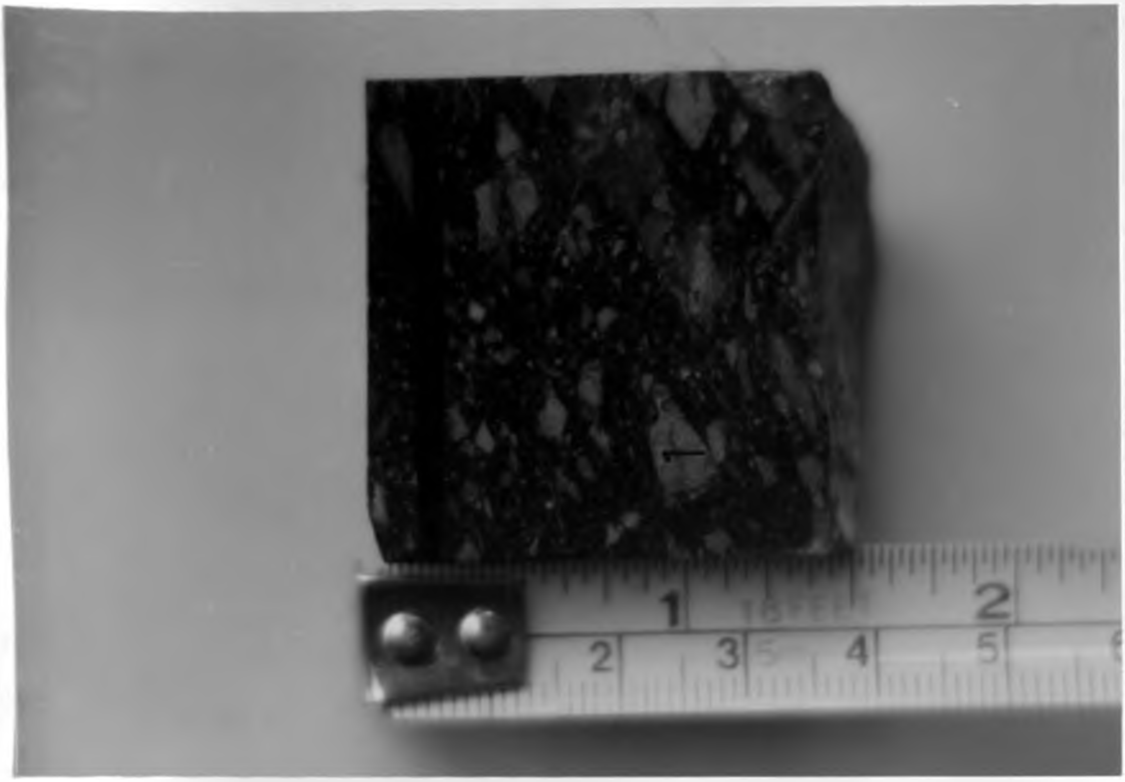


PLATE 23

Replacement pyrite body. Pyrite concentrations (1) replace pumice fragments. The host rock which appears dark in the photograph is silicified lapilli tuff.

cavities and from the solution, crystals of pyrite formed.

4.2.6. Colloidal 'Massive' Sulphide Body

The colloidal texture can be observed both in microscopic and macroscopic scales for the 'Massive' pyrite in ddh. RF/33 (Appendix) In band specimen, the texture is exhibited by the body having concentrations with spheroidal outlines (Plate 24). The spheroidal nature of the deposit is attributed to colloidal precipitation of the mineral (Bastin, 1950). The present observable shapes have been modified by external forces and hence appear as distorted spheroidal units. This type of texture is more frequent in pyrite bodies and rarely well developed the in pyrrhotite bodies. The ease of formation of colloidal texture by pyrite compared to pyrrhotite is attributed to the high relative density of pyrite (5.02g/c.c.) which exceeds that of pyrrhotite (average = 4.61g/c.c.). The colloidal texture being a product of surface tension phenomena, is dependent on the density of the colloidal suspensions and that of the colloidal solution (Bastin, 1950). Therefore when the solution is capable of precipitating both pyrite and pyrrhotite, the pyrite will tend to form colloidal structures in preference.

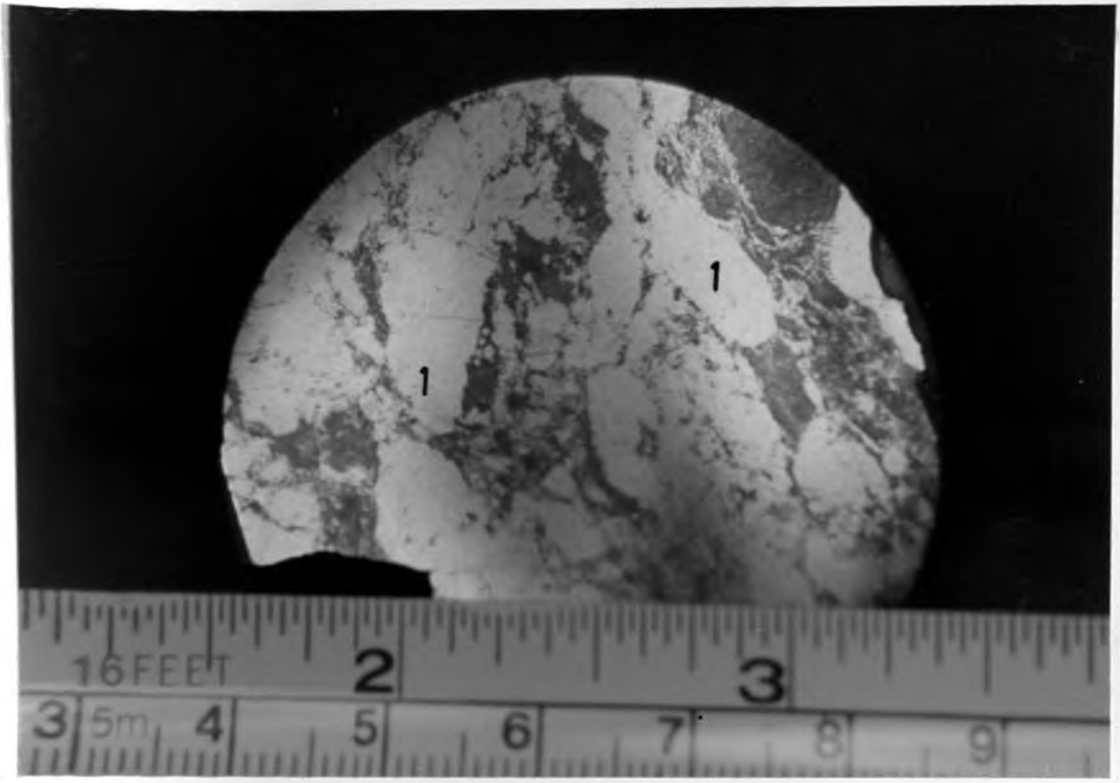


PLATE 24

Colloidal pyrite mineralization. Colloidal texture is shown by pyrite concentrations (1) in chert.

4.3 Mineralogy of the Sulphide Deposit

The mineralogy of the deposit is characterised by the presence of sulphide minerals, magnetite and the associated gangue minerals .

4.3.1 Sulphide Minerals

The major sulphide minerals indentified include pyrite pyrrhotite, chalcopyrite and arsenopyrite while sphalerite occurs in minor amounts.

(a) Pyrite (FeS_2)

Pyrite is the dominant sulphide mineral in the deposit . It constitutes more than 60% of the sulphide minerals and occurs as an important constituent of the massive, disseminated, colloidal and veined bodies. The minerals occur in fine to coarse grained aggregates. In the former case, it forms the massive bodies and veins while in the latter, it constitutes the disseminated pyrite body. In fine grained aggregates of the massive body, the mineral assumes a dull yellowish colour but when it occurs in coarse crystals it has a bright yellowish colour. The commonly associated sulphide minerals include pyrrhotite and chalcopyrite.

(b) Pyrrhotite ($Fe_{1-x}S$)

Pyrrhotite is the second abundant mineral after pyrite. The mineral is pinkish-brown and occurs in fine granular aggregates with moderate to strong magnetism. The mineral constituents part of the massive, veined and disseminated bodies. The other sulphide minerals commonly associated with pyrrhotite include chalcopyrite and pyrite while the associated gangue minerals includes chlorite, quartz and calcite. The strong magnetic property of the mineral indicates that the variety is of monoclinic type as opposed to the hexagonal variety which is non-magnetic. Pyrite grains that occur in pyrrhotite are both of replacement and primary origin while chalcopyrite occurs as inclusions in pyrite.

(c) Chalcopyrite ($CuFeS_2$)

The mineral occurs in bright shiny yellow anhedral masses. It is mainly present in the stringer zone which underlies the sulphide bodies. In this zone, chalcopyrite occurs as veins and disseminated units in the host rock. Chalcopyrite is the main source of copper in the sulphide deposit and an XRF analysis of monomineralic sample of chalcopyrite reveals that the copper content is as high as 11% (Table 11). It's most associated sulphide minerals include pyrrhotite, pyrite and arsenopyrite in order of decreasing abundance. The associated gangue minerals are calcite, quartz and chlorite.

(d) Arsenopyrite (FeAsS)

Arsenopyrite forms a minor fraction of the total mineral content of the sulphide deposit. It commonly occurs in shiny metallic grey euhedral crystals. The identity of the mineral was further confirmed by X-ray diffraction analysis (Table 8). The data agrees with the diffraction data for arsenopyrite (JCPDS data book, 1984). The mineral commonly occurs in veins where it is associated with calcite and quartz in the stringer zone.

Table 8 XRD Data for Arsenopyrite

Reflection	d-spacing nm.	Intensity %
001	3.6928	30
002	2.8667	20
003	2.6828	100
004	2.5780	10
005	2.4617	80
006	2.2116	15
007	2.1035	22
008	1.9530	17
009	1.8240	55

4.3.2 Gangue Minerals

The common gangue minerals associated with sulphide mineralization are: Quartz, chlorite and calcite. The minerals are discussed in detail below:

(a) Quartz (SiO_2)

Quartz ussually forms the dominant gangue mineral associated with the sulphide minerals . It occurs inthe form of veins and anhedral masses associated with the sulphide minerals. The quartz veins are mainly associated with the sulphide minerals in the stringer zone which underlies the main sulphide deposits. The quartz that occurs in the massive ores are microcrystalline in texture and the sulphide minerals occur within it. The intimate association between the quartz and the sulphide minerals indicate that silica was an important component of of the mineralizing solution.

(b) Chlorite $(Mg, Fe, Al)_6 (Si, Al)_4 O_{10} (OH)_8$

The most important variety of chlorite which occurs as a gangue mineral is clinochlore given by the above formula. It occurs in deep green flaky and also in granular aggregates. Chlorite often forms an important gangue mineral for the pyrrhotite deposit. It also occurs in minor quantity in chalcopyrite, arsenopyrite and pyrite deposits.

(c) Calcite $CaCO_3$

Calcite is the only carbonate mineral identified by the XRD analysis. It occurs mainly in the footwall rocks as veins which are either concordant or discordant to the foliations. Dissemented grains of calcite are also common in the highly chloritised host rocks. Calcite is associated with the sulphide minerals mainly in the stringer zone. The frequently associated sulphide minerals include: Arsenopyrite, chalcopyrite and pyrrhotite. Arsenopyrite forms euhedral disseminated grains in calcite. The close association between the carbonates and the sulphide minerals indicate that the carbonate was also contained in the mineralizing solution that precipitated the sulphides.

(d) Magnetite (Fe_3O_4).

Magnetite occurs in dark grey, massive form which is strongly magnetic. The mineral is frequently intimately associated with the highly chloritised lithologic units and occurs in disseminated form and in bands of about 10cm in thickness. It has been identified by its strong magnetic property and by ore microscopic study. A vein of chalcopyrite was noted to occur within magnetite.

When the mode of occurrence of the mineral is considered, it is suggested that it was formed as a result of oxidation of ferrous silicates in rocks by water and carbon dioxide contained in the invading solutions as proposed by Hutchinson, (1982). The reactions leading to the formation of the magnetite is given by the formulae below:

Fe- Silicates + CO_2 $=Fe_3O_4$ + C and

Fe- Silicates + H_2O $=Fe_3O_4$ + H_2 (aq)

CHAPTER 5

EVALUATION OF THE SULPHIDE DEPOSIT

5.1 Interpretation of Geochemical Data

The X-ray flouresence (XRF) analysis of monominerallic sulphide samples and the corresponding sulphides were analysed for the major and minor element contents (Tables 9 and 10). The maximum values of the elements present are as follows: 11.2% Cu, 0.35% Zn, 0.13% Pb, 14.74% As, 0.02% Sn and 0.002% Ag. The metals and their sources are briefly discussed below.

(a) Silver

Silver commonly occurs in the Wire hills sulphide deposit with the highest value of about 0.02% in chalcopyrite deposits and an average of about 0.005% in pyrite and pyrrhotite deposits. The maximum concentration of silver in the monominerallic samples is about 0.005% in pyrite and pyrrhotite and 0.067% in chalcopyrite. The analysis indicates that silver is commonly associated with chalcopyrite than the other minerals. This is further confirmed by the correlation between copper and silver as revealed by the calculation of the coefficient of correlation which is 0.95 (Table 11).

TABLE 9 XRF ANALYSIS OF SULPHIDE BODIES

SPEC.NO.	MINERALIZATION	Ag	Cu	Zn	Pb	As	Mn	Sn
1.180	Pyrite	0.005	0.043	0.011	0.020	0.020	0.086	nd
2.180	Pyrite	0.005	0.045	0.040	0.043	0.085	0.144	0.005
2.181	Pyrite	0.005	0.015	0.005	0.048	0.001	0.160	0.001
33.205	Pyrite	0.006	0.097	0.004	0.012	0.127	nd	0.001
23.180	Pyrite	0.004	0.008	0.005	0.066	0.001	0.236	-
27.215	Pyrite	0.001	0.001	0.013	0.025	0.001	0.175	0.004
8.130	Pyrite	0.006	0.030	0.010	0.001	0.010	0.024	0.003
33.210	Pyrite	0.004	0.020	0.009	0.049	0.001	0.062	0.001
33.220	Pyrite	0.005	0.025	0.011	0.046	0.001	0.238	0.008
33.215	Pyrite	0.005	0.029	0.015	0.130	0.010	0.302	0.060
21.180	Pyrhotite	0.002	0.004	0.010	0.009	0.006	0.980	0.020
25.105	Pyrhotite	0.001	0.005	0.015	0.006	0.001	0.331	0.001
1.220	Arsenopy.	0.010	0.060	0.021	0.001	9.513	0.181	0.008
25.250	Arsenopy.	0.005	0.012	0.025	0.001	14.740	0.771	0.025
21.240	Chalcopy.	0.010	2.645	0.065	0.012	0.100	0.141	0.006
25.180	Chalcopy.	0.020	11.219	0.348	0.009	0.300	0.579	0.010

Excitation Source = Cd - 109

Specimen number indicate drillhole and sampling depth

i.e. 1.180 drillhole no. 1 at 180m.

TABLE 10 XRF ANALYSIS OF MONOMINERALLIC SAMPLES. (%)

SPEC. NO.	MINERAL	Ag	Cu	Zn	Pb	As	Mn	Sn
1.180	Pyrite	0.005	0.049	0.012	0.063	-	0.087	0.003
2.180	Pyrite	0.004	0.012	0.039	-	0.012	0.050	0.003
2.181	Pyrite	0.001	0.008	0.045	0.026	0.012	0.050	0.003
33.205	Pyrite	0.005	0.857	0.080	0.007	0.113	0.048	0.006
23.180	Pyrite	0.001	0.001	0.012	0.008	0.010	0.010	0.005
27.215	Pyrite	0.001	0.151	0.001	0.036	-	0.061	0.008
8.130	Pyrite	0.005	0.020	0.163	0.010	0.004	0.030	0.003
21.180	Pyrrhotite	0.001	0.008	0.002	0.122	0.001	0.001	0.003
25.105	Pyrrhotite	0.005	0.034	0.010	0.001	0.001	0.001	0.002
1.220	Arsenopyrite	0.005	0.061	0.045	-	17.310	0.001	0.004
25.250	Arsenopyrite	0.009	0.015	0.013	-	19.153	0.001	0.002
21.240	Chalcopyrite	0.012	8.674	0.040	0.020	0.020	0.094	0.003
25.180	Chalcopyrite	0.067	11.657	0.284	0.019	0.010	0.114	0.010

Excitation Source = Cd - 109 Isotope

The specimen number indicates drillhole and sampling depth

i.e. Spec.no. 1.180 indicates drillhole 1 sampled at 180m. depth.

TABLE 11 TRACE ELEMENT DATA FOR WIRE HILLS SULPIDE DEPOSIT (ppm or g/t)

Ag	Cu	Zn	Au	Ag	Cu	Zn	Au
3.00	0.02	0.01		0.50	0.01	0.12	
6.00	0.09	0.01		0.40	0.01	0.09	
8.10	0.05	0.01		0.50	0.01	0.03	
12.30	0.06	0.01		0.50	0.01	0.03	
4.10	0.03	0.01		0.30	0.01	0.03	
3.60	0.02	0.01		*	0.01	0.02	
6.20	0.02	0.01			0.01	0.02	
8.70	0.17	0.05		0.30	0.01	0.02	
2.50	0.16	0.01		0.60	0.01	0.02	
2.50	0.42	0.01		66.00	0.75	0.15	
0.60		0.01		0.80	0.01	0.02	
0.60		0.01		9.20	0.03	0.01	
0.40		0.01		5.60	0.02	0.01	
2.60	*	0.20		7.00	0.01	0.01	
2.60		0.30		1.00	0.01	0.02	
2.20		0.01		1.20	0.01	0.02	
1.80		0.02		1.20	0.01	0.04	
0.20		0.02		1.00	0.01	0.05	
1.40		0.06		2.80	0.07	0.01	
4.20	0.06	0.03		2.40	0.05	0.02	
14.80	0.25	0.02		3.20	0.08	0.01	
2.20	0.02	0.21		2.80	0.06	0.01	
2.20	0.03	0.01		3.00	0.05	0.06	
2.80	0.02	0.03		4.60	0.07	0.02	
2.60	0.01	0.01		3.60	0.05	0.01	
2.00	0.01	0.01		3.80	0.05	0.02	
10.60	0.09	0.24		1.00	0.01	0.03	
3.40	0.02	0.01		2.20	0.01	0.04	
1.40	*	0.01		1.50	0.01	0.02	
2.40	0.04	0.02		0.60	*	0.01	
23.00	0.75	0.05		1.20	0.01	0.02	
3.60	0.18	0.01		0.30		0.01	
6.00	0.17	0.02		0.20	0.01	0.02	
26.40	0.80	0.08		1.70	*	0.02	
1.40	0.03	0.03		1.70		0.01	
5.40	0.14	0.05		1.10	0.01	0.01	
2.40	0.08	0.02		1.30	0.02	*	
1.80	0.05	0.02		0.20	*	0.01	
1.40	0.01	0.03		2.40	0.09	0.98	
1.40	0.01	0.03		2.20	0.09	0.18	
0.80	*	0.03		*	0.03	0.02	
2.60	0.07	0.03			0.01	0.03	
11.80	0.30	0.07		0.60	*	0.02	
1.20	0.03	0.03		0.40	0.02	0.03	0.02
*	0.01	0.03		1.20	0.01	0.03	
2.80	0.07	0.29		2.20	0.01	0.02	
0.20		0.02		0.60	0.02	0.10	
0.80	*	0.02		2.20	0.02	0.02	
0.80		0.06		1.20	0.02	*	
0.80	0.01	0.07		2.00	0.02	0.01	

Table 11

0.40		0.01		1.20	0.03	0.01	
0.80	*	0.01		1.80	0.02	0.01	
0.40		0.01		4.00	0.02	*	
*	0.01	0.03		2.60	0.01	0.01	
1.00	0.03	0.30		7.00	0.02	0.01	
0.80	0.01	0.33			0.07	0.02	
0.20	*	0.42			0.12	0.01	
*	0.01	0.08			0.04	0.01	
	0.01	0.09			0.01	0.01	
12.80	0.26	0.08		*	0.01	0.01	
1.50	0.02	0.09			0.01	0.01	
1.30	0.02	0.05			0.04	0.01	
7.30	0.10	0.08			0.02	0.01	
1.50	0.01	*			0.02	0.01	
*	0.03	0.08		5.00	0.06	0.01	
	0.01	0.03			0.03	0.01	
	0.01	0.02		*	0.04	0.01	
0.80	0.01	0.02			0.04	0.01	
0.20	0.04	0.08		60.00	2.43	0.13	0.05
2.00	0.07	0.10		126.00	3.18	0.07	0.03
0.90	0.04	0.25		*	0.01	0.01	
1.90	0.05	0.10		10.00	0.01	0.01	
3.60	0.13	0.21		1.00	*	0.01	
4.10	0.13	0.09		0.80	0.21	0.03	
0.70	0.06	0.05		1.00	0.02	0.01	0.03
126.00	4.51	0.21	0.04		0.01	0.01	0.02
7.20	0.33	0.13		*	0.03	0.03	
0.30	0.09	0.15			0.01	0.01	
*	0.02	0.17		0.70	0.06	0.03	
0.80	0.03	0.22		1.60	0.08	0.02	
*	0.02	0.07		0.60	0.01	0.06	
0.70	0.03	0.03		0.70	0.01	0.12	
1.00	0.09	0.05		15.30	0.49	0.08	
0.30	0.02	0.05		0.40	0.01	0.05	
4.50	0.23	0.04		0.80	0.01	0.09	
0.40	0.01	0.03					
0.40	0.02	0.05					
7.70	0.11	0.08					

Silver :mean=5.519
Standard dev.=16.469

Zinc: mean=0.057
Standard dev.=0.099

Copper : mean=0.134
Standard dev.=0.499

Correlation Coefficient, r,
Cu-Zn =0.1449 Cov.=0.00735
Cu-Ag =0.950 Cov.=9.462

* = Corresponding values not used in the calculations.

(b) Copper

The copper content in the sulphide deposit varies from 0.001% in the pyrite and pyrrhotite ores to about 11% in the chalcopyrite deposits (Table 9). Monomineralic samples also registered copper values between 0.001 and 11%. The highest values were recorded in chalcopyrite while the concentration in the other sulphide minerals is low with no apparent trends. From the analysis, it can be concluded that chalcopyrite is the main source of copper in the Wire hills sulphide deposit.

(c) Zinc

Zinc is a common metal in the sulphide deposit. The average content of the element in the deposit is about 0.01% in pyrite and pyrrhotite deposits while the value in chalcopyrite ore is higher, upto 0.35% (Table 9). In the monomineralic samples, the zinc content is low in pyrite, pyrrhotite and arsenopyrite but relatively higher in chalcopyrite, reaching 0.28% (Table 10). Although no zinc mineral was separated for analysis, it is considered that sphalerite forms the main source of zinc as in Macalder (Ogola, 1984). The occurrence of sphalerite in the deposit was revealed by ore microscopic studies. However, the mineral occurs in minor quantities in the deposit. Although higher zinc values appear to be associated with chalcopyrite-rich zones, the two metals are not paragentically associated as revealed by the low coefficient of correlation between Cu and Zn of about 0.14 (Table 11).

(d) Lead

The lead content of the deposits vary from 0.001% to about 0.13% (Table 9). This is the same range for the lead content in the monomineralllic samples (Table 10). Among the sulphide minerals analysed, higher lead values occur in pyrite and lower in chalcopyrite and arsenopyrite. The source mineral for lead was not confirmed because of the failure to identify such minerals under reflected light and by X-ray diffraction (XRD) methods, but it is assumed that the sulphide deposit have traces of galena as is the case in the Macalder massive sulphide deposit (Ogola, 1984).

(e) Arsenic

Arsenic commonly occurs as a constituent of the sulphide deposit. The arsenic values are frequently in the range of 0.001% to 0.1% in the deposits and similar concentrations have been noted in the sulphide minerals (Tables 9 and 10). The maximum arsenic value in the deposits is about 14% and this was noted in arsenopyrite - rich veins. The arsenic content of arsenopyrite was noted to reach a maximum of 19.3% and hence is the main source of arsenic in the deposits (Table (10).

(f) Gold

Gold is of minor importance in the Wire hills sulphide deposit. The element often occurs in values of less than 0.01g/ton and the maximum value obtained by Atomic Absorption Spectrophotometric (AAS) method is 0.07g/ton. Examination of the AAS-analytical results, reveals that gold frequently occurs in zones having high silver and copper values (Table II). From this observation, it can be concluded that the elements; gold, silver and copper are highly associated.

(g) Tin

Tin is a common constituent of the deposit. It frequently occurs in amounts varying from 0.001% to 0.01% both in the monomineralic and sulphide deposits samples (Table 9 and 10). The concentration of tin, however does not follow any observed trend in respect to the other elements.

5.2 Estimation of the Sulphide Deposit Reserves

The evaluation of the deposit is based on five drill holes sunk in the northern flank of the Wire hills. The zone assumed to have uniform mineralization covers an area of about 250m by 470m.(Figure 15).

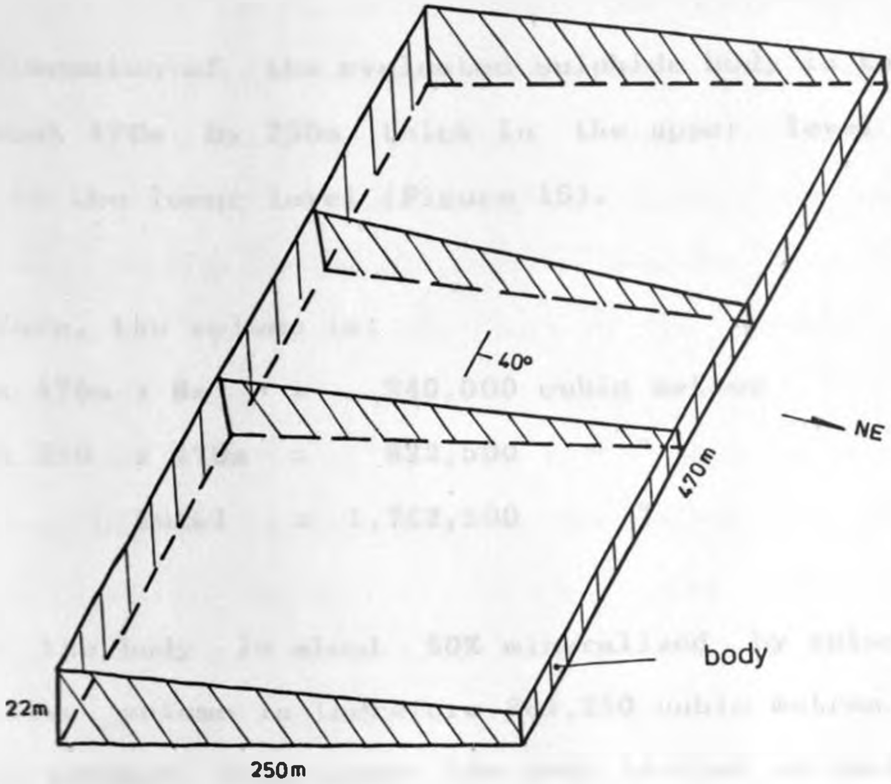


Fig. 15 SKETCH DIAGRAM SHOWING THE DIMENSIONS OF THE EVALUATED BODY

In evaluating the size of the deposit, the sulphide bodies are assumed to occur in a wedge shaped structure (Figure 14). However, the upper body (Figures 13 and 14) is not considered in the evalution because of it's non-uniform nature and to the fact that it is intersected by only three drillholes which lie in a linear pattern.

The dimension of the evaluated sulphide body is taken to be about 470m by 250m thick in the upper level and 8m thick in the lower level (Figure 15).

Therefore, the volume is:

250m x 470m x 8m = 940,000 cubic metres

14/2 x 250 x 470m = 822,500 "

Total = 1,762,500 "

Since the body is about 50% mineralized by volume, the effective volume is therefore 881,250 cubic metres. Also it is assumed that since the body is rich in pyrite and pyrrhotite and the densities of the minerals are 5.02 and 4.65 - 4.58 g/c.c respectively, the density of the sulphide deposit is taken to be the average between these densities i.e.

sulphide density = (5.02 + 4.65 + 4.58)/3 g/c.

= 4.75g/c or 4750 kg/ cubic metre

Therefore, mass of the sulphide deposit

= (881,250 x 4750) /1000

CHAPTER 6

DISCUSSION AND CONCLUSIONS

6.1 Discussion

It is now established that the Wire hills massive sulphide deposit occurs within the Nyanzian rhyolitic rocks which form the domical complex of the Wire hills. The host rocks to the sulphide deposit are sheared into steeply dipping units which conform to the general structural trend of the rocks of the Nyanzian Group as a whole.

According to Sanders (1970), the geological evolution of the Nyanzian Group, within which the Wire hills area forms a part, began with the growth of volcanic island arcs that had gently sloping volcanoes rising above the sea level. From the evidence of the present study, the Sanders' (1970) hypothesis appear agreeable in that the Wire hills volcanism is of a calc-alkaline nature. This is suggested from the finding that within the study area, there is a compositional variation in the volcanic rocks. The rock sequence grades from calcic at the bottom to alkaline at the top. Andesites occur in the lower stratigraphic zones followed by dacites and finally, rhyolites occur at the top, often associated with its pyroclastic equivalents. Despite their great age of the Japanese island arcs, particularly at Kuroko (Sato, 1977). In the project area, the andesites were previously mapped as Nyanzian basalts while the dacites were lumped together with the rhyolites as being the grey variety, Saggerson (1952). Therefore in adopting the present classification, a thorough field mapping was carried out coupled with both petrographic studies and whole rock chemical analysis.

The stratigraphic sequence described above points to the Wire hills as having been the possible centre of the volcanic eruption. This postulation is further supported by the fact that tuffs and agglomerates occur on the top of the hills. The presence of agglomerates indicate a close proximity to a volcanic vent since the agglomeratic fragments are embedded in a lava of similar composition to the fragments. This indicates that the fragments settled on a molten lava of rhyolitic composition. According to Saggerson (1952), the rhyolitic outcrop on the Wire hills forms the greatest rhyolite accumulation when the entire greenstone belt in western Kenya is considered. Gross (1973), further postulated that rhyolitic and dacitic rocks are thickest and abundant in the succession of volcano-sedimentary formations in and around the ancient volcanic centres. These facts put together strongly point to Wire hills as being an Archean fossil volcanic centre.

The type of volcanism that occurred during the eruption of the Wire hills is suggested to have been of an explosive nature. This is deduced from the observation that pumice fragments form an essential component of the lapilli sized fragments in the tuffs. The eruption was therefore sub-aerial since the pumice fragments can only form when air or volatiles are trapped in the lava but this could not be possible in a submarine environment since the large hydrostic pressure involved would inhibit the escape of the volatiles (Spence and de Rosen-Spence 1975). However, part of the eruption must have occurred under water or the lava flowed in water because auto-brecciated rhyolites have been observed within the rocks of the Wire hills. The auto-brecciation of rhyolite occurs only when rhyolitic lava flows in water (Spence and de Rosen-Spence, 1975).

The morphology of the Wire hills as describing a semi-circular linear pattern is attributed to structural control. The main structural control is suggested to have been a fracture zone which existed during the Archean. This weak zone must have been striking in the same trend as that shown by the present hills. The existence of such structural weak zones and their influence on volcanism has been postulated for other Archean volcanic centres in different regions of the world (Goodwin and Ridler, 1970).

The volcanism of the Wire hills was accompanied by periods of volcanic eruptions and periods of sedimentary deposition. Sedimentary units form a notable portion of the rocks of the Wire hills area. These sedimentary rocks are represented by the banded ironstone and cherts which occur in isolated patches within the Wire hills. The presence of these rocks as described above indicates that the Wire hills area was once in a marine environment. The banded ironstone and chert outcrops that now appear in isolated patches are relicts defining the existence of an ancient sea floor. It can therefore be concluded that these banded ironstone outcrops were once one uniform body which was affected by various processes,namely, tectonic, weathering and erosion. This conclusion is reached from the fact that these isolated outcrops occur at almost the same altitude. However, the pure white chert that occurs capping the Wire hills main peak possibly represents a later period of deposition of silica from an iron poor colloidal solution. The chert was deposited on later rhyolitic lava that had covered the earlier deposited sedimentary ironstone and hence is relatively younger in age.

The occurrence of these during the different periods of volcanism indicates that subsidence resulted from an eugeosynclinal volcanism which occurred in a large scale. The formation of the banded ironstone units in the basins involved rhythmic precipitation of chert and ironstone. The chert was precipitated from colloidal silica while iron rich bands were precipitated from the iron carbonates and hydroxides (Shackleton, 1946; Beukes, 1973; Gross, 1973).

The present geographical and geological position of these banded ironstone and chert units is due to the uplift of the area. The uplift, especially of the Wire hills, was possibly due to a later domal felsic volcanism. This suggestion is reached in the light of the fact that the Wire hills form a rhyolitic dome and such domal volcanism has been proposed for the other Archean domical complexes (Goodwin and Ridler, 1970; Sangster, 1972; Hutchinson, 1973). The uplift therefore promoted the weathering and erosional activites which removed the overlying volcanic rocks but further erosional activity was inhibited by the resistant banded ironstone and chert outcrops which form caps at the summits of the hills.

The mineralization of the Wire hills area was as a result of the submarine volcanism that occurred in this area. The sulphide mineralization is a typical pyritic deposit where there is a dominance of pyrite and pyrrhotite as the iron sulphide minerals. Generally, the pyritic deposits, according to Smirnov (1976), mainly occur in Archean settings and in such areas, the ore is a product of volcanogenesis. The theory of volcanogenesis gives the origin of the sulphide deposits as being governed by the volcanisms associated with the massive sulphide deposits. The mineralization resulted from effusive hydrothermal activity and when the mineralizing solution reached the sea floor, the sulphide minerals were deposited. Subsequent volcanic eruptions may cover the sulphide bodies and hence these bodies frequently occur intra-stratified by the volcanic rocks. The volcanogenic theory has been postulated for many Archean massive sulphide deposits by several authors who include Sangster, (1972); Hutchinson, (1973); Smirnov, (1976) and Spence, (1975). However, the arguments for volcanogenesis are opposed by those of Boyle, (1976) who prefers a replacement origin for the massive sulphide deposits.

The Wire hills sulphide deposit is here suggested to be of volcanogenic-hydrothermal origin. Several features which have been observed and are of importance in the discussion of the mode of formation of the deposit include: Simple mineralogical composition, sharp contact between the sulphide bodies and the host rocks, lack of intercommunicative veins between the sulphide bodies and the observed hydrothermal alteration patterns.

The composition of the sulphide deposit at the Wire hills is dominated by pyrite, pyrrhotite and minor amounts of chalcopyrite, arsenopyrite and sphalerite. Silver and gold occur in trace amounts in the deposit. Such a simple mineralogy has been advocated by various geologists such as Smirnov, (1976) and Sillitoe, (1977) to be typical of volcanogenic sulphide deposits whereas in an epigenetic vein deposit or ore of replacement origin, the precious metals often occur in substantial amounts. Although minerals of replacement origin occur, they are of very small extent and mainly involve the replacement of one sulphide mineral by another and not a rock by a sulphide mineral as proposed by Boyle, (1976). The type of replacement present is mainly the interchange of pyrite and pyrrhotite and to some extent chalcopyrite. In a main replacement ore as is proposed by Boyle, (1976), the replacement involves, to a large extent, substitution of the rock by the sulphide minerals.

The type of contacts present between the sulphide bodies and the host rock is of most importance in interpreting the origin of the sulphide deposit. An observed sharp contact is inferred to imply that the minerals were deposited on an already consolidated rock and that after its deposition, a later volcanic eruption must have occurred after the deposit had consolidated and hence the sharp contact with little or no interchange of chemicals with the overlying volcanic rocks. This type of contact as noted in the Wire hills sulphide deposit has also been described in several volcanogenic sulphide deposits (Sangster, 1972; Smirnov, 1976; Bowen, 1977; Platt, 1977).

The Wire hills sulphide bodies are occasionally underlain and/or overlain by cherty layers. The occurrence of these units indicates a sedimentary origin of both the cherts and the sulphide minerals. The presence of cherty layers have been observed in other volcanogenic sulphide deposits and in particular in the Canadian greenstone belt where they are referred to as cherty exhalite (Sangster, 1972, Hutchinson, 1973; Spence and De Rosen-Spence, 1975; Casselman and Mioduszewska, 1982). Petrographic studies of the Wire hills cherty units indicate that the rock units are chert since the microcrystalline nature which indicates colloidal precipitation is observed. The cherts underlying the deposits of pre-mineralization while those overlying the deposits are of post-mineralization age.

The volcanogenic origin of the sulphide deposit at the Wire hills area is further supported by the fact that the sulphide bodies are conformable to the strike and dip of the host rocks. This is interprated to indicate that the mineralization occurred on a rock surface and was covered by later pyroclastics as indicated by the tuff layers. The process followed a cyclic path of alternated volcanism and sulphide deposition as shown by the two sulphide bodies occurring parallel to each other. In a veined epigenetic deposit, the structure may form conformable units as observed above but minor veins would occur forming an inter-communicated network which is lacking in the Wire hills sulphide deposit. Further, the structures in a veined epigenetic deposit frequently show branching patterns which are increasingly complex upward

(Sillitoe, 1977), a fact which is also lacking in the Wire hills deposit.

The alteration patterns as noted in the Wire hills host rocks are diagnostic of a volcanogenic massive sulphide deposit. The alterations are interprated not to be due to the reaction between the host rock and the sulphide body but a product of the mineralization process. The alterations, dominated by chloritization, silicification and sericitization have been described in all volcanogenic sulphide deposits (Sangster, 1972; Hutchinson, 1973; 1982; Spence, 1975; Smirnov, 1976; Franklin et al, 1981). These geoscientists argue that the alteration products are due to hydrothermal solutions that pass through the host rocks and deposit the minerals on the sea floor. However, Boyle, (1976), argues that these secondary minerals form as a product of the replacement process that forms the sulphide minerals. This latter argument by Boyle, (1976) is not favourable in the Wire hills sulphide deposit due to the fact that such a large scale replacement of the host rock was not observed and also the structure of the deposit does not favour a replacement origin. On the possibility that the alterations are due to the reaction between the sulphide minerals and the host rocks, Sillitoe (1977), Meyer and Hemley (1967), argue that a reaction halo would form on either side of the vein with the intensity decreasing outwards from the vein.

In the Wire hills deposit, the main sulphide mineralization observed in the footwall rocks is the stringer type although sparsely disseminated mineralization occasionally occurs especially in the tuffaceous zones. These minor veined mineralization occurred during the ascent of the mineralizing solution through fractures and fissures and hence are epigenetic in origin (Smirmov, 1976). These fractures and fissures were the channelways through which the hydrothermal solution flowed to the surface to deposit sulphide minerals on the sea floor.

The composition of the sulphide deposit at the Wire hills area by containing both pyrite and pyrrhotite is indicative of the conditions at the time of formation of the sulphide minerals. The presence of pyrite in the deposit indicates that there was a high sulphur concentration during the formation of the minerals. However, on the other hand, the abundance of pyrrhotite in the deposits indicates that there were periods of low sulphur concentrations or that the activity of sulphur was low in the solution (Smirnov, 1976). On the formation of pyrrhotite, Smirnov, (1976), further suggests that a high oxidation - reduction potential in an alkaline solution would promote the transition of Fe^{2+} to Fe^{3+}. This transition would favour the formation of pyrrhotite, more than pyrite.

6.2 Conclusions

1. The Wire hills area represents volcanic rocks deposited both aerially and sub-aerially. These volcanic rocks are arranged in a semi circular pattern because they were emitted along such fracture zones.

2. The massive sulphide deposit at the Wire hills are of volcanogenic-hydrothermal origin because of the following features which are characteristic of the volcanogenic hydrothermal deposits:

(a) Existence of sharp contacts between the sulphide bodies and the host rocks.

(b) The sulphide bodies occur inter-stratified with the volcanic rocks.

(c) Extensively hydrothermally altered footwall rocks.

(d) Cherts frequently underlie and or overlie the sulphide bodies.

(e) Epigenetic-vein sulphide mineralization underlie the massive sulphide bodies.

(f) Pyrite and pyrrhotite are the dominant sulphide minerals.

(g) Banding and colloidal features occur in the massive sulphide bodies

3. The sulphide minerals were deposited in an alternated rhythmic volcanic eruption and sedimentation sequence.

4. The known sulphide deposit is estimated to be over 4 million tonnes .

5. A more detailed exploration work is recommended and this should include deeper drilling to about 1000m since volcanogenic sulphide mineralization can occur at such depths.

REFERENCES

Bastin, E.S., 1950, Interpretation of Ore Textures Geological Society America. Memoir 45.

Beukes, N.J., 1973, Precambrian iron formations of Southern Africa. Econ. Geol. v.68 pp. 960-1004.

Binge, F.W. 1962, Geology of the Kericho Area. Report 50 Geological Survey of Kenya. pp. 45

Bowen, R., 1977, Copper: It's geology and Economics. Appl. Sci. Publ. Co, pp, 21-56, 129-149, 152-201.

Boyle, R.W., 1976, Mineralization processes in Archaean greenstone and sedimentary belts. Geol. Surv. Canada. Paper 75-15. pp 1-45.

Bryant, D.G., 1968, Intrusive breccia associated with ore, Warrent (Bisbee) Mining District Arizona. Econ. Geol. vol. 63 pp 1-12.

Cahen, L. and Snelling, N.J., 1966. The Geochronology of Equatorial Africa North Holl. Publ. Co, pp 82-42.

Casselman, M.J. and Mioduszewska, B.M., 1982. The Barthurst Norsemines sulphide deposits, Hacket River, N.W.T. In Prec. Sulp. Deposits, H.S. Robinson Memorial

Vol. Ed. Hutchinson et al. Geol. Ass. Canada. spec. paper 25. pp. 365-402.

Carmichael, I.S., Turner, F.J. and Verhoogen, J., 1974, Igneous Petrology. McGraw-Hill Book Co. p. 250.

Franklin, J.M.; Kasarda, J. and Poulsen, K.H., 1975, Petrology and chemistry of the alteration zone of the Mattabi massive sulfide deposit. Econ. Geol. v. 70 pp. 63-79.

Franklin, J.M. Lydon, J.W. and Sangster,D.F, 1981, Volcanic associated massive sulphide deposit. Econ. Geol. 75th Ann. Vol. pp. 485 - 627.

Garlic, W.G., 1963, Hydrothermal Vs. Syngenetic theories of ore - Deposition. Econ. Geol v-50 pp. 447-456.

Goodwin, A.M., 1973, Archean iron formations and tectonic basins of the Canadian Shield. Econ. Geol. v. 68 pp. 915-933.

Goodwin, A.M. and Ridler, R.H., 1970, The Abitibi orogenic belt, basins and Geosynclines of the Canadian Shield, Ottawa. Baer. A.J. (Ed). Geol. Surv. Can. paper 70-40 pp. 1-24.

Gross, G.A, 1973, The deposition environment of principal types of Precambrian iron formations. In Genesis of Prec. Iron and Manganese deposits. Proc. Kiev. Symp. Symp. UNESCO - 1970. (Earth. Sci. 9) 00. 1521

Hatch. F.H.; Wells A.K. and Wells, M.K., 1972, Petrology of Igneous Rocks. Thomas Murby Co. 551 pp.

Helgeson, H.C., 1964, Complexing and Hydrothemal Ore Deposition. Pergamon press pp 80-108.

Huddleston,A. 1951, The geology of Kisii District. Report No. 18 Geol. surv. Kenya pp 64.

Hutchinson, R.W.,1973.,Volcanogenic sulphide deposits and their metallogenic significance. Econ. Geol. v.68 pp 1223 - 1246.

Hutchinson, R.W., 1982, Syn-depositional hydrothermal processes. In Precambrian sulphide deposits, H.S. Robinson memorial volume, Hutchinson, R.W. et al (editor) Geol. Ass. Canada. Special paper 25 pp 761 - 791.

Kerr, P.F., 1977, Optical Mineralogy McGraw-Hill Book co. pp. 492.

Kinyua, A.M., 1982, Multi-Element Analysis of Solid and Liquid samples by X-Ray Fluorescence (XRFA). M.Sc. Thesis, University of Nairobi, Kenya. pp 109.

Kitson, A. 1934, Geological Reconnaissance in Kavirondo and other Districts of Kenya. Geol. Surv. Kenya.

Knuckey, M.J., Comba, C.D.A and Riverin, G., 1982, Structure, metal zoning and alteration at the Millenbach deposit, Noranda, Quebec. In Prec. Sulphide Deposits, H.S. Robinson Memorial volume. Hutchinson, R.W. et al (Editor). Geol. Ass. Canada. Spec. Paper 25 pp. 255 - 295.

Krauskopf, K.B., 1967, Introduction to Geochemistry. McGraw-Hill Book Co. p. 300

Matsukuma, T and Horikoshi, E, 1970, Kuroko Deposits in Japan, a review: In volcanism and ore Genesis. Edited by Tatsumi, T., University of Tokyo Press. pp. 153-179.

McLaughlin, R.J.W., 1977, Atomic Absorption Spectroscopy. In physical methods in Determ. Mineralogy. Edited by Zussman, J. Acad Press. pp. 371-389.

Meyer, C., 1981, Ore forming processes in geological history. Econ. Geol. 75th Ann. vol. pp 6-41.

Meyer, C. and Hemley, J.J., 1967, Wallrock alteratic In Geochemistry of Hydrothermal Ore Deposits, Barnes H.L. (Ed). Holt, Rinehart and Winston, INC. pp 166-235.

Mineral powder diffraction file search manual (1984), compiled by Joint Committee on Powder Difraction Standards (JCPDS). Published by the Intern. Centre for diffraction data. U.S.A.

Mitcham, T.W., 1974, Origin of breccia pipes. Econ. Geol. v. 69 pp 412-413.

Norrish, K. and Chappell, B.W., 1967: X-ray fluorescence spectrography. In Physical Methods in Determinative Mineralogy. Zussman, J. (Edit.). Acad. Press. pp 161-214.

Ogola, J.S., 1984, Geological structure and mineral composition of massive sulphide ores of Macalder deposit, Kenya.

Oswald, F., 1914, The Miocene Beds of the Victoria Nyanza and geology of the country between the lake and Kisii highlands. Quart. Journ. Geol. Sci vol. 70. pp. 128-198

Platt, J.W., 1977, Volcanogenic mineralization at Avoca Co. Wicklow, Ireland and its regional implications. In Volcanic Processes in Ore Genesis. Geol. Soc. London. pp. 163-174.

Riverin, G. and Hodgson, C.J. 1980, Wallrock alteration, at the Millenbrach Cu-Zn mine, Noranda, Quebec Econ. Geol. v. 75 pp. 424-444.

Roberts, R.G. and Reardon, E.J., 1978, Alteration and ore forming processes at Mattagami, lake mine, Quebec. Can. Journ. Earth. Sci v. 15, pp. 1-21.

Saggerson, E.P., 1952, Geology of Kisumu District, Report. No. 21. Geol. Surv. Kenya pp. 67.

Sanders, L.D., 1964, Copper in Kenya. Memoir No. 4 Geol. Surv. Kenya. pp. 51.

Sangster, D.F., 1972, Precambrian volcanogenic massive sulphide deposits in Canada : a review: Canada Geol. Surv. Paper 72-22, 44pp

Sato, T., 1977, Kuroko Deposits: Their geology, geochemistry and origin. In Volcanic Processes in Ore Genesis Geol. Soc. London. pp. 153-161.

Selected powder diffraction data for minerals, (1984), Data Book. Compiled and Published by the Joint Committee on Powder Diffraction Standards. U.S.A.

Shackleton, R.M., 1946, Geology of the Migori Goldbelt and Adjoining Areas. Report No. 10. Geol. Surv. Kenya. pp.60.

Sillitoe, R.H., 1977, Metallic mineralization affiliated to sub-aerial volcanism: a review. In Volcanic Processes in ore Genesis. Geol. Soc. London. pp. 99-116.

Smirnov, 1976: Geology of Ore Deposits. Mir Publishers, Moscow. 687pp.

Spence, C.D., 1975, Volcanogenic features at Vauze sulphide deposit. Noranda, Quebec. Econ. Geol. V.70. pp. 90-101.

Spence, C.D. and de Rosen Spence, A.F., 1975, The place of sulphide deposit mineralization in the volcanic sequence at Noranda, Quebec. Econ. Geol. V.70. pp. 90-101.

UNRFNRE, 1983. Mineral Exploration in Western Kenya - Exploration for Base Metals and Gold in the Migori Belt and the Oyugis and Pala areas, Final Report Part I pp. 35 -80 (Unpublished).

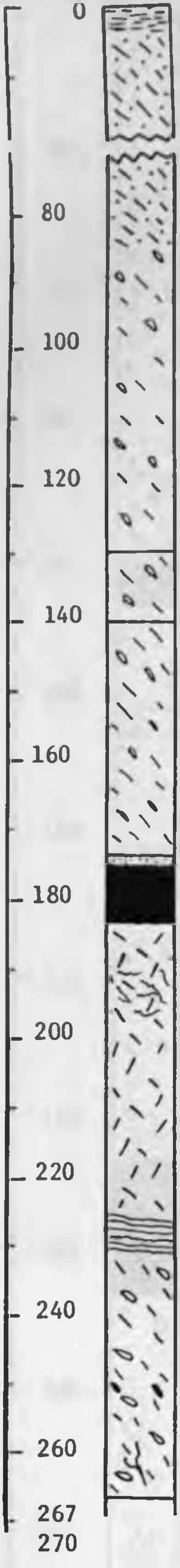
UNRFNRE, 1986, Mineral exploration in Western Kenya prof. KEN/NR/78/001. Semi-Annual Report (Unpublished).

Wayland, E.J., 1931, Report on a geological reconnaissance of South Kavirondo with appendices on the petrology and assaying by Groves, A.W. Geol. Surv., Kenya. pp70.

APPENDICES

LOG OF DDH NO. 86/1   Drilling angle = 61.5, Maximum depth = 267 m

Apparent depth (m)   LOG   Description



Soil

TUFF

Altered white soft

Weakly sheared

End of weathered zone

LAPILLI TUFF

Contains pumice and rhyolitic fragments which are elongated in the direction of strain

Weakly chloritised

Pinkish, pyrite forms along bedding planes

MASSIVE SULPHIDE - Pyrite-pyrrhotite

Brecciated Rhyolite

Breccias partially cemented with Pyrite and pyrrhotite

Pyrite stringers and disseminations

VEINED ORE - Arsenopyrite, pyrite & chalcopyrite

LAPILLI TUFF

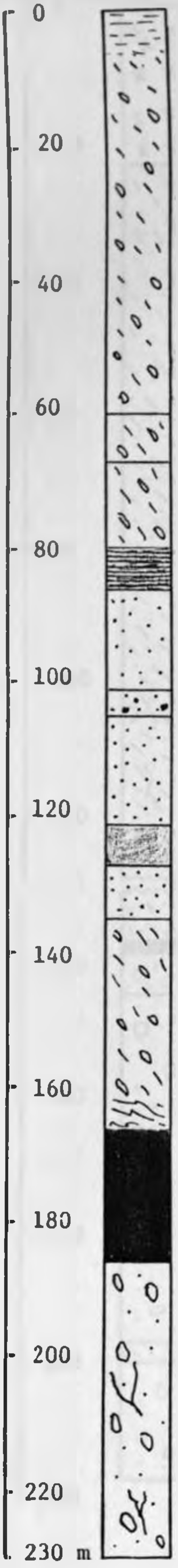
Some of the pumice fragments are replaced by pyrite

Stringers of pyrite, calcite & quartz

END

LOG OF DDH NO. 86/2 Drilling angle = 61°, Maximum depth = 230 m

Apparent depth (m) LOG Description



Soil

LAPILLI TUFF

Pale-pinkish, sheared and weathered

Pink lapilli tuff

End of weathered zone

Banded pyrite-magnetite ore

Cherty tuff

Pyritic cherty tuff

Cherty tuff

Semi-massive pyrite-pyrrhotite-chalcopyrite ore

Cherty tuff

LAPILLI TUFF

White, soft, non-mineralized

Minor folds in lapilli tuff

MASSIVE ORE

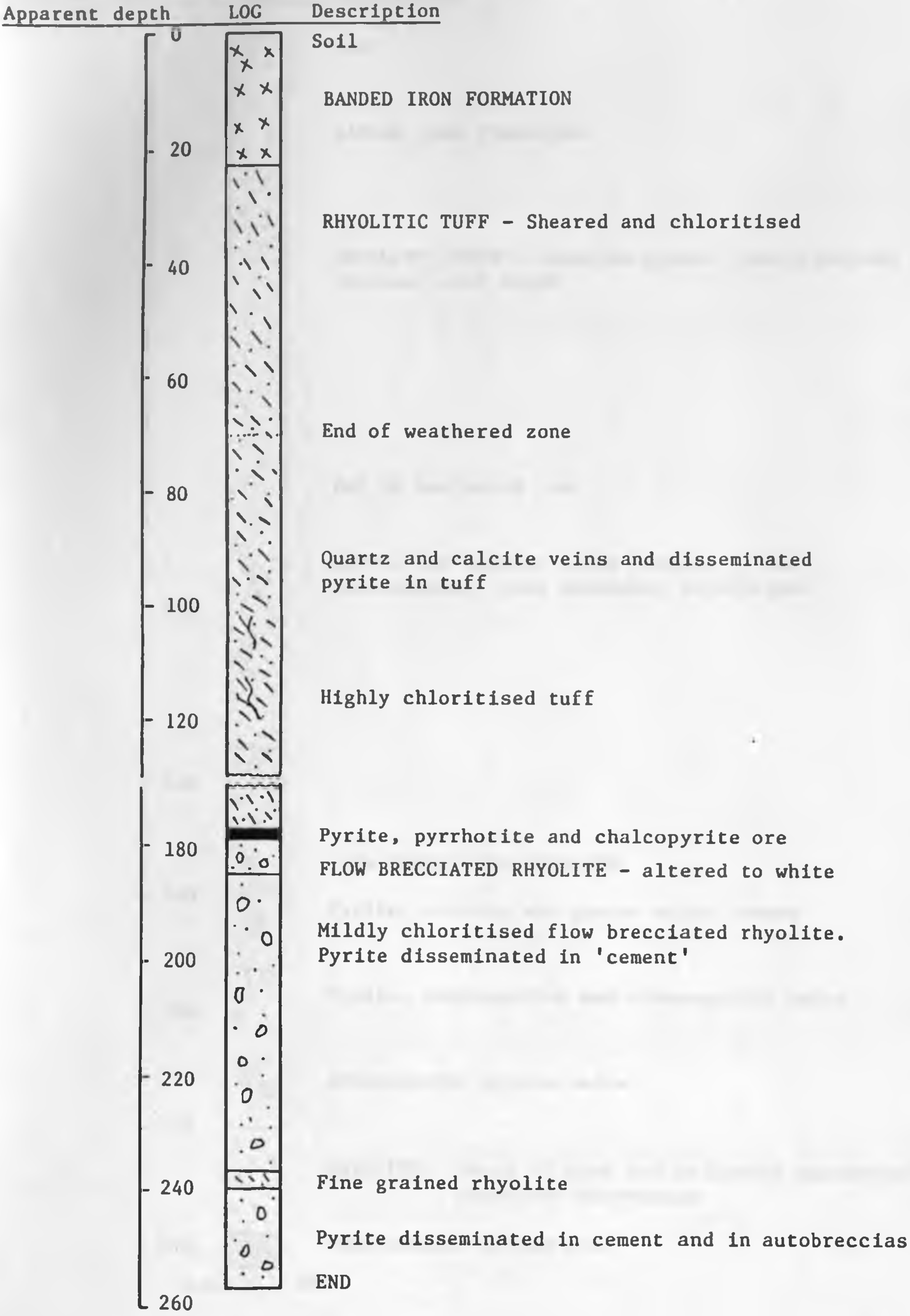
Pyrrhotite dominant, pyrite minor. Contact of orebody and host rocks are sharp

FLOW BRECCIATED RHYOLITE

Massive, non-sheared but weakly chloritised

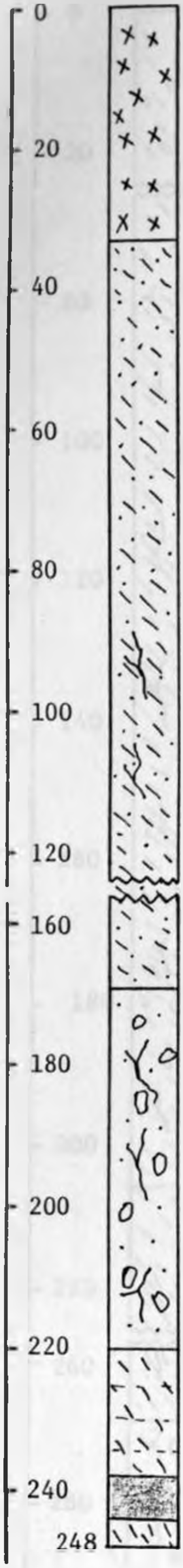
Chalcopyrite, pyrite and quartz stringers

LOG OF DDH NO. 86/3. MAXIMUM DEPTH = 257 m



LOG OF DRILLHOLSE 86/4. MAXIMUM DEPTH = 248 m.

Apparent depth (m) LOG Description



Soil

BANDED IRON FORMATION

RHYOLITIC TUFF - brownish-green, chloritisation increase with depth

End of weathered zone

Quartz and calcite veins common, pyrite disseminated, rock intensely chloritised

FLOW BRECCIATED RHYOLITE

Pyrite, calcite and quartz veins common

Pyrite, chalcopyrite and arsenopyrite veins

Arsenopyrite pyrite veins

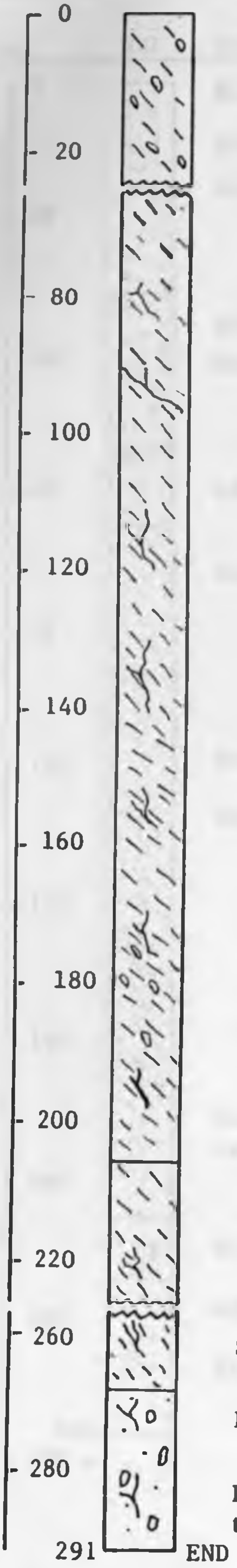
RHYOLITE: Bands of pink and yellowish porphyritic rhyolites alternates

Semi-massive pyrite ore

END

LOG OF DDH NO. 86/5 , MAXIMUM DEPTH = 291 m

Apparent depth (m) LOG Description



Soil

LAPILLI TUFF - weathered to brownish colouration

RHYOLITIC TUFF - highly altered

End of weathered zone

Chalcopyrite, pyrite, pyrrhotite and calcite veins in highly chloritised tuff

Chalcopyrite, pyrite and quartz veins in sheared tuff. The veins are discordant to shear planes.

Chalcopyrite, pyrite, calcite veins

Chalcopyrite, pyrite veins

LAPILLI TUFF

Chalcopyrite vein in massive magnetite

RHYOLITE - greenish-yellow and massive

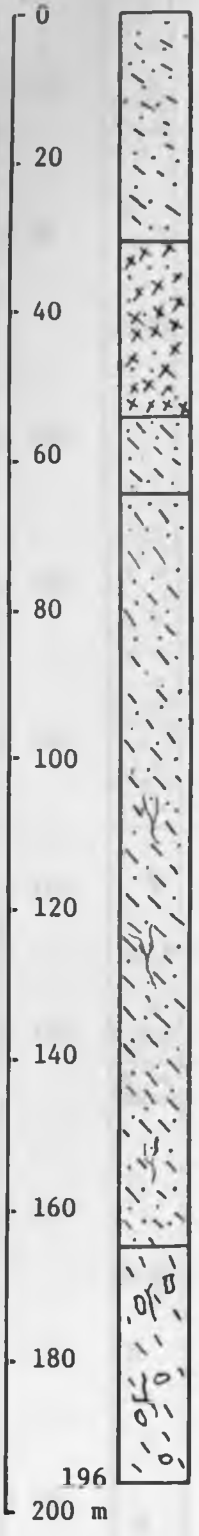
Stringers of chalcopyrite and pyrite in rhyolite

FLOW BRECCIATED RHYOLITE - weakly chloritised

Pyrite, pyrrhotite and chalcopyrite veins in the cement

LOG OF DDH NO. 86/6 Maximum depth = 196 m

Apparent depth (m) LOG Description



Soil

RHYOLITIC TUFF

Weathered to white colour

BANDED IRON FORMATION

Composed of chert and reddish iron oxides

RHYOLITIC TUFF - Pinkish

Downwards, the tuff is mildly chloritised

End of weathered zone

Chalcopyrite, pyrite, arsenopyrite & calcite veins

Quartz, pyrrhotite, arsenopyrite & chalcopyrite veins

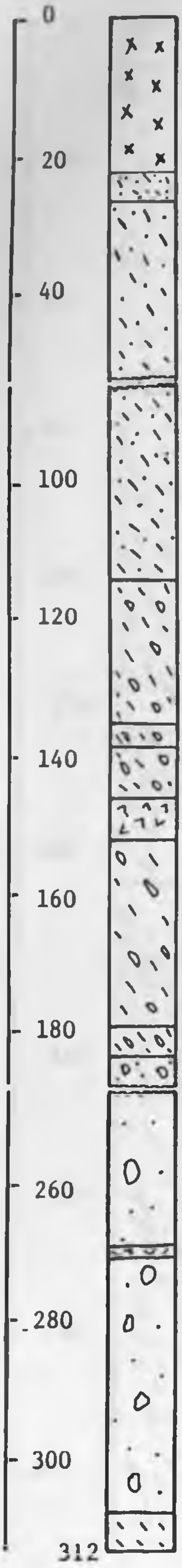
FLOW BRECCIATED RHYOLITE

Mildly chloritised

Stringers of chalcopyrite, pyrite and arsenopyrite

LOG OF DDH NO. 86/7, MAXIMUM DEPTH = 312 m

Apparent depth (m)   LOG   Description



Soil

BANDED IRON FORMATION

White sheared tuff

RHYOLITIC TUFF

End of weathered zone

Pyrite grains disseminated in tuff

LAPILLI TUFF - chloritised

Reddish stained lapilli tuff, pyrite veins present

Reddish-black carbonaceous fractured band

Disseminated pyrite in lapilli tuff

Pinkish-red lapilli tuff

FLOW BRECCIATED RHYOLITE

Calcite veins common

Pinkish-red fractured zone

Autoclasts are yellowish but 'cement' greenish

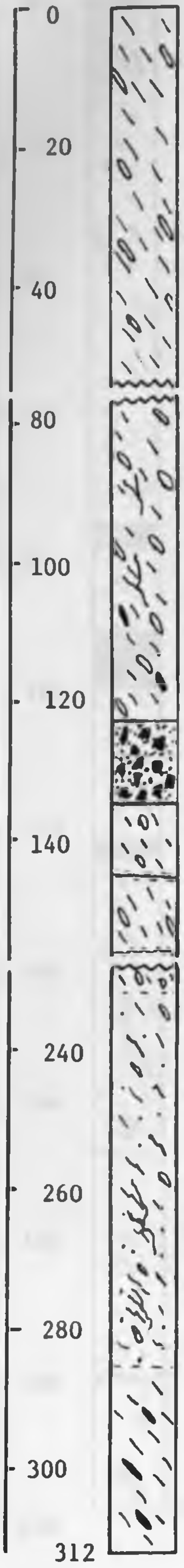
Disseminated pyrite grains present in cement and in autoclasts

Yellow green massive rhyolite

END

LOG OF DDH NO. 86/8, MAXIMUM DEPTH = 312 m

Apparent depth (m) LOG Description



Soil

LAPILLI TUFF - sheared and weathered in brownish-white

End of weathered zone

Greenish, highly sheared and folded lapilli tuff

Chlorite occur as elongate structures with frayed ends

Disseminated pyrite in lapilli tuff

Veined pyrite

Pumice lapilli fragments are replaced by pyrite

Brecciated ore-pyrite forms the breccias and part of the cement

Black carbonaceous bands

Chloritised lapilli tuff

Lapilli tuff

Highly deformed lapilli tuff, weakly chloritised

Discordant calcite veins and disseminated grains common

Chloritised lapilli tuff

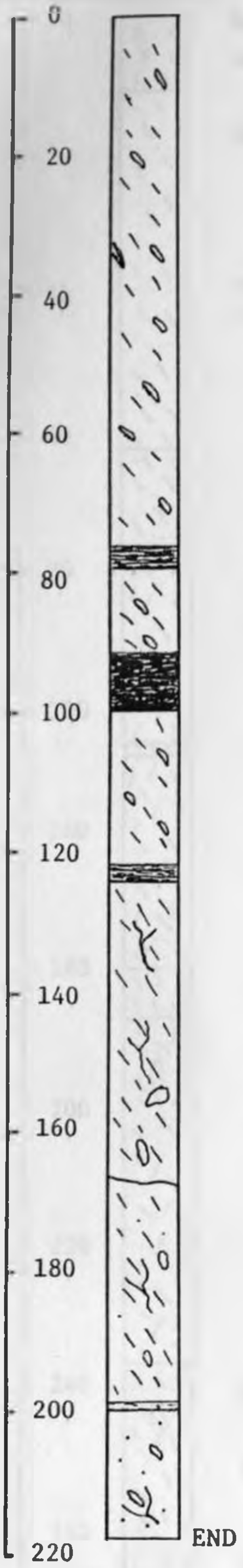
Pumice fragments are replaced by pyrite

Quartz veins common

END

LOG OF DDH NO. 86/9. MAXIMUM DEPTH = 218 m

Apparent depth (m) LOG Description



Soil

LAPILLI TUFF

Pale pinkish white lapilli tuff, mild increase in chloritisation with depth

Layered pyrite in silicified and sheared tuff

Layered pyrite in chloritised & silicified tuff

Pinkish lapilli tuff

Pyrite forms minor veins along foliation planes

Layered pyrite band

Pyrite, pyrrhotite veins

Lapilli tuff, locally agglomeratic

Chalcopyrite, pyrite, pyrrhotite stringers and disseminations

Pyrite, pyrrhotite & arsenopyrite veins

Pyrite and pyrrhotite veins

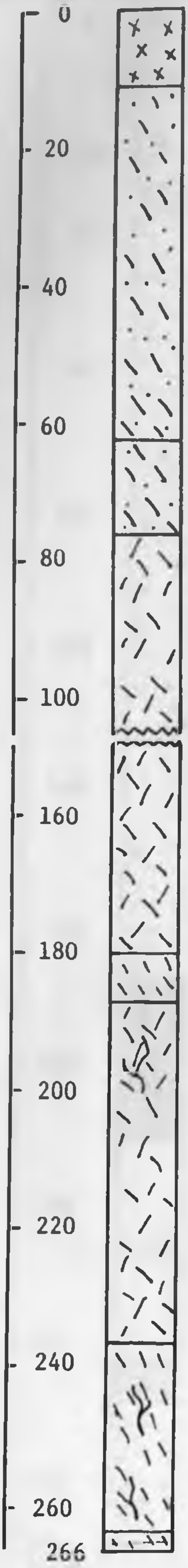
Dolerite sill

FLOW BRECCIATED RHYOLITE

Chalcopyrite, arsenopyrite stringer in rhyolite

LOG OF DDH NO. 86/10 MAXIMUM DEPTH = 266 m

Apparent depth (m) LOG Description



Soil

Gossanous formation, forms boxworks

RHYOLITIC TUFF - altered to whitish-pink

Reddish silicified tuffs, leached in places forming boxworks

Pinkish-brown tuff with greenish streaks

BRECCIATED RHYOLITE

The breccias are fine grained, yellowish and rhyolitic in composition, the cement is fine grained and highly chloritised

Pyrite veins occasionally occur in the cement

Massive fine grained rhyolite-yellowish

Pyrite occur in disseminated grains as veins within highly chloritised cement

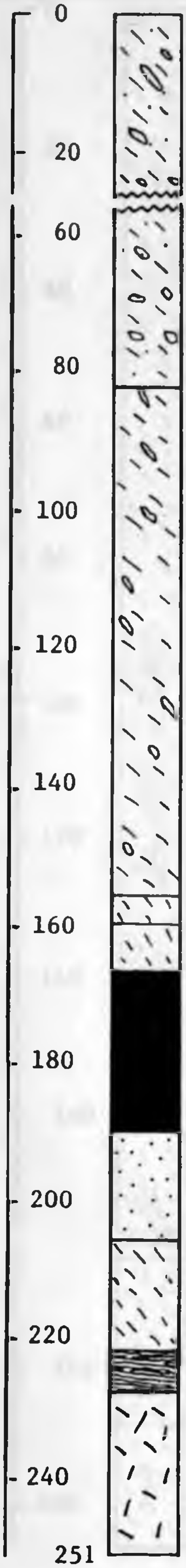
RHYOLITE - massive, fine grained and chloritised

Pyrite and chalcopyrite veins

Bands of yellow and reddish rhyolites

LOG OF DDH NO. RF-21, DRILLING ANGLE = 45°, MAX. DEPTH = 251 m

Apparent depth (m) LOG Description



Soil

LAPILLI TUFF - Weathered to reddish-pink

Mildly chloritised tuffs, greenish streaks occur in brownish-green tuff

End of weathered zone

Sheared lapilli tuff, chlorite bands occur as streaks. Calcite and pyrite veins present

Intensely chloritised lapilli tuff, pyrite and calcite veins present. Disseminated pyrite crystals.

Yellowish fine-grained rhyolite band, non-sheared

garnetiferous, chloritised band, pyrite 'clots' present

MASSIVE SULPHIDE

Pyrrhotite dominant, minor pyrite, chalcopyrite and arsenopyrite

CHERTY TUFF - chloritised

Chalcopyrite, pyrite & pyrrhotite disseminated in the rock

RHYOLITE - weakly chloritised

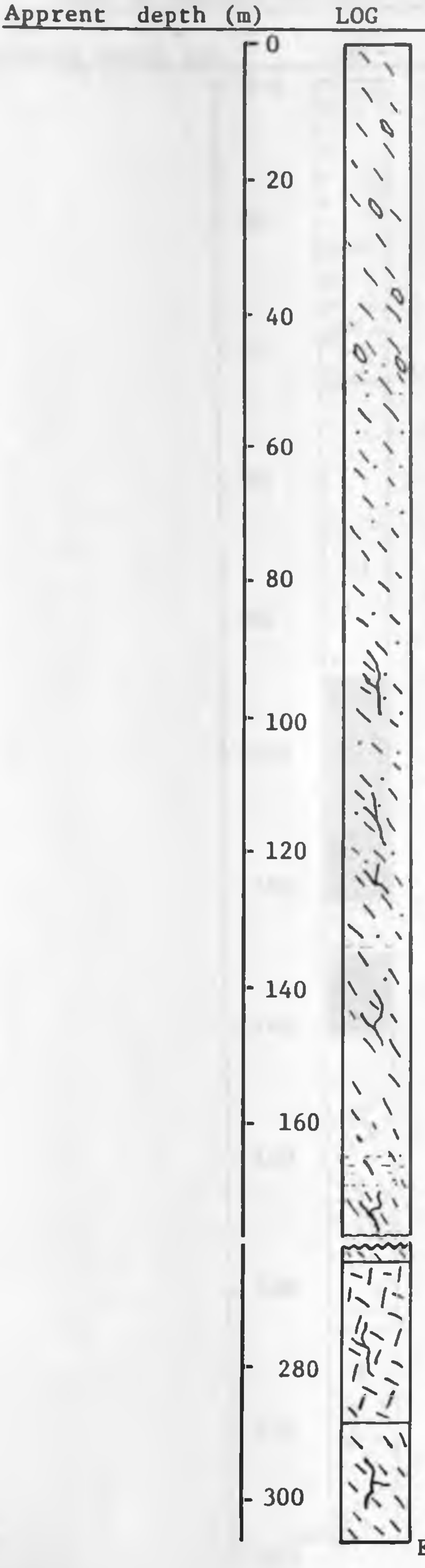
Chalcopyrite, pyrite and pyrrhotite veins

Brecciated rhyolite

Cement is chloritised and has disseminated chalcopyrite, pyrite and pyrrhotite

END

LOG OF DDH NO. RF/22, DRILLING ANGLE = 45°, MAXIMUM DEPTH = 306 m



Description

Soil

LAPILLI TUFF - highly weathered

RHYOLITIC TUFF

Brownish-green highly sheared

End of weathered zone

Highly chloritised rhyolitic tuff

Pyrite, chalcopyrite veins along foliations

Quartz, calcite veins

Pyrite veins and disseminated grains in tuff

RHYOLITE - weakly chloritised

Discordant quartz veins

Magnetite in deep green chloritic rock

Chalcopyrite, pyrrhotite veins

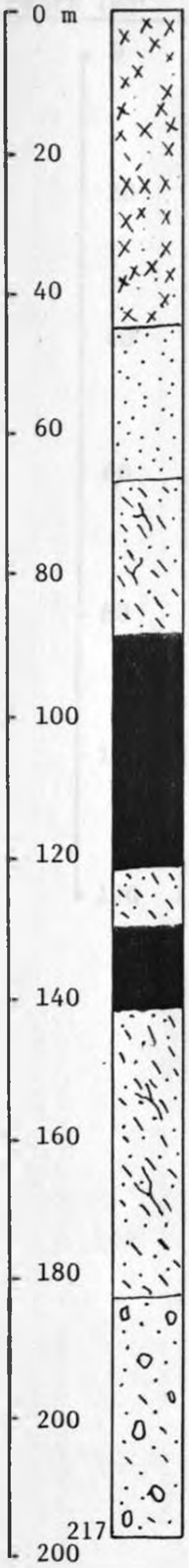
Brecciated RHYOLITE - cement is strongly chloritised

Chalcopyrite and quartz veins common in cement

Chalcopyrite, arsenopyrite veins in massive chloritised rhyolite

LOG OF DDH NO. RF/23 Drilling angle 50°, Max. depth 217 m

Apparent depth (m) LOG Description



BANDED IRON FORMATION

CHERT
Pyritic

RHYOLITIC TUFF
Chalcopyrite, pyrite veins and disseminations in chloritised tuff

Sharp contact

MASSIVE SULPHIDE

Pyrrhotite dominant, pyrite, chalcopyrite present

Chloritised tuff

Pyrrhotite dominant, chalcopyrite minor

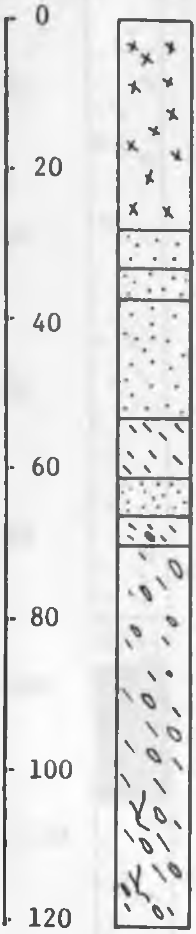
Pyrite stringers in chloritised tuff

FLOW BRECCIATED RHYOLITE

Yellowish-green, compact & hard

LOG OF DDH NO. RF/24 Drilling angle = 80°, Max. depth = 121 m

Apparent depth (m) LOG Description



BANDED IRON FORMATION
Pinkish-Red, locally boxworks

CHERT
Ferruginous

Pyritic

Tuff - chloritised, 20% mineralised with pyrite

Pyritic chert

LAPILLI TUFF - altered to white colour

Chloritisation increase with depth

Pyrite disseminations

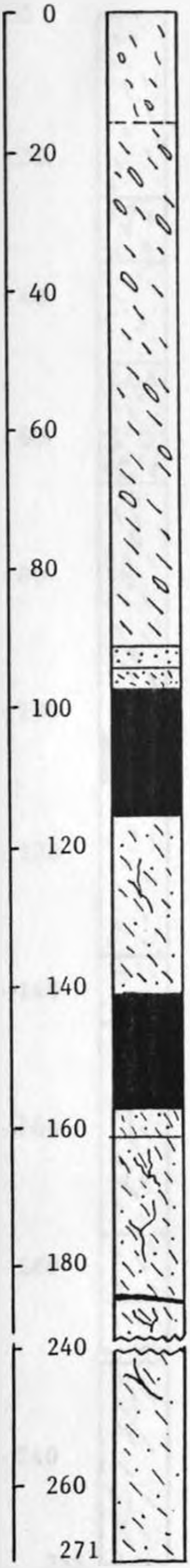
Chalcopyrite, pyrite stringers

Pyrrhotite in intensely chloritised rock

END

LOG OF DDH NO. RF-25. DRILLING ANGLE = 60°, MAX. DEPTH = 271 m

Apparent depth (m) LOG Description



Soil

LAPILLI TUFF - highly weathered to reddish colour

Strongly altered and sheared pink lapilli tuff

Whitish phyllitic lapilli tuff

Pyritic chert

MASSIVE SULPHIDE - pyrrhotite dominant, chalcopyrite and pyrite disseminated

RHYOLITIC TUFF
Chloritised and has yellowish patches
Stringers of pyrite and pyrrhotite present

MASSIVE SULPHIDE - pyrhotite dominant, pyrite disseminated

Creamy-white highly weathered zone

Pyrite, pyrrhotite stringers and disseminated grains in chloritised tuff

Chalcopyrite vein (= 10 cm width)

Arsenopyrite veins and disseminated pyrite in chloritised tuff

END

LOG OF DDH NO. RF/27. DRILLING ANGLE = 55°. MAX. DEPTH = 255 m.

Apparent depth (m) LOG Description

Soil

RHYOLITIC TUFF - Weathered to white soft formation

BANDED IRON FORMATION

Ferruginous tuffs

Leached iron formation

Layered pyrite in sheared tuff

Pyrite cubes (> 2mm) in tuff

LAPILLI TUFF

Sheared and chloritised, intensity of alteration increase with depth

MASSIVE ORE - pyrrhotite dominant, pyrite minor

RHYOLITIC TUFF

Sheared and highly chloritised tuff, pyrite disseminated

Pyrite vein

RHYOLITE

Chalcopyrite & pyrite veins in weakly chloritised rock

Disseminated pyrite cubes present in rhyolite

Yellowish Rhyolite

Yellowish Rhyolite

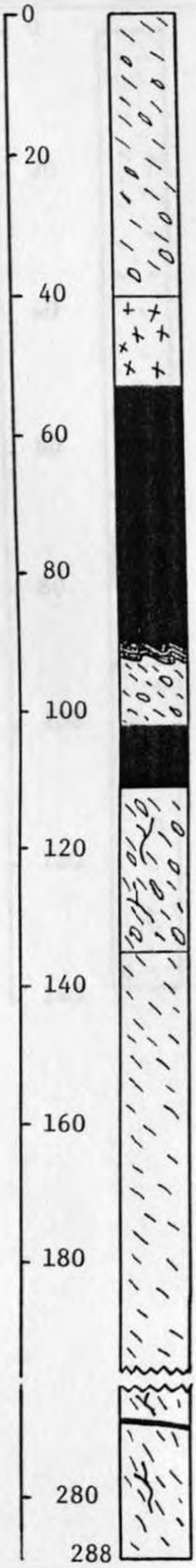
Greenish rhyolite

Chalcopyrite, quartz and calcite stringers in weakly chloritised rhyolite

END

LOG OF DDH NO. RF/33. DRILLING ANGLE = 60°, MAXIMUM DEPTH = 288.7 m

Apparent depth (m) LOG Description



Soil

LAPILLI TUFF - white

Highly sheared tuff

Gossanous formation. Leached forming boxworks

MASSIVE SULPHIDE

Pyrite dominant, pyrrhotite disseminated, stringers of chalcopyrite, banded in places

Banded and folded pyrite ore

Highly chloritised lapilli tuff

Massive ore. Pyrite dominant, pyrrhotite disseminated

Pyrite veins within chloritised and sheared lapilli tuff. Pyrite 'clots' after pumice fragments

RHYOLITE - massive and porphyritic, weakly chloritised

Disseminated pyrrhotite in mildly chloritised rhyolite. Stringers of pyrite and pyrrhotite common

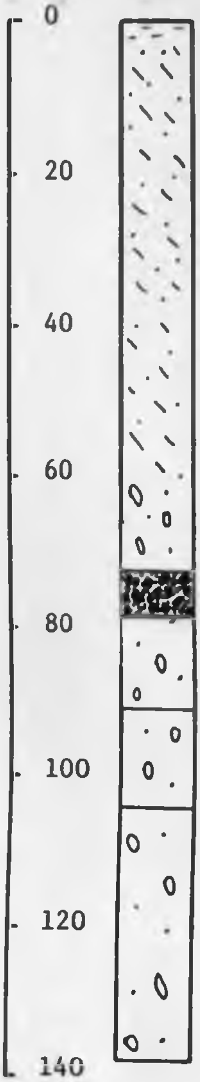
Pyrite vein

Pyrrhotite stringers in greenish-white-rhyolite

END

LOG OF DDH NO. RF/35, DRILLING ANGLE = 55°, MAXIMUM DEPTH = 138 m

Apparent depth (m) LOG Description



Soil

RHYOLITIC TUFF

Brownish-yellow tuff

Chloritised, sheared tuff

Disseminated pyrite

FLOW BRECCIATED RHYOLITE

Yellow and highly silicic

Brecciated pyrite ore

Yellowish highly silicic flow brecciated rhyolite

Pinkish flow brecciated rhyolite

Whitish autobrecciated rhyolite, mildly sheared

Disseminated pyrite in rhyolite

End of drilling