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Full Name of Author — Nom complet de l'auteur

Isaac Oriechi Onuonga

Date of Birth — Date de naissance

December 20, 1955

Country of Birth — Lieu de naissance

Kenya

Permanent Address — Résidence fixe

Mines and Geology Department

P.O. Box 30009

Nairobi, Kenya

Title of Thesis — Titre de la thèse

Geology and Geochemistry of Macalder Mine, Kenya

University — Université

Carleton University

Degree for which thesis was presented — Grade pour lequel cette thèse fut présentée

M.Sc.

Year this degree conferred — Année d'obtention de ce grade

1984

Name of Supervisor — Nom du directeur de thèse

John M. Moore

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THE GEOLOGY AND GEOCHEMISTRY OF
MACALDER MINE - KENYA

by

Isaac Oriechi Onuonga, B.Sc.

A thesis submitted to the Faculty of
Graduate Studies in partial fulfilment
of the requirements for the degree of
Master of Science

Department of Geology
Carleton University
Ottawa, Ontario
November, 1983

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The undersigned hereby recommend to the Faculty of
Graduate Studies acceptance of this thesis, submitted by
Isaac Oriechi Onuonga, B.Sc., in partial fulfilment of
the requirements for the degree of Master of Science.

.....
Thesis Supervisor

.....
Chairman, Department of Geology

ABSTRACT

The mine is located in Archean rocks of the Migori Gold belt. It initially extracted gold from the gossan; later the primary ore yielded copper and gold.

The host rocks are the Nyanzian group of basaltic and dacitic rocks with interlayered metasediments, intruded by the Migori granite and mafic to felsic, subvolcanic intrusions, and metamorphosed to green-schist facies. Petrochemistry shows the mafic rocks to be tholeiitic, whereas the felsic rocks are calc-alkaline.

The primary ore, layered in part, comprises pyrite and pyrrhotite with chalcopyrite, sphalerite, interstitial calcite.

Footwall alteration involves Fe and Mg enrichment and depletion of Na, Ca, and Sr. Cu, Pb, Zn and Au are also enriched. Anomalies are detectable in weathered surface samples.

Pre-metamorphic deposition, conformable layered structure, association with subaqueous volcanic rocks and chert, Cu-Zn-rich composition and footwall alteration indicate the deposit to be of volcanogenic origin.

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Plate 1

(Photomicrographs with crossed polars)

- (a) Porphyritic dacite (unit 5) showing plagioclase phenocrysts in a fine-grained matrix. Epidote lens in upper right.
- (b) Dolerite (unit 7) showing randomly oriented plagioclase with crystal of pyroxene (at centre). Granophyric aggregates of quartz and alkali feldspar are also prominent.
- (c) Matrix of coarse volcanoclastic debris flow (unit 4) showing sericitized plagioclase and heavily embayed quartz in volcanic fragment.
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Plate 2

- (a) Highly fractured pyrite (py) replaced partly by chalcopyrite (cp).
- (c) 'Bird's eye' texture of pyrite developed during the alteration of pyrrhotite (po).
- (b) Chalcopyrite exsolved from sphalerite (sp) as linear trails and outlining grain boundaries.
- (d) Euhedral arsenopyrite (asp) crystals with subhedral pyrite.

CHAPTER 1

1.1 Introduction

Macalder Mine is a massive sulfide deposit that occurs in Archean rocks of the Migori Gold Belt, south-west Kenya. The mine, which opened in 1941, initially extracted gold from the oxidized zone (gossan), but as the primary ore was reached, copper and zinc were extracted together with gold and silver as by-products; the ore was shipped to Kilembe, Uganda for smelting. The Mine closed in 1967 because the smelter became inactive at that time. Remaining ore reserves are not determined. The deposit was originally interpreted as epigenetic, and related to the nearby Migori granite. Only recently (Onuonga and Moore, 1982), has it been recognized that Macalder is a typical volcanogenic massive sulfide deposit.

1.2 Purpose of the study

The main objective of this study is to use geochemistry of fresh and weathered rocks to identify primary element distribution patterns related to mineralization. Recent work (Govett and Nichol, 1979) has shown that recognition of primary alteration patterns might be an aid in:

- (i) Outlining significantly larger targets than the massive sulfides and thus identifying possible extensions of zones of mineralization;
- (ii) Locating favourable stratigraphic horizons in the exploration for unknown sulfide deposits.

- (iii) Defining and evaluating characteristic elemental associations (pathfinders) useful for base-metal exploration.

The purpose of the present investigation is therefore to:

1. Define the lithology and stratigraphy of Macalder Mine;
2. Determine the petrochemical characteristics and trends in the associated metavolcanic rocks;
3. Define the primary alteration patterns related to massive sulfide mineralization;
4. Propose a model for the origin of Macalder Mine.

1.3 Location and Physiography

The Macalder massive sulfide deposit is located in the Migori Gold Belt, south-west Kenya, approximately 20 km from the shore of Lake Victoria. The Belt, which trends roughly northwest - southeast, has a width of 20 km and a length of 100 km (Fig. 1).

To the west the Migori Gold Belt is covered by Lake Victoria (1128 m); to the east by the Tertiary lavas of the Isuria plateau (1859 m). Faulting in the Isuria region and subsequent subsidence of the Lake region tilted the terrain towards the Lake and produced an even slope from the Isuria escarpment to Lake Victoria. Most of the Belt is in flat rolling country; Masara (1300 m) is the main topographical feature in the mine area.

Fig. 1: Location map and regional geology of Western Kenya including Migori Gold Belt (shaded); Sanders (1964).

In the vicinity of the mine, the country is dry; drainage is mainly by the Kuja and Migori Rivers and their tributaries. The small tributaries are only active during the rainy season. The low terrain is covered by thick lateritic soils. Rock exposures are confined mainly to hills and streams.

1.4 Previous Work

The regional geology of the mine area, and the whole of Migori Gold Belt, has been mapped in detail by Shackleton (1946) at 1: 125,000 and 1: 250,000.

Sanders (1964) carried out detailed mapping, producing a map of 1: 15,000 scale of the geology of Macalder Mine and adjacent areas, plus more detailed maps of the surface and underground geology of the mine area.

The mine was also examined and reported on by mine geologists, especially J. A. E. Allum and W. Wierzbicki of Macalder Nyanza Mines Ltd., who carried out detailed core logging and sampling and produced plans and sections of the mine workings.

Geophysical prospecting in the vicinity of Macalder Mine has included surface magnetic, slingram (electrical), and gravity measurements in addition to airborne magnetic and electromagnetic surveys. Surface geophysical surveys were carried out by Brown (1954) and Geophysical Surveys (Pty) Ltd.

in 1950; Hunting Surveys Ltd., London, Lundberg Explorations Ltd., Toronto and McPhar Geophysics Ltd., Ottawa under contract to the Directorate of Overseas Geological Surveys carried out airborne geophysical surveys over the Migori Gold Belt during 1959-1960. These surveys were carried out with the aim of proving the extent of sulfide mineralization in the vicinity of the mine and to search for other concealed sulfide orebodies within the Migori Gold Belt.

Investigations of soil geochemistry were carried out between 1954 and 1962 by Macalder Mine Ltd. and Macalder Nyanza Mines Ltd. A number of copper anomalies identified were interpreted to be related to faults and geological contacts.

United Nations Development Programme (UNDP) carried out a reconnaissance stream sediment survey in the Migori Gold Belt between 1964 and 1965; Mwaniki (1976) compiled and interpreted the data, which indicated some potential for the discovery of further mineralization.

1.5 Methods of Study

Geological mapping was carried out between June and September of 1982. Surface mapping around the deposit was done at a scale 1: 100 whereas traverses on the Kuja and Migori Rivers were plotted at a scale of 1: 10,000.

Samples were collected from all rock types in the area, although emphasis was placed on the Macalder deposit, Migori gold mine and the Kuja and Migori River traverses (Figs. 2 and 4).

Petrographic studies of thin-sections and polished thin-sections were done to supplement the chemical analyses. Petrographic data of representative specimens of the rock units are tabulated in Appendix A.

Samples were chemically analysed by X-ray fluorescence spectroscopy and other techniques for both major and trace elements, by Bondar - Clegg and Co. Ltd. of Ottawa. Density determinations on rock powders were done at the University of Waterloo. The techniques and results of the analyses are detailed in Appendices B and C.

1.6 Regional Geology

The Migori Gold Belt is composed mainly of rocks of the Nyanzian and Kavirondian groups.

The Nyanzian group (system*), the oldest rocks in the Migori Gold Belt, consists of basaltic to dacitic volcanic rocks and a variety of sedimentary rock units. The lower part of the section has been intruded by the Migori granite, and by small mafic to felsic subvolcanic intrusions occur throughout the succession. The group has been metamorphosed

* 'system' is traditional but not correct stratigraphic usage - group is used throughout the text.

to greenschist facies, becoming higher grade near granitic contacts, where rocks show evidence of shearing. Relict textures and structures are commonly preserved and permit inference of the original character of much of the rock. The Nyanzian group is overlain unconformably by the Kavirondian group, which is composed mainly of conglomerates with subordinate grits and mudstones.

A C K N O W L E D G E M E N T S

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I dedicate this thesis to Elijah Onyangi.

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Images en couleur

A

B

102 mm

CHAPTER 2

GEOLOGY OF THE MACALDER MINE AREA

2.1 Introduction

The distribution of lithological map-units in the Macalder Mine area is shown on Fig. 2.

Whole rock chemical analyses have been used to characterize the volcanic suite. The close relationship between the massive sulfide deposits and tholeiitic volcanism indicates the economic importance of description and classification of the volcanic rocks in the study area. The lithology section below includes a description of each map unit including typical textures and mineralogy. Descriptions of map units are followed, where applicable, by a tentative interpretation of the original pre-metamorphic rocks and environment of deposition¹.

2.2 Lithologic Descriptions

2.21 Mafic volcanic rocks (1)²

Mafic volcanic rocks in the study area include non-pillowed and pillowed basalt flows, though the latter

1. All rocks in the study area have been metamorphosed, thus for reasons of brevity the prefix 'meta' will not be used.

2. Numbers refer to map-units in Fig. 2.

predominate and are the most characteristic rock type. This unit is invariably fine-grained; outcrop surfaces vary considerably in colour from gray-green to light brown depending upon the amount of weathering and staining. Pillows can be seen in several places in the main open pit (Fig. 3) and along the Migori River (Fig. 2). The pillows show an irregular weathering profile; their selvages appear slightly harder and at some places were seen to be marked by a concentration of round varioles suggesting radial growth of fibrous feldspar crystals in the glassy lava. Where observed, the stratigraphic tops face to the north. The presence of pillow lavas in the succession is evidence of sub-aqueous deposition.

In the main open-cast mine, the basalts have been extensively altered underneath the ore and weathered to a brownish-green colour. Contacts between basalts and the overlying graywacke are largely obscured but where seen, are irregular due to small fingers of basalt penetrating locally the graywacke margin, especially in the open-cast containing No. 8 orebody. At some horizons, the basalts are highly vesicular, giving the lava a spotted appearance. The vesicles are small, spherical and filled with calcite, quartz or dark-green chlorite, though most of these minerals weather out leaving holes that now have various shapes. Varioles and vesicles have also been observed in the underground workings as reported by Shackleton (1946) and Sanders (1964). The

occurrence of this vesicular basalt appears to be restricted to the mine area. An explanation of this feature may be that the mine lavas were extruded into shallow water whereas the lava units outside the vicinity of the mine were extruded into a deeper submarine environment with the resultant absence of a gas phase (cf. Moore, 1965). It should be noted that the presence of vesicles in the lavas is indicative of boiling, an important factor in massive sulfide deposition.

A number of graywacke layers and ferruginous chert lenses are observed within the basalt unit (Fig. 3). The presence of such sediments suggests that the mafic volcanic succession consists of many separate flows, some separated by sediments which indicate time intervals between successive eruptions. Alternatively, this alternation may be due to a complex system of faults or folds that have produced repetitions of mafic lavas, graywackes and ferruginous chert. It is also noted that both the hanging and footwall basalt are physically and chemically similar (see Chapter 3). Malachite and azurite are fairly abundant within the basalts and are seen traversing the rock in veinlets.

In thin-section, the basalts are seen to be very fine-grained and universally altered. The groundmass is composed chiefly of a fine-grained mass of calcite, sericite and chlorite. Laths of feldspars (0.5 mm) of uncertain composition are seen together with thin veinlets of secondary quartz.

2.22 Ferruginous chert (2)

The massive sulfide deposit at Macalder is intimately associated with a prominent bed of ferruginous chert which can be traced from west to east across the mine area. This unit measures less than 10 m in thickness and is displaced in several places by faults. A number of smaller lenses of laminated ferruginous chert are also intercalated with mafic lavas and the graywackes.

The appearance of this unit in hand specimen varies considerably between the weathered and fresh types. Fresh samples from underground workings are generally greenish, translucent chert with calcite as the main carbonate mineral and varying amounts of ankerite, siderite and chlorite (Shackleton, 1946).

Weathered samples, especially in the vicinity of the mine are distinctly layered; consisting of pale green and white translucent chert alternating with hydrated iron oxides. Individual layers are seldom more than 4 mm in thickness. No primary sulfides are present in the weathered ferruginous chert; if once present they have either been leached or altered to iron oxides.

Thin-sections show the chert to consist chiefly of microcrystalline silica with some veinlets of a more coarsely crystalline variety. A number of rhombohedral cavities are interpreted to have been occupied by siderite (?). Hematite dusting is also noted.

Chemical analysis of the cherts indicates that they are depleted in all major elements except silica and iron, which range between 73-78 wt. % SiO_2 and 18-20 wt. % Fe_2O_3^* ¹ (Appendix B). The low amount of iron does not warrant them to be called "Banded Iron Formation" as they have been formerly classified by early workers.

The close association of the cherts with the mafic lavas suggests that they are part of the Nyanzian volcanic-sedimentary succession, deposited in a sub-aqueous environment as suggested by the presence of pillows and the poorly sorted graywackes with which they are closely associated.

It is therefore likely that the ferruginous chert is an 'exhalative' product deposited during an hiatus in local volcanism.

2.23 Graywacke (3a) and interlayered wackes and mudstones (3b)

The graywacke unit, including interlayered wackes and mudstones, is the most widespread rock type in the Migori Gold Belt. These rocks are cleaved, green-grey, fine to medium grained and generally bedded. They contain quartz grains which are commonly visible to the unaided eye, especially on the weathered surface. Other grains, mainly feldspar and fragmental dacitic rocks, are also scattered in a greenish-grey matrix.

(1) Fe_2O_3^* : Total iron as Fe_2O_3 .

Graywacke (3a) and interlayered mudstones (3b) are well exposed in the mine, especially in the NNE section of the main open pit, and above Migori River bridge. Some graywacke lenses are widely intercalated with the basalts in the vicinity of the mine as mentioned above. Along the Migori River, north of the bridge, most of the graywacke outcrops are seen to be well-bedded, displaying alternating sandy and silty beds that measure 5 cm and 2 cm respectively. Most of the sandy and silty beds are graded and show tops facing north.

The unit comprising fine to medium-grained mudstones and interlayered wackes (3b) (previously mapped as shales, slate, and slaty tuffs Shackleton, 1946 and Sanders, 1964), is difficult to distinguish from (3a) and its stratigraphic relationship with the graywacke unit is obscure.

In thin section (a specimen from the open pit) the graywacke is seen to consist of angular to subangular and, very rarely, rounded quartz grains that show undulose extinction due to strain, and some altered feldspars in a dark, fine-grained matrix of chlorite and sericite. A few grains of altered lava(?) or chert also occur. Accessory minerals include muscovite, calcite, and epidote. The brown colour dusted within the section is possibly due to oxidation of chlorite.

Another specimen studied microscopically was sampled north of the mine and consists of an unsorted sand-size mixture of chert or altered lava and feldspar, most of which has been altered to chlorite and sericite. Broken quartz phenocrysts that show undulose extinction are also common. Accessories include Fe-Ti oxides, carbonate, and possibly flakes of muscovite. Chlorite and sericite define a weak metamorphic fabric. Some sections along the Migora River traverse show abundant disseminated pyrite and chalcopyrite mineralization.

These volcanic sediments are interpreted to be epiclastic in origin; the presence of dacitic fragments and broken quartz phenocrysts suggests that they were derived from a source region including dacitic rocks.

2.24 Coarse volcanoclastic rocks (4)

Before proceeding with a description of coarse volcanoclastic rocks in the study area some definitions are presented, because there is lack of uniformity in volcanic rock terminology. Volcanoclastic rocks include all rocks consisting of volcanic fragments that result from any mechanism of fragmentation.

A pyroclastic rock is a clastic rock whose clasts were fragmented by volcanic activity and ejected from a volcanic vent.

Reworked pyroclastic rock indicates that the volcanic rock has been reworked by sedimentary processes but there has been no major mixing with material derived from non-volcanic rocks (Fisher, 1961).

The terminology used to define grain size of pyroclastic fragments is that proposed by Fisher (1961), and is outlined in Table 1. Mixture terms and end-member terms are also those proposed by Fisher (1966, Fig. 5). "Agglomerate" follows the definition of Williams and McBirney, 1979 p. 133: "a poorly sorted or stratified deposit composed chiefly of monolithologic bombs of intermediate or basaltic composition; the matrix consists mainly of scoriaceous fragments". Agglomerates result from rapid accumulation within or close to eruptive vents.

Essential ejecta consist of material derived from the molten magma of the same eruption. Accessory ejecta are fragments of the pre-existing volcanic rocks that were formed by the same volcano during a prior eruption. Accidental ejecta consist of any type of debris that was not formed by the volcano from which it was ejected. The definitions correspond to those of Macdonald (1972).

Epiclastic fragments result from the weathering of volcanic rocks. It should be noted that pyroclastic and epiclastic refer to different processes of fragmentation, but not necessarily to different processes of deposition (Fisher, 1966). Processes of pyroclastic and epiclastic fragmentation

Grade size (mm)	Epiclastic fragments	Pyroclastic fragments	
256	Boulders (and "blocks")	Coarse	Blocks and bombs
	Cobble	Fine	
64			
	Pebble	Lapilli	
2			
	Sand	Coarse	Ash
1/16	Silt		
1/256	Clay	Fine	

Table 1. Terminology used to define grain size of epiclastic and pyroclastic fragments (after Fisher, 1961).

Figure 5. Mixture and end-member terms used for rocks composed of pyroclastic fragments (after Fisher, 1966).

often grade into one another, which causes difficulties in classification of these deposits, especially in ancient terranes.

A major component of many volcanoclastic deposits is the volcanic debris flow or lahar that has been defined by Crandell (1971, p. 3) as "a general designation of deposits that have resulted from rapid mass flowage of rock debris mobilized by water, that have originated on the slopes of volcanoes". Fisher (1960) also classified lahars as epiclastic breccias.

Felsic volcanoclastic rocks occur mainly in two units in the mine area. The lower unit to the south of the mine occupies an extensive area extending between Kuja and Migori Rivers. The upper unit occurs to the north of the mine and also extends between the two rivers. The unit has been given different names by Shackleton (1946) and Sanders (1964) who considered the rocks to be pyroclastic, essentially andesitic with varying amounts of tuff and crystal tuff.

From the present investigation, the writer concludes that most of these volcanoclastic rocks are actually debris flows (lahars) that have been derived from a deposit that had a dacitic rather than andesitic composition.

The unit north of the mine, mapped as granite porphyry by Shackleton (1946) and Sanders (1964), is also interpreted as a debris flow. It has the same characteristics as the

granodiorite. The colour varies from white or greenish-white to pink. The central part of the granite is massive and contains preserved igneous textures, whereas the contacts with the volcanic rocks are moderately to strongly foliated. The feldspar in foliated rocks is normally pinkish, which is interpreted to result from hematite dusting.

The G-2 granite typically consists of quartz, microcline, plagioclase (oligoclase-andesine) and hornblende phenocrysts in a matrix of quartz, microcline and hornblende. Microcline shows less alteration than does plagioclase, which is clouded with sericite. Hornblende blades that measure 3 mm long are commonly epidotized and chloritized with a rim of Fe-Ti oxides. Most of the quartz is recrystallized and frequently shows undulose extinction. Accessories include epidote, titanite, Fe-Ti oxides and chlorite.

The G-3 granites consist of various leucocratic non-foliated bodies that tend to outcrop as enormous smooth tors. It is believed that the G-2 granite occupies the margin of the Migori intrusion and becomes leucocratic (G-3 granite) towards the core of the intrusion.

The age relationship between the granites and the Archean volcanic rocks is not well documented. Dodson et al (1975) reported a Rb-Sr isochron age of the Migori granite (G-2) to be 2740 ± 120 with initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.7013 ± 7 . They interpreted the age to be the date of emplacement of the

is more schistose and foliated than the upper unit, possibly due to the proximity of the Migori granite.

Field and microscope evidence leads to the suggestion that these volcanoclastic rocks are debris flows and are epiclastic in origin, because of their heterolithic character, lack of internal stratification, unsorted matrix, broken phenocrysts of feldspar and quartz and high content of lithic volcanic fragments.

2.25 Porphyritic dacite (5)

The so called 'barren and rocky country' (Sanders, 1964, p. 18) lying to the north of the mine is underlain by an extensive, almost uniform mass of porphyritic dacite. This unit was formerly named dioritic porphyrite by Shackleton (1946), and Huddleston (1951), and porphyritic andesite by Sanders (1964).

The unit is fine to medium-grained, massive, and blue-gray with abundant cloudy white plagioclase and fresh hornblende phenocrysts. Both plagioclase and hornblende crystals are euhedral and average about 3 mm and 2 mm long respectively. A few quartz phenocrysts also occur. Apparent effects of weathering are minimal, though a rusty colour is rarely seen on the weathered surfaces. On the road to Gogo dam, 4 km north-east of the mine, an outcrop with rounded to subrounded clasts measuring 3-4 cm long was noted.

In thin section, the groundmass is seen to be extremely fine-grained and recrystallised. Feldspar laths indicate a primary texture, possibly with some metamorphic modification as evidenced by the occurrence of epidote dusted in all the thin-sections studied (Plate 1).

Phenocrysts of feldspar (oligoclase-andesine) typically occupy about 30-40% of the rock. Most of them are anhedral, cloudy, and largely replaced by secondary minerals, particularly sericite, carbonate, chlorite and epidote. Phenocrysts of green hornblende with a brown core and Fe-Ti oxides at the edges are also common. Some roundish pseudomorphs, now largely chlorite and carbonate, could have been augite or hornblende. Broken quartz phenocrysts, heavily embayed and strained, also occur (Plate 1). Minor accessories include carbonate, chlorite, and epidote. The matrix of the rock is fine grained with some prismatic crystals of feldspar.

The origin of this unit has been an enigma. Shackleton (1946), McCall (1958) and Sanders (1964) described the unit as a shallow intrusion on the basis of its fine-grained groundmass homogeneity, absence of vesicles and its regular jointing. Huddleston (1951) mapped tuff horizons in some sections of the unit and interpreted it to be extrusive.

The fine-grained matrix could indicate rapid cooling of lava or a shallow intrusion; the rock fragments and feldspar fragments that are broken and anhedral could be found in a

crystal ash. However, this is not an airfall deposit, because stratification, well-sorted matrix and graded bedding that are normally characteristic of airfall deposits are not present. Coarse fragments in a fine-grained matrix indicate poor sorting and could suggest a reworked pyroclastic or debris flow. Resorbed or broken quartz and SiO_2 content of 67 wt.% (Table 2C) indicate dacitic rather than andesitic composition.

On the above basis, the writer suggests that the deposit, having both flow and fragmental features is extrusive rather than a shallow and subvolcanic intrusion. It is unlikely that all the above features could arise in an intrusion, but it could be however partly intrusive.

INTRUSIVE ROCKS

2.26 Migori granite (6)

A large granitic intrusion, the Migori batholith forms the structurally lowest unit in the Migori area and extends southwards to the Tanzanian border and beyond. Two rock types, the older G-2 and the younger G-3 have been recognized in the Migori area by Shackleton (1946). Within the study area, only the G-2 occurs, 3-4 km southwest of the Macalder deposit.

The G-2 Migori granite contains a variety of massive, porphyritic, non-foliated rocks ranging from granite to

granodiorite. The colour varies from white or greenish-white to pink. The central part of the granite is massive and contains preserved igneous textures, whereas the contacts with the volcanic rocks are moderately to strongly foliated. The feldspar in foliated rocks is normally pinkish, which is interpreted to result from hematite dusting.

The G-2 granite typically consists of quartz, microcline, plagioclase (oligoclase-andesine) and hornblende phenocrysts in a matrix of quartz, microcline and hornblende. Microcline shows less alteration than does plagioclase, which is clouded with sericite. Hornblende blades that measure 3 mm long are commonly epidotized and chloritized with a rim of Fe-Ti oxides. Most of the quartz is recrystallized and frequently shows undulose extinction. Accessories include epidote, titanite, Fe-Ti oxides and chlorite.

The G-3 granites consist of various leucocratic non-foliated bodies that tend to outcrop as enormous smooth tors. It is believed that the G-2 granite occupies the margin of the Migori intrusion and becomes leucocratic (G-3 granite) towards the core of the intrusion.

The age relationship between the granites and the Archean volcanic rocks is not well documented. Dodson et al (1975) reported a Rb-Sr isochron age of the Migori granite (G-2) to be 2740 ± 120 with initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.7013 ± 7 . They interpreted the age to be the date of emplacement of the

granite. Bell and Dodson (1981) obtained a Rb-Sr isochron age of porphyritic dacite from Migori area to be 2380 ± 250 with an initial ratio of 0.7019 ± 15 . The age of the porphyritic dacite is much younger than expected. Bell and Dodson (1981) interpreted the low age as resulting from the fine-grained nature of the porphyrite, rendering it easily susceptible to open-system behaviour, consequently the ages obtained are younger than the correct value.

2.27 Dolerite (7,8)

The Nyanzian rocks in the mine area have been intruded by sills (unit 7, 'older dolerite' of Shackleton) which are locally transgressive in detail but generally follow the regional strike of the country rocks. They range from fine to coarse-grained. Fine-grained dolerite is dark green and composed essentially of pyroxene and plagioclase. The coarse-grained dolerite is characteristically mottled with blades of augite and is mineralogically the same as the fine-grained variety.

These dolerites are altered. The cores of these bodies preserve igneous textures but they are strongly sheared towards the margins. Disseminated pyrite mineralization is common.

In thin-section, the more altered dolerites are seen to consist of blades, formerly augite, that have been replaced

by chlorite and actinolite, enclosing laths of feldspar (andesine-labradorite) that measure about 1 mm to 2 mm long. One section shows intergrowth of two amphiboles, one variety with a light green pleochroic colour (hornblende) and tremolite (?) that is seen to be colourless. One core of augite surrounded by amphibole (actinolite ?) was observed. Accessories include quartz, epidote, chlorite and carbonate.

A less altered, fine-grained variety of dolerite seen in the north of the mine area occurs in the middle of the coarse mottled type and is not shown separately on the map. In thin-section, it is seen to contain interlocked laths of plagioclase and blades of green to brown augite in an ophitic texture. Granophyric aggregates, composed of quartz and alkali feldspar are prominent; these are also seen in the more altered dolerite (Plate 1).

It is suggested that the fine-grained, less altered dolerite is a later intrusion than the coarse-grained variety; alternatively, the core might have escaped hydration during metamorphism (J. M. Moore, personal communication, 1983).

The younger dolerite (8) that is seen mainly in the south-western part of the study area transgresses the older dolerite, the volcanoclastic rocks and the Migori granite. Microscopically, these dyke rocks are seen to be very altered and have the same mineralogy as the older dolerite. There is no apparent difference between these two dolerites except for the age relationship.

2.28 Quartz porphyry (9)

A number of quartz porphyry dykes and sills or a combination extrusive-intrusive complex are seen in the vicinity of Macalder Mine. They usually follow the strike of the country-rocks, and intrude both mafic lavas and the sediments. They are usually less than 10 m in width, and vary in thickness along strike.

Weathered surfaces have a brown to yellowish-brown cast. Glassy quartz phenocrysts that are sometimes 3-5 mm in diameter are prominent. They occupy 30-40% of the rock. Fresh surfaces are green; pyrite mineralization is common.

In thin-section, the fine-grained matrix enclosing the quartz phenocrysts is seen to be a quartz-feldspar mosaic with chlorite and sericite. The quartz-eye shapes vary from rounded to bipyramidal, in places with heavily embayed margins. Where recognizable in unaltered matrix, feldspars show euhedral shapes, but in most cases the feldspars are extensively altered and are seen to be dusted with sericite and chlorite. With increasing deformation, the feldspars tend to merge texturally with the groundmass.

The close petrological affinities with the volcanic rocks and their occurrence among them indicates that they are part of the same volcanic episode and are probably contemporaneous with the volcanic rocks.

2.3 Structures

The Nyanzian rocks in the Migori Gold Belt mainly strike northwest-southeast and dip steeply (60-80°) to the south towards the granite contact. In the mine area however the country rocks dip consistently to the northeast. Cleavage is subparallel to bedding and parallel to the granite contact and both dip steeply south.

Folds

The close parallelism of bedding and cleavage throughout the area that consistently dip south towards the granite contact implies the existence of major isoclinal folding. The southward-dipping structures are proved by graded bedding to be unreversed.

Direct evidence of folding in the vicinity of the mine was obtained from the drill core where sharp irregular folds in the graywacke are recorded (Sanders, 1964).

Along the Migori River, small scale tight to isoclinal early (F_1) folds were noted as well as later (F_2) folds distinguished by the presence of folded S_1 cleavage surfaces.

Lineation

Lineation for example below Migori River bridge is defined by elongation of fragments which are both flattened and drawn out. At the contact between the country rocks

and the granite, the rocks are sheared and have a strong lineation, defined principally by elongate aggregates of minerals, especially feldspar and quartz. A few measurements taken by the writer indicate that the pitch is towards the west. Shackleton (1946) has shown that lineation everywhere in the Migori Gold Belt pitches towards the west.

Faults

Faulting is extensive in Macalder area (Fig. 2), though very few faults are actually visible at the surface close to the vicinity of the mine. A number of faults can be inferred from the apparent displacement of ferruginous chert or other rock units within the mine area. The post mineralization - Masara fault can be traced to the west of the mine. Major faults strike approximately northwest-southeast within Macalder area.

It is noted that at least most of the structures discussed above are post-Nyanzian but pre-Kavirondian. At the southern part of the margin, the Kavirondian rocks dip to the north. Structures exhibited by the Kavirondian rocks include broad folds, strike faults and minor cleavage that have the same strike (northwest-southeast) as the post-Nyanzian structures Shackleton (1946).

2.4 Metamorphism

The Nyanzian rocks of the Migori Gold Belt exhibit a low grade, greenschist facies regional metamorphism, characterized by widespread occurrence of the assemblage quartz- chlorite- sericite- epidote.

Shearing is common near the faults. North of Migori River bridge where Masara fault crosses the river, and also in most other fault zones, the rocks are schistose and chloritic suggesting that during faulting, the grade of metamorphism also reached greenschist facies.

Plate 1

(Photomicrographs with crossed polars)

- (a) Porphyritic dacite (unit 5) showing plagioclase phenocrysts in a fine-grained matrix. Epidote lens in upper right.
- (b) Dolerite (unit 7) showing randomly oriented plagioclase with crystal of pyroxene (at centre). Granophyric aggregates of quartz and alkali feldspar are also prominent.
- (c) Matrix of coarse volcaniclastic debris flow (unit 4) showing sericitized plagioclase and heavily embayed quartz in volcanic fragment.
- (d) Porphyritic dacite (unit 5) showing phenocrysts of plagioclase and pseudomorphs of pyroxene with embayed quartz in a fine-grained matrix.

COLOURED PICTURES
Images en couleur

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C H A P T E R 3

CHEMISTRY OF THE MACALDER MINE ROCKS3.1 Introduction

Within the study area, classification of rocks is based primarily on chemical analysis, supplemented by field criteria obtained from outcrop, hand-specimen identification and study of thin sections.

The chemical analyses shown in Tables 2a, 2b and 2c are recalculated to totals of 100% on a volatile-free basis with total iron expressed as Fe_2O_3 . Raw data are shown in Appendix B.

3.2 Sampling and analysis

Localities of specimens for chemical analysis and other samples related to this study are shown Figs. 2 and 4. To study the effects of alteration related to mineralization, rocks associated with an orebody must be compared with those at a distance from mineralization. For the present study, surface samples of basalts, sedimentary rock, quartz porphyry and dolerite were taken from 3 traverses across the main open pit and No. 8 orebody. Basalts from Kuja River, distal to mineralization were sampled for comparison with the mine

TABLE 2A MACALDER MINE ALTERED BASALTS

Sample No.	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃ *	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅
025	55.51	0.82	14.45	20.53	0.16	8.17	0.14	0	0.19	0.04
033	56.54	0.85	16.69	18.85	0.32	5.69	0.36	0	0.65	0.06
034	49.90	0.70	13.71	32.06	0.16	5.20	0.76	0	0.48	0.05
035	52.91	0.64	13.57	27.27	0.12	4.30	0.23	0	0.92	0.04
036	56.20	0.86	16.59	20.87	0.21	4.06	0.75	0	0.80	0.05
037	54.85	0.73	12.83	25.55	0.23	5.28	0.14	0.02	0.33	0.04
038	52.92	0.98	15.07	24.20	0.21	6.41	0.08	0	0.03	0.06
039	53.01	1.07	14.79	24.00	0.06	6.82	0.03	0	0.06	0.09
040	56.20	0.98	16.13	21.38	0.01	2.80	0.80	0.28	1.37	0.15
042	57.57	0.99	15.42	18.13	0.14	7.55	0.07	0	0.08	0.07
043	48.38	1.12	13.18	27.28	0.67	9.13	0.09	0	0.09	0.06
044	50.22	0.73	14.06	26.41	0.24	7.62	0.09	0	0.53	0.09
045	52.76	0.89	15.86	21.69	0.06	7.64	0.09	0.02	0.91	0.09
046	49.82	0.83	14.95	25.45	0.12	7.73	0.07	0.03	0.89	0.11
047	58.65	0.89	17.28	14.09	0.22	8.56	0.03	0.02	0.19	0.08
048	56.59	0.99	17.00	17.00	0.22	7.14	0.82	0.02	0.09	0.11
049	53.56	0.95	15.45	17.59	0.23	7.46	4.24	0.26	0.15	0.12
054	60.63	1.04	17.53	12.06	0.13	4.32	0.03	0	1.16	0.09
055	56.86	0.94	15.33	17.20	0.20	6.29	0.09	0.33	2.65	0.11
061	54.85	0.66	13.66	22.98	0.04	7.50	0.09	0	0.15	0.05
062	57.24	0.64	14.70	17.06	0.42	10.03	1.01	0	0.11	0.01
065	60.99	0.57	13.17	12.33	0.05	12.54	0.03	0	0.25	0.04
066	57.64	0.62	11.23	14.68	0.13	15.33	0.09	0	0.27	0.09
067	57.44	0.66	10.92	21.99	0.08	8.13	0.34	0	0.38	0.08
075	58.09	0.89	15.94	15.09	0.28	7.54	0.14	1.33	0.65	0.04
078	60.46	1.15	17.56	14.26	0.21	3.76	0.14	0.11	2.24	0.11
094	55.91	0.85	13.75	21.60	0.09	6.18	0.08	0.01	1.45	0.08
097	45.36	1.24	20.39	22.32	0.18	6.15	3.26	0	0.97	0.12
098	50.34	0.95	16.24	15.37	0.22	7.16	8.43	0.23	0.63	0.11
099	50.93	0.99	16.94	22.43	0.22	7.85	0.34	0	0.17	0.11
100	54.69	0.94	20.15	17.42	0.28	3.56	2.30	0.24	0.36	0.07

KUJA RIVER BASALTS

Sample No.	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃ *	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅
006	50.28	1.22	14.38	14.38	0.22	6.91	9.24	3.19	0.05	0.05
010	52.35	0.92	13.85	12.72	0.26	6.78	8.97	2.89	1.17	0.10

TABLE 2B DACITES

Sample No.	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃ *	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅
011	67.40	0.63	16.06	4.74	0.15	1.74	3.10	2.70	3.39	0.13
014	68.00	0.54	13.74	5.53	0.19	1.74	5.27	3.11	1.64	0.15
016	65.21	0.74	15.67	6.11	0.14	2.44	3.61	4.75	1.15	0.19
018	66.13	0.62	14.84	5.37	0.15	2.73	4.84	3.77	1.38	0.15
019	68.00	0.68	13.99	6.92	0.30	1.35	3.03	2.76	2.70	0.19
020	66.00	0.50	15.23	5.64	0.12	1.11	2.05	4.87	3.95	0.24
022	66.62	0.71	15.04	6.97	0.19	1.69	3.22	3.17	2.34	0.15
023	62.10	0.69	14.25	8.53	0.33	2.49	6.60	2.89	2.09	0.17
105	67.56	0.50	14.33	3.06	0.12	2.12	5.45	3.90	2.60	0.26
109	66.51	0.56	15.18	3.71	0.10	1.71	5.51	3.82	2.55	0.29
112	65.08	0.50	16.08	3.76	0.13	1.38	4.93	4.59	2.44	0.28
113	67.69	0.55	14.45	4.10	0.10	1.57	4.89	4.50	1.83	0.30
115	59.61	0.67	14.88	5.02	0.15	3.52	9.17	4.44	2.13	0.45
116	62.20	0.62	13.57	5.93	0.15	3.81	7.72	3.27	2.33	0.41
117	63.83	0.56	14.18	5.86	0.19	3.11	5.82	3.99	2.16	0.29
118	64.00	0.59	14.79	4.79	0.17	2.73	5.48	4.86	2.09	0.51
119	66.76	0.56	13.54	5.32	0.23	2.20	4.67	3.95	2.40	0.37
120	64.27	0.47	13.70	5.32	0.12	3.32	7.45	3.70	1.49	0.16
121	67.56	0.49	14.47	3.80	0.12	2.00	4.96	4.32	2.10	0.17
122	64.06	0.63	15.54	4.33	0.17	3.21	4.34	6.37	0.69	0.45
123	62.62	0.63	16.01	4.85	0.12	3.31	5.28	4.24	2.49	0.45

RHYOLITES

Sample No.	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃ *	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅
012	69.30	0.61	14.53	5.16	0.17	0.86	4.02	2.22	2.94	0.13
013	70.44	0.58	14.96	3.19	0.14	0.97	2.85	4.74	1.99	0.13
015	69.53	0.58	14.74	6.02	0.15	1.80	1.53	3.87	1.65	0.15
017	68.60	0.72	14.53	5.64	0.21	2.01	1.31	5.40	1.34	0.19
021	68.60	0.58	14.04	6.85	0.19	1.56	2.73	3.11	2.20	0.13
101	73.10	0.50	14.61	3.49	0.13	0.78	1.25	2.59	3.73	0.21
102	69.80	0.50	14.86	4.10	0.14	1.05	3.15	3.21	2.93	0.28
103	72.15	0.54	14.01	4.05	0.22	0.78	1.77	3.19	3.09	0.27
104	68.78	0.49	13.03	3.17	0.20	2.24	6.31	3.63	1.91	0.23
106	68.20	0.46	15.04	2.34	0.14	1.55	5.27	3.99	2.75	0.29
107	75.00	0.33	10.00	4.66	0.09	2.10	4.66	2.14	1.12	0.21
108	72.25	0.54	13.81	2.47	0.13	1.00	3.36	3.63	2.54	0.29
110	72.71	0.53	13.76	2.60	0.09	0.72	3.00	3.79	2.50	0.28
111	69.98	0.53	14.67	2.84	0.09	1.00	3.89	4.35	2.38	0.29
114	68.12	0.54	14.40	4.97	0.14	1.42	4.17	3.61	2.37	0.29

TABLE 2C MACALDER MINE DOLERITES

Sample No.	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃ *	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅
029	42.36	1.40	18.30	17.96	0.20	8.63	9.32	0.07	1.64	0.12
030	50.66	1.24	14.87	13.94	0.28	5.53	10.51	2.57	0.27	0.14
031	48.72	0.96	14.07	13.76	0.25	9.78	10.76	1.35	0.27	0.09
032	49.88	0.98	15.26	13.31	0.31	6.50	11.37	1.71	0.57	0.10
079	50.69	0.97	12.94	12.64	0.25	8.18	12.16	1.83	0.26	0.09
080	50.86	1.26	15.93	13.89	0.19	6.12	8.68	2.58	0.34	0.11
081	49.74	0.76	12.69	12.99	0.18	10.10	12.18	0.99	0.27	0.09
082	54.91	0.72	14.34	11.29	0.26	6.20	8.58	2.34	1.24	0.12
083	48.00	0.96	14.33	13.69	0.24	9.77	11.25	1.22	1.52	0.06
084	50.05	1.03	13.70	12.98	0.27	8.41	11.33	1.94	0.20	0.11
085	49.88	1.03	13.87	13.87	0.25	8.03	10.97	1.80	0.20	0.12

QUARTZ PORPHYRY

Sample No.	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃ *	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅
003	73.31	0.29	13.50	4.50	0.19	0.17	0.45	6.37	1.09	0.12
056	74.49	0.57	15.62	3.96	0.08	0.85	0.22	4.14	2.68	0.09

PORPHYRITIC DACITE (ANDESITE)

Sample No.	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃ *	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅
024	67.03	0.50	14.85	5.16	0.19	1.59	3.67	4.07	2.74	0.21

basalts. Trench and drill core samples of volcanoclastic rocks from the Migori Gold property, and outcrop samples from both Kuja and Migori Rivers were used to demonstrate the effects of weathering on surface rocks.

Rock samples were crushed and pulverized to minus 100 mesh in a jaw crusher and Tema Mill in the Mines and Geology Department, Nairobi. Samples were chemically analysed by emission spectroscopy, X-ray fluorescence, atomic absorption and wet chemical techniques by Bondar-Clegg & Company Ltd. of Ottawa. Density determinations were made on powdered samples at University of Waterloo under the supervision of Dr. E. C. Appleyard. Details of the analytical techniques, precision and accuracy are given in Appendix C.

3.3 Effects of alteration

"Any assumption that Archean total rock, major element analyses reflect primary composition is a gross oversimplification that cannot be made without consideration of their alteration patterns" (Gelinas et al, 1977, p. 276).

Most of the volcanic rocks in the study area have been altered. A combination of processes, especially hydrothermal alteration in a sub-seafloor geothermal system related to the deposition of massive sulfide deposits, sub-seafloor metamorphism and surficial chemical weathering may have modified the primary geochemistry of the volcanic rocks to a

large extent, particularly the contents of alkalic elements and iron. It is not normally easy to isolate the effects of hydrothermal alteration related to an ore deposit from those of later metamorphism and chemical weathering on the host rocks.

To screen chemical data for metasomatism, all the volcanic rocks, including the dolerites and quartz porphyry were plotted on the "igneous spectrum" diagram of Hughes (1972). Hughes proposed the "igneous spectrum" as a means of identifying spilites and keratophyres. The lines in Fig. 6 enclose the field in which unaltered igneous rocks generally lie. If the volcanic rocks plot outside the igneous spectrum their analyses are rejected or treated with caution. The data from Macalder Mine area suggest that basaltic volcanic rocks which are host to Macalder massive sulfide have undergone extensive sodium depletion with slight potassium enrichment and consequently all of them plot outside the Hughes igneous spectrum, in the keratophyre field. Samples from Kuja River (006 and 010 Table 2a), that are distal to mineralization and stratigraphically equivalent to the basalts hosting the Macalder massive sulfide deposit plot inside the igneous spectrum and are considered normal igneous rocks.

All the felsic rocks plot inside the igneous spectrum except samples 011, 012, 017, 101, and 122 (Table 2b). Most of the dolerites plot inside the igneous spectrum except

LEGEND¹

- Macalder Mine basalts²
- Kuja River basalts
- ▲ Dacites
- △ Rhyolites
- ▲ Porphyritic dacite
- Dolerite
- Quartz porphyry

(1) LEGEND TO FIGS. 6, 7, 8, 9, 10, 11, 12, 13, 14,

15, 16, 17 & 18

(2) Where points coincide, larger symbol is used in plots.

Fig. 6: The alkali igneous spectrum of the metavolcanic and related intrusive rocks in Macalder Mine area, as proposed by Hughes (1972).

samples 029, 081 and 083. One quartz porphyry (056) plots inside the spectrum whereas the other (003) plots outside.

Samples that plot outside the igneous spectrum are excluded from subsequent diagrams, except for the altered basalts spatially related to mineralization, which are retained for comparison with the two basalt samples 006 and 010 that are distal to mineralization. Trench samples (Nos. 124-135) are very much more enriched in iron than the core samples, and since they are of the same rock type, they are not plotted in the subsequent diagrams.

Fig. 7a-e is a SiO_2 -variation diagram for volcanic and intrusive rocks. Fe_2O_3 , MgO , and to a lesser extent TiO_2 and also CaO in unaltered rocks indicate a systematic decrease with increasing silica.

Na_2O and CaO are shown to be extremely depleted in the altered basalts. Dolerites, felsic rocks and the Kuja River basalts that are remote from mineralization show normal CaO , and Na_2O contents. There is clearly an increase of K_2O and Na_2O with increasing silica content.

Geochemical comparison of the Macalder basalts with the Kuja River basalts reveals characteristic chemical differences that are mainly attributed to hydrothermal alteration. However, interpretation of data collected from the surface rocks, such as those of the study area, must take into account the possible effects of supergene reactions in the rocks.

Fig. 7a: SiO_2 - variation diagram for major oxides of metavolcanic and related intrusive rocks of Macalder Mine area.

Fig. 7b: SiO₂ - variation diagram for major oxides of metavolcanic and related intrusive rocks of Macalder Mine area.

Fig. 7c: SiO_2 - variation diagram for major oxides of metavolcanic and related intrusive rocks of Macalder Mine area.

Fig. 7d: SiO_2 - variation diagram for major oxides of metavolcanic and related intrusive rocks of Macalder Mine area.

Fig. 7e: SiO_2 - variation diagram for major oxides of metavolcanic and related intrusive rocks of Macalder Mine area.

Chemical weathering in rocks of Macalder Mine area undoubtedly has distorted the primary haloes now recognized to some extent but as discussed later, the reactions have not destroyed the original patterns in mineral concentrations imparted to the rocks during hydrothermal alteration.

Frequency distributions of Na_2O , CaO , MgO , Fe_2O_3 , Sr and CO_2 in Macalder Mine basalts and Kuja River basalts are shown in Fig. 8. A number of studies around massive sulfide deposits as summarized by Franklin et al. (1981) and Govett (1983, p. 340) demonstrate that removal of Na_2O and a possible addition of K_2O is a characteristic feature of volcanic rocks related to mineralization. As Fig. 8 suggests, Macalder Mine basalts are extremely depleted in Na_2O . Values of less than 0.2 wt.% Na_2O characterize this unit whereas the Kuja River basalts have normal Na_2O values of 2.89 and 3.19 wt.%. K_2O data do not show any significant difference between the Macalder Mine basalts and the Kuja River basalts.

Magnesium and iron have also been identified as elements that are typically enriched in the footwall of the massive sulfide deposits (Sangster, 1972, Govett and Nichol, 1979, Riverin and Hodgson, 1980 and Pirie and Nichol, 1981). The Macalder Mine basalts are characteristically enriched in both magnesium and iron relative to the Kuja River basalts. Magnesium enrichment towards the orebody is associated with a marked increase of

Fig. 8: Frequency distributions of Na₂O, CaO, Fe₂O₃*, MgO, Sr and CO₂ in mine and Kuja River basalts.

Fig. 9a-b reveal that Pb, Zn, Co, Ni and Au are very much enriched in the mine basalts relative to the Kuja River basalts. Cu, Ag, and As, not shown in the diagram are also enriched in the mine basalts.

3.4 Chemical Classification

Volcanic rocks are classified as basalt, andesite, dacite, or rhyolite on the basis of SiO_2 values, normalized to a volatile-free basis as follows:

Basalt	47-54% SiO_2
Andesite	54-62% SiO_2
Dacite	62-68% SiO_2
Rhyolite	>68% SiO_2

The above classification is essentially similar to those used by Gelinas et al. (1977) and Condie and Moore (1977).

The altered volcanic rocks that are host to Macalder massive sulfide deposit have a silica range between 45-60% SiO_2 , thus straddling the basalt and andesite field. As no fresh samples are available within the mine area to determine the original nature of these rocks, the author treats all the host Macalder Mine volcanics as altered basalts. Kuja river basalts have silica range between 50-52% silica. Dolerites have silica range between 42 and 54 SiO_2 , whereas the felsic rocks have mainly dacitic composition, though a number of samples, especially the drill core samples, have rhyolitic composition.

Fig. 9a: Frequency distributions of Pb, Zn, and Au in mine and Kuja River basalts.

Fig. 9b: Frequency distributions of Ni and Co in mine and Kuja River basalts.

Titanium (Rose et al., 1979) and titanium and zirconium (Floyd and Winchester, 1978), have been considered relatively immobile during hydrothermal alteration. A plot of TiO_2 vs Zr (Fig. 10) for the Macalder volcanic rocks and their contemporaneous intrusive equivalents indicates a distinct gap between fields of rocks identified as mafic and felsic on the basis of structure and petrography. Mafic volcanic rocks have TiO_2 contents that mainly exceed 0.7 wt.% (cf. Gill, 1976 and Gibson et al., 1983). This distinction between the mafic and felsic rocks appears to hold despite the effects of alteration.

3.5 Alkaline vs sub-alkaline classification

Fig. 11 is a total alkalis vs SiO_2 diagram with the division between alkaline and sub-alkaline field as proposed by Irvine and Baragar (1971). It clearly indicates that Macalder Mine volcanics and their contemporaneous intrusives are sub-alkaline. It is also shown that there is alkali enrichment with increase of silica. Comparison with Hughes' diagram (Fig. 7) indicates that most of the felsic rocks, Kuja River basalts and dolerites have normal alkali contents and are thus unlikely to have become sub-alkaline through the loss of alkalis. It is noted that all the altered Macalder Mine basalts still plot in the sub-alkaline field which leads to the conclusion that regardless of alkali

Fig. 10: TiO₂ vs Zr plot for metavolcanic and related intrusive rocks of Macalder Mine area.

Fig. 11: Alkali - SiO_2 diagram of the metavolcanic and related intrusive rocks of Macalder Mine area. Proposed division between alkaline and subalkaline fields (dashed line) after Irvine and Baragar (1971).

metasomatism, the rocks can readily be identified as being sub-alkaline (cf. Stauffer et al. 1975).

3.6 Tholeiitic vs calc-alkaline classification

Fig. 12 is an AFM diagram (Irvine and Baragar, 1971). It indicates that most felsic rocks (dacites and rhyolites including the quartz porphyry) are calc-alkaline. The spread of points in the tholeiitic field is thought to represent iron enrichment in the samples during alteration as discussed below. The Kuja River basalts and the dolerites are tholeiitic in character. The altered Macalder basalts are seen to be highly enriched in iron and depleted in alkalies and plot mainly on the FM join.

Other confirmation of the essentially tholeiitic nature of the mafic volcanic rocks in the study area is provided in Figs. 13 and 14. These diagrams were proposed by Miyashiro (1974) to distinguish between tholeiitic and calc-alkaline volcanic series from island arcs. Both these diagrams indicate the tholeiitic nature of the Kuja River basalts and the dolerites. The altered basalts also plot in the tholeiitic field, with a significant iron enrichment. Most of the felsic rocks are shown to be clearly calc-alkaline on both diagrams. Felsic rocks that plot in the tholeiitic field are interpreted to be due to enrichment of iron, particularly during chemical weathering.

Fig. 12: AFM diagram of the metavolcanic and related intrusive rocks of Macalder Mine area. The division between tholeiitic and calc-alkaline fields as proposed by Irvine and Baragar (1971).

Fig. 13: SiO_2 - $\text{Fe}_2\text{O}_3^*/\text{MgO}$ diagram of the metavolcanic and related intrusive rocks of Macalder Mine area.

Fig. 14: Fe_2O_3^* - $\text{Fe}_2\text{O}_3^*/\text{MgO}$ diagram of the metavolcanic and related intrusive rocks of Macalder Mine area.

Widespread metasomatism, especially that involving the migration of alkali elements and iron, can alter the classification of individual samples and obscure the distinction between calc-alkaline and tholeiitic nature of the rocks. Fig. 15 is a variation diagram proposed by Jensen (1976) to provide a better discrimination among sub-alkaline Archean igneous rock types. The substitution of Al_2O_3 for alkalis (cf AFM diagram) provides a trend indicator which is less sensitive to metasomatic changes because aluminum is considerably less mobile than the alkali elements. Within the map area, the volcanic rocks show much less scatter on this diagram than the others, and the trends noted above are confirmed. The altered Macalder Mine basalts, the relatively fresh Kuja River basalts, and the dolerite plot as a coherent suite in the high iron tholeiitic field. A few samples of the dolerite plot in the high magnesium tholeiitic field whereas two samples of the altered basalts are highly enriched in magnesium and thus plot in the komatiitic field.

The felsic volcanics are clearly calc-alkaline though there is a slight spread of points, mainly of rhyolites into the tholeiitic field. This variation is attributed to iron enrichment in the samples during chemical weathering as will be shown later in this chapter. The felsic rocks are shown to portray a linear trend in the Jensen diagram, spreading

from dacite to andesite fields. This linear trend is interpreted as a primary magmatic trend though the trend could suggest evidence of alteration of these felsic rocks due to the addition of iron and magnesium (cf Walford and Franklin, 1982).

From the above variation diagrams, the presence of two groups (tholeiitic and calc-alkaline) within the Macalder area is apparent. The two differentiation trends are common in volcanic rocks and can even be observed from the products of a single volcano (Kuno, 1950). It is important to note that Macalder massive sulfide deposit occurs in the tholeiitic suite rather than in the calc-alkaline suite that is commonly suggested to host most of the Archean copper-zinc massive sulfides in the Canadian Shield (Descarreaux, 1973, Sopuk et al. 1980, and Sangster, 1972). However recent studies (MacGeehan and Machlean, 1980, and Gibson et al., 1983), do suggest that these supposedly calc-alkaline rocks have 'pseudo' calc-alkaline trends which have been superimposed on tholeiitic rocks by hydrothermal alteration and thus reflect the geochemical imprint of sub-seafloor geothermal activity.

These variation diagrams also indicate the distinctly bimodal nature of the volcanic rocks in Macalder area despite the effects of alteration. The mafic volcanic rocks are tholeiitic whereas the felsic rocks are essentially calc-

alkaline. Coexistence of two compositional groups, mafic and felsic, may indicate originally separate mafic and felsic melts or could also result from liquid immiscibility.

3.7 Correlation of alteration and mineralization in Macalder

Chemical alteration patterns in volcanic rocks can be useful in identifying potentially favourable horizons for massive sulfide exploration (Sangster, 1972).

Within the mine area, the basalts are altered beneath the ores whereas the overlying wackes are largely unaltered and free from sulfides though the wackes that are in contact with the orebody contain some secondary copper minerals (azurite and malachite), especially at the No. 8 orebody. The dolerites that overlie the wackes do not show any alteration, though pyrite was noted in some samples. Most of the dolerites retain some primary textures.

Intense metamorphism has obliterated the original minerals in both altered and unaltered rocks within the area and therefore the chemistry of alteration is based only on the chemical analyses.

Analytical results for all surface rock samples from one of the traverses across No. 8 orebody are shown in Figs. 16, 17 and 18. The data for the major elements show that in the vicinity of the open pit mine, the footwall basalts are depleted in Na_2O and CaO and greatly enriched

Fig. 16: Frequency distributions of Fe_2O_3 , CaO , MgO and Na_2O in surface rocks across No. 8 orebody (traverse A-A Fig. 4), Macalder sulfide deposit.

Fig. 17: Frequency distributions of Zn, As and Sr in surface rocks across No. 8 orebody (traverse A-A' Fig. 4), Macalder sulfide deposit.

Fig. 18: Frequency distributions of Cu, Ba and Au in surface rocks across No. 8 orebody (traverse A-A' Fig. 4), Macalder sulfide deposit.

in MgO and Fe_2O_3 . The metasedimentary rocks show a trend of Na_2O depletion close to the pit, both on footwall and hanging wall sides (though from 50 m above the hanging wall, normal values of Na_2O are recorded). CaO closely follows the trend of Na_2O in the sediments whereas MgO shows slight depletion. The dolerites do not seem to be modified with respect to any of the major elements. Because these rocks have been exposed to the same weathering processes as the mine basalts, this observation suggests that chemical weathering is not the major factor responsible for the alteration halos observed in the vicinity of the open pit.

To further demonstrate the effects on rock chemistry, trench and drill core volcanoclastic rock samples from the Migori Gold property were compared with regard to the behaviour of major elements during weathering. Results are shown in Figs. 19a-19c. The data suggest that Fe_2O_3 and Al_2O_3 are enriched in the surface rocks; this contrast is attributed to chemical weathering. CaO and P_2O_5 are evidently depleted on the surface and enriched in the drill core. Na_2O shows slight depletion on the trench samples. K_2O , MgO , TiO_2 and MnO do not show any apparent trend between the surface and drill core samples suggesting that these elements do not seem to have been substantially redistributed during weathering processes.

Fig. 19a: Major element distribution between drillcore and trench samples from the horizontal line - Migori Gold property, Macalder area.

Fig. 19b: Major element distribution between drill core and trench samples. - Migori Gold property, Maqalder area.

in volcanism during which submarine hydrothermal activity was able to develop.

The orebodies are lenticular and irregular in places. They generally have sharp contacts with the wallrocks especially the basalt and are cut by subvolcanic quartz porphyry. The irregular nature of the orebodies is interpreted as resulting from later deformation and as reviewed by Vokes (1969), metamorphism and deformation can produce locally discordant, epigenetic relationships that complicate, obscure and ultimately destroy the original primary and syngenetic characteristics.

4.2 Gossan

The sulfide orebodies have been oxidized to a depth of 30 m (Shackleton, 1946) to a mass of iron oxides and hydroxides (gossan) of which the base is marked by a zone of secondary copper enrichment. On the surface, the gossan varies from reddish brown to dark brown. It consists mainly of limonite and goethite, with some hematite. Malachite and azurite occur in trace amounts in the gossan. A typical box-work texture is generally lacking.

Chemical analysis (Appendix B) reveals that the gossan is essentially composed of iron and silica; other major elements occur in trace amounts. The data suggest that in the transformation of the sulfide minerals to iron-rich

It is concluded that the chemical halos identified in the vicinity of the open pit can be attributed mainly to hydrothermal alteration. It is however emphasized that weathering reactions have probably amplified some original differences in the metal concentrations imparted to the rocks during hydrothermal alteration (cf. Fe_2O_3 and CaO in mine basalts, Fig. 9).

Data for the trace elements reveal that Cu, Zn, As, Au (Figs. 17 and 18) and Pb (not shown) are enriched in footwall basalts close to the orebody compared to other rock units. The sediments show enrichment of Cu and Zn. Sr and Ba are depleted in the footwall basalt but show normal values in the dolerites. The data also suggest that Sr is depleted in the sediments. Rubidium (not shown) shows erratic distribution but is generally depleted as the orebody is approached. Extensive trace element geochemical haloes are thus also evident though with secondary modifications, especially close to the orebody. It is noted that, within the present sampling limit, there is no indication that elements have reached background values.

From the above comparison, it is evident that alteration patterns in Macalder volcanic rocks indicate that rocks coincident with mineralization are chemically anomalous with respect to rocks distal to mineralization. Perhaps the most significant chemical variations indicative of alteration are:

depletion of Na_2O , CaO , Sr and CO_2 and addition of MgO and Fe_2O_3 . Cu , Zn , Co and Au alteration halos could also be used to 'fingerprint' the locus of mineralization.

Another important conclusion from the above discussion is that geochemical halos are evident even in an environment of deep weathering, suggesting that weathered bedrock may be useful in rock geochemical exploration especially in areas where fresh rocks are hard to find.

3.8 Model for the alteration patterns in Macalder Mine

The chemical characteristics at Macalder have been compared with data from a literature survey of alteration in modern hydrothermal systems and similar alteration patterns in the Canadian Shield and elsewhere. The alteration patterns are interpreted as the result of rock-water interaction in a sub-seafloor geothermal system, where seawater convects through the volcanic pile producing extensive alteration of the mineral assemblage and leaching out the base metals which are subsequently deposited at the seafloor by submarine fumarolic activity. It must be emphasized that this is only a working hypothesis which should be tested by more detailed work, especially on the underground geology and by closer sampling of host rocks.

Numerous experimental studies have shown that basalt-seawater interaction will result in depletion and enrichment

of various chemical components. Kajiwara (1973) has proposed chemical equilibria involving primary minerals of volcanic rocks and has shown that interaction of fresh volcanic rocks with seawater results in the enrichment of the rock in potassium and its depletion in sodium. Studies by Hajash (1975) have shown that interaction between tholeiitic glass of basaltic composition and seawater at 200°C and 300°C, results in more than 98% of the magnesium in the seawater being removed and concentrated in a Mg-rich smectite clay. It has been shown that in a rock-dominated system the composition of the solution changes towards that of the rock, whereas in a water-dominated system the rock changes composition in favor of the solution. Seyfried and Bischoff (1977) have demonstrated that at a low water/rock ratio (<50), MgO in solution is usually reduced to 3 percent of its original value; at higher water/rock ratios (>50), MgO is retained in solution.

According to White (1970), (quoted by Hodgson and Lydon, 1977, p. 95) "a hydrothermal system is a type of geothermal system in which the fluids circulate, and it will form where certain combinations of favourable structures and rocks occur together in an area of high heat flow". Four features typical of all hydrothermal systems include:

1. Heat source;
2. Aquifer zone to store solutions;
3. Cap-rock, overlying the aquifer;

4. Channelways for recharge and discharge of solution to and from the aquifer.

Any heat source can drive a circulating hot-water system (Hodgson and Lydon, 1977). Evidence for a local heat source in the study area is the presence of numerous dolerite sills. Small sub-volcanic quartz porphyry bodies may have also formed a significant portion of the heat source in Macalder.

Aquifer and caprock have not been positively identified in Macalder Mine massive sulfide deposit, however it is suggested that owing to their permeability, the basalts are likely to have acted as aquifer rocks. Ferruginous chert is interpreted to have acted as a cap-rock¹ though the basalts may have also developed a cap by a 'self-sealing' mechanism such as discussed by Facca and Tonal (1967). However no evidence of silicification was observed by the writer.

With respect to the Cu-Zn mineralization in Macalder, it is suggested that the hydrothermal fluids were capable of leaching Na, Ca and Sr and depositing Mg and Fe, at the seawater-rock interface. Near the discharge area, boiling occurred and fluid was capable of selectively precipitating Cu, Zn, Fe, Pb, Au and Ag to form a massive sulfide deposit. Other trace elements are also thought to have been mobilized, transported and deposited by the same circulating hydrothermal fluids.

(1) That is, it may have acted to preserve the sulfides from later erosion.

A high degree of vesicularity of the Macalder Mine basalt suggests that boiling did occur near the discharge area and is also indirect evidence of the relatively shallow (<500 m) environment required for boiling as suggested by Hodgson and Lydon (1977). The host rocks at Macalder Mine do not have coarse or angular breccias, suggesting that relatively quiet volcanic activity, marked by an absence of phreatic explosions, prevailed through the period when the deposit was formed (cf. Franklin et al. 1975). However, nearby occurrences of volcanoclastic breccias, felsic and mafic sub-volcanic intrusions suggest that the area was a centre of intrusive and extrusive activity.

C H A P T E R 4

MACALDER MASSIVE SULFIDE OREBODIES4.1 Field relations

The Macalder Mine massive sulfide deposit has been discussed by Shackleton (1946) and Sanders (1964). Because the writer did not have the opportunity to investigate the underground geology, this discussion is obtained mainly from their published reports supplemented by data obtained from the surface workings.

The sulfide orebodies are contained in a steep north-east dipping succession of volcanic rocks and volcanogenic sediments. Four orebodies have been exploited. Orebody A, the largest has a strike length of 500 m and varies in width between 0.2 m to 2 m. It dips northeast at about 70° , and pitches eastwards (Sanders, 1964). B and C orebodies are subparallel to A and lie in its hanging wall. A fourth orebody, No. 8 is located east of the main workings (Fig. 20).

The orebodies tend to occur at more than one specific horizon within the succession, in basalts or more commonly on basalt-grywasche contacts. It is notable that the ore is typically accompanied by ferruginous chert. This 'exhalative' chert has been interpreted by the writer to indicate a pause

Fig. 20: Macalder Mine plan for No. 3 level Sanders (1964).

in volcanism during which submarine hydrothermal activity was able to develop.

The orebodies are lenticular and irregular in places. They generally have sharp contacts with the wallrocks especially the basalt and are cut by subvolcanic quartz porphyry. The irregular nature of the orebodies is interpreted as resulting from later deformation and, as reviewed by Vokes (1969), metamorphism and deformation can produce locally discordant, epigenetic relationships that complicate, obscure and ultimately destroy the original primary and syngenetic characteristics.

4.2 Gossan

The sulfide orebodies have been oxidized to a depth of 30 m (Shackleton, 1946) to a mass of iron oxides and hydroxides (gossan) of which the base is marked by a zone of secondary copper enrichment. On the surface, the gossan varies from reddish brown to dark brown. It consists mainly of limonite and goethite, with some hematite. Malachite and azurite occur in trace amounts in the gossan. A typical box-work texture is generally lacking.

Chemical analysis (Appendix B) reveals that the gossan is essentially composed of iron and silica; other major elements occur in trace amounts. The data suggest that in the transformation of the sulfide minerals to iron-rich

Chalcopyrite typically occurs as an anhedral matrix to pyrite, magnetite and in fractures in pyrite crystals. It also occurs as numerous rings of discontinuous blebs and linear trails in sphalerite (Plate 2), interpreted to result from exsolution.

Sphalerite occurs as irregular masses with chalcopyrite, pyrite, magnetite and galena. It commonly contains randomly distributed inclusions of chalcopyrite blebs and inclusions of unaltered pyrrhotite.

Magnetite occurs as subhedral grains closely associated with pyrrhotite, sphalerite and chalcopyrite.

Galena occurs as irregular masses and also as inclusions in pyrite. Tetrahedrite is present as inclusions in galena whereas most arsenopyrite occurs as minute euhedral grains. Ilmenite was observed as a major mineral in one of the sections that contained no magnetite.

The euhedral nature of the pyrite and the presence of different types of inclusions of sulfide minerals and gangue suggest that the pyrite crystals are porphyroblasts, formed by metamorphic recrystallization. Fracturing of the porphyroblasts is probably post or late recrystallization whereas chalcopyrite fracture fillings in pyrite are interpreted to be the result of mobilization during or after deformation. It is therefore suggested that metamorphism, deformation and mobilization of the ore took place most probably after deposition.

Samples of sulfide ores collected from the mine dumps are characteristically layered. Dark streaks (2-4 mm) rich in sphalerite alternate with lenses and layers containing pyrite and chalcopyrite. Pyrite, the dominant mineral is seen as megacrysts (1-2 mm) in hand specimen. Calcite cross-cuts all the ore minerals.

4.4 Ore petrography

Six polished sections of ores collected from mine dumps were studied. Data on the minerals present and the relative proportions are shown in Table 3. It is difficult to determine the exact relative proportions due to the disseminated nature of the minerals and alteration of pyrrhotite to pyrite and magnetite.

Pyrite occurs as subhedral to euhedral megacrysts. Most of the pyrite megacrysts have been fractured and partly replaced by chalcopyrite (Plate 2). The fractures in pyrite are typically filled by inclusions of chalcopyrite, sphalerite, pyrrhotite, galena and gangue minerals that are randomly distributed throughout the pyrite grains.

Inclusions of unaltered pyrrhotite occur in sphalerite and pyrite whereas in some sections several small grains of partly altered pyrrhotite are associated with sphalerite, chalcopyrite and fracture fillings in pyrite. Pyrrhotite shows a characteristic "birds eye" texture that is typical of its alteration to pyrite and magnetite (Plate 2).

Chalcopyrite typically occurs as an anhedral matrix to pyrite, magnetite and in fractures in pyrite crystals. It also occurs as numerous rings of discontinuous blebs and linear trails in sphalerite (Plate 2), interpreted to result from exsolution.

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TABLE 3 MODAL DATA - MACALDER ORE SAMPLES (VOL. %)

Mineral	Sample Number					
	MO-1A	MO-1B	MO-1C	MO-1D	MO-1E	MO-1F
Pyrite	60	70	50	70	75	Major
Pyrrhotite	1	-	Trace	-	1	Major
Magnetite	20	5-10	15	-	10	-
Sphalerite	10	2-5	30	5	Trace	-
Chalcopyrite	10	2-5	5	25	15	Trace
Galena	-	1	Trace	Trace	-	-
Tetrahe- drite	-	1	-	-	-	-
Arsenopy- rite	-	Trace	-	Trace	1	-
Ilmenite	-	-	-	-	-	Major

Plate 2

- (a) Highly fractured pyrite (py) replaced partly by chalcopyrite (cp).
- (c) 'Bird's eye' texture of pyrite developed during the alteration of pyrrhotite (po). Ilmenite (ilm) is also observed.
- (b) Chalcopyrite exsolved from sphalerite (sp) as linear trails and outlining grain boundaries.
- (d) Euhedral arsenopyrite (asp) crystals with subhedral pyrite.

4.5 Ore chemistry

A chemical analysis of a composite sample of the sulfide ore from a cross-cut on the third level (Table 4) reveals that the ore is essentially Cu-Zn^{rich} with significant amounts of lead, silver and gold. Tin is also an important element in this deposit (P. Bakker, personal communication, 1982).

Table 4 Chemical analysis of Macalder
Ore (Shackleton, 1946)

Pb	0.89
Cu	3.83
Bi	Trace
As	0.52
Sb	0.03
Fe	32.29
Al ₂ O ₃	3.27
TiO ₂	Trace
Mn	0.18
Zn	5.13
Co	0.26
Ni	Trace
CaO	5.60
MgO	0.97
SiO ₂	9.89
S	25.70
U	Trace
CO ₂	7.23
H ₂ O-	0.49
Te	Nil
Au	3.5 dwt. per ton
Ag	3 oz .2 dwt. per ton

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Al ₂ O ₃	3.27
TiO ₂	Trace
Mn	0.18
Zn	5.13
Co	0.26
Ni	Trace
CaO	5.60
MgO	0.97
SiO ₂	9.89
S	25.70
U	Trace
CO ₂	7.23
H ₂ O-	0.49
Te	Nil
Au	3.5 dwt. per ton
Ag	3 oz .2 dwt. per ton

4.6 Genesis

The Macalder Mine deposit was formerly considered as of epigenetic, replacement origin (Shackleton, 1946; Sanders, 1964). As outlined by Onuonga and Moore (1982), the deposit has similar characteristics to many recognised volcanogenic massive sulfide deposits in the Precambrian of Canada and elsewhere. Recent theories of the formation of volcanogenic massive sulfide deposits as reviewed by Franklin et al. (1982), explain their origin in the light of processes active in hydrothermal systems. Metals contained in the deposit are suggested to have been derived from underlying rocks, whereas the ore solution is considered to be seawater modified and enriched in metals by reaction with rocks.

At Macalder Mine the hydrothermal fluids at the discharge area were capable of selectively precipitating Cu, Zn, Fe, Pb, Au, Ag, and other minor elements to form a massive sulfide deposit.

On the basis of its pre-metamorphic deposition, conformable layered structure, association with subaqueous volcanic rocks and exhalative chert, Cu-Zn-rich composition and footwall alteration zone, Macalder Mine is interpreted to be of volcanogenic origin rather than of replacement origin.

CHAPTER 5

Conclusion

On the basis of petrochemistry, the presence of two volcanic groups, tholeiitic and calc-alkaline, within Macalder area has been identified. These volcanic rocks portray a distinct bimodal distribution despite the effects of hydrothermal alteration related to mineralization, sub-seafloor metamorphism and/or surficial chemical weathering. Mafic volcanic rocks are tholeiitic with iron enrichment whereas the felsic rocks are essentially calc-alkaline.

Alteration patterns in Macalder Mine indicate that the footwall of the deposit is chemically anomalous with respect to rocks distal to mineralization. Alteration is characterized by enrichment of Fe_2O_3 and MgO and depletion of Na_2O and CaO . Cu, Pb, Zn and Au are also enriched whereas Sr is depleted near the orebody.

The primary ore is a fine, granular aggregate, layered in part, of pyrite and pyrrhotite with chalcopyrite, sphalerite, magnetite, arsenopyrite galena and interstitial calcite. Textural evidence from polished sections shows that recrystallization and mobilization during metamorphism have affected these sulfides.

Coexistence of two compositional groups in Macalder indicates originally separate mafic and felsic melts or liquid immiscibility. Alteration patterns are interpreted as the result of hot water-rock interaction in a sub-seafloor geothermal system, where seawater convects through the volcanic pile producing extensive alteration of the mineral assemblage and leaching out of the base metals which are subsequently deposited at the seafloor by submarine fumarolic activity.

This study has also confirmed that geochemical haloes are evident, even in deeply weathered environments suggesting that in lithogeochemical exploration, weathered bedrock is a useful substitute for fresh rock in tropical regions.

On the basis of its pre-metamorphic deposition, conformable layered structure, association with subaqueous volcanic rocks and chert, Cu-Zn-rich composition and footwall alteration zone, Macalder Mine is interpreted to be of volcanogenic origin.

Alteration patterns in volcanic rocks can be used to discriminate between potentially mineralized and barren areas of volcanism. It is therefore recommended that the results obtained from this study be applied to similar Archean rocks of the Migori Gold Belt and elsewhere in Western Kenya to identify volcanic stratigraphy that may contain concealed Cu-Zn mineralization.

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A P P E N D I X A

Table 5

Abbreviations for minerals and rock types
used in Appendix A, Table 6 and Appendix B,
Table 7

<u>Mineral</u>	<u>Abbreviation</u>
Quartz	qtz
Plagioclase	pl
Orthoclase	or
Sericite	se
Chlorite	cl
Carbonate	cb
Epidote	ep
Hornblende	hn
Tremolite	tr
Actinolite	ac
Pyrite	py
Fe-Ti oxides	ft
Titanite	ti
Chert	ch
Pyroxene	px
Hematite	he
Muscovite	mu
<u>Field Rock Type</u>	
Metabasalt	MB
Ferruginous Chert	FC
Graywacke	Gw
Dacite	DA (coarse volcaniclastic)
Interlayered Wackes and Mudstones	WM
Porphyritic Dacite	PD
Dolerite (older)	Do
Dolerite (younger)	DY
Quartz-porphry	QP
Gossan	GO
Granite	GR

General notes

Fe₂O₃* - total iron as Fe₂O₃
 ND - not determined

APPENDIX A, TABLE 6

Mineral Assemblages for Macalder Area Rocks as Determined by Thin-Section Study*

Section	Rock Type	qtz	pl	or	se	cl	cb	ep	hn	tr	ac	py	ft	ti	ch	he	px	mu
X-56	MB	X			X	X	X									X		
X-61	FC	X																
X-55	GW	X	X		X	X	X	X							X			X
X-53a	WM	X	X		X	X	X	X					X		X			X
X-46	DA	X	X		X	X	X						X			X		
X-50	DA	X	X		X	X	X	X					X					
X-51	DA	X	X		X	X	X						X					
X-54	DA	X	X		X	X	X						X					
X-15	DA	X	X		X	X	X						X					
X-53	DA	X	X		X	X	X	X					X					
X-65	DA	X	X		X	X	X						X					
X-63	DA	X	X		X	X	X						X					
X-25	DA	X	X		X	X	X						X					
X-62	DA	X	X		X	X	X	X	X?				X					
X-33b	DA	X	X		X	X	X	X					X					
X-64	PD	X	X		X	X	X	X					X				X	X
X-27a	PD	X	X		X	X	X	X					X				X	X
X-36	GR	X	X	X	X	X	X	X					X					
X-60	DO	X	X		X	X	X	X					X				X	X
X-59	DO	X	X		X	X	X	X				X	X				X	X
X-58	DO	X	X		X	X	X	X					X				X	X
X-33b	DO	X	X		X	X	X	X					X				X	X
X-37a	DO	X	X		X	X	X	X					X				X	X
X-34	DO	X	X		X	X	X	X					X				X	X
X-32	DY	X	X		X	X	X	X					X				X	X
X-57	QP	X	X		X	X	X	X					X					
X-19	QP	X	X		X	X	X	X					X					X?

* Thin-sections outside area in Fig. 2 are not included.

APPENDIX B

CHEMICAL COMPOSITION OF ROCKS
FROM MACALDER MINE AREA

TABLE 7

Sample No.	001	002	003	004	005	006	007
Field Rock Name	WM	MB	QP	WM	WM	MB	MB
<u>Oxide (wt. %)</u>							
SiO ₂	66.70	48.90	72.20	64.60	60.80	43.70	55.80
TiO ₂	0.59	2.35	0.29	0.61	0.53	1.06	1.45
Al ₂ O ₃	14.70	10.80	13.30	15.70	13.70	12.50	16.70
Fe ₂ O ₃ *	8.24	18.50	4.43	5.54	7.92	12.50	14.70
MnO	0.14	0.36	0.19	0.20	0.33	0.19	0.21
MgO	0.75	1.97	0.17	1.20	3.28	6.01	3.50
CaO	0.27	6.39	0.44	1.27	2.76	8.03	0.43
Na ₂ O	1.99	1.48	6.27	5.15	3.16	2.77	3.75
K ₂ O	3.80	0.96	1.08	2.07	2.21	0.04	1.17
P ₂ O ₅	0.17	0.59	0.12	0.25	0.16	0.12	0.10
LOI	2.80	7.90	0.80	1.55	4.70	10.15	3.75
TOTAL	100.15	100.43	99.29	98.14	99.39	97.07	101.56
<u>Trace Elements (ppm)</u>							
Cu	92	20	70	154	42	70	220
Pb	8	4	33	8	5	8	6
Zn	275	96	98	82	63	76	93
Co	15	28	9	9	18	24	40
Ni	69	6	23	50	64	71	95
Mn	830	2690	1590	1700	2950	1550	1550
Ag	<0.1	<0.1	0.5	0.4	0.2	0.1	0.2
Au (ppb)	<5	<5	10	<5	<5	<5	35
As	84	52	792	296	74	43	602
Ba	448	528	432	776	597	106	411
Rb	118	24	36	67	64	3	43
Sb	<1	<1	<1	<1	<1	<1	<1
Sn	3	<1	2	5	1	<1	3
Sr	82	78	433	178	178	149	137
V	101	345	31	103	103	312	460
Zr	150	153	118	101	101	59	81
S (wt. %)	0.021	0.017	0.024	0.095	0.270	0.092	0.034
CO ₂ (wt. %)	0.27	4.08	0.17	0.35	3.65	7.06	0.09
Density	2.82	2.90	2.71	2.76	2.83	2.83	2.86

TABLE 7 CONTD.

Sample No.	008	009	010	011	012	013	014
Field Rock							
Name	WM	WM	MB	WM	DA	DA	DA
Oxide (wt.%)							
SiO ₂	65.00	69.00	46.50	64.60	65.80	69.20	63.90
TiO ₂	0.56	0.49	0.82	0.60	0.58	0.57	0.51
Al ₂ O ₃	14.60	14.70	12.30	15.40	13.80	14.70	12.90
Fe ₂ O ₃ *	6.22	5.59	11.30	4.54	4.90	3.14	5.19
MnO	0.29	0.14	0.23	0.14	0.16	0.14	0.18
MgO	1.16	1.31	6.02	1.67	0.82	0.95	1.63
CaO	3.37	0.45	7.97	2.97	3.82	2.80	4.95
Na ₂ O	4.17	3.55	2.57	2.59	2.11	4.66	2.92
K ₂ O	2.21	2.19	1.04	3.25	2.79	1.95	1.54
P ₂ O ₅	0.13	0.10	0.08	0.12	0.17	0.13	0.14
LOI	3.80	2.35	11.90	4.85	4.85	4.15	5.20
TOTAL	101.51	99.87	100.73	100.73	99.80	102.39	99.06

Trace Elements
(ppm)

Cu	60	42	85	32	29	39	34
Pb	7	7	5	4	5	6	8
Zn	71	75	96	54	79	42	84
Co	15	12	38	12	9	8	29
Ni	60	48	82	31	33	21	49
Mn	2600	1300	1900	1250	1550	1250	1600
Ag	0.1	<0.1	<0.1	<0.1	0.1	0.2	0.1
Au (ppb)	5	10	<5	<5	<5	<5	<5
As	104	124	84	3	6	7	9
Ba	437	623	167	524	549	461	368
Rb	76	90	34	108	93	75	63
Sb	<1	<1	<1	<1	<1	<1	<1
Sn	6	4	3	<1	6	7	<1
Sr	250	164	159	117	130	284	249
V	99	71	284	104	91	109	81
Zr	124	138	51	161	143	166	140
S (wt. %)	0.300	0.026	0.38	0.012	0.014	0.017	0.015
CO ₂ (wt. %)	3.48	0.16	10.30	3.50	2.90	3.05	4.38
Density	2.78	2.74	2.87	2.77	2.76	2.71	2.74

TABLE 7 CONTD.

Sample No.	015	016	017	018	019	020	021
Field Rock Name	DA	DA	DA	DA	DA	DA	DA
<u>Oxide (wt. %)</u>							
SiO ₂	65.10	61.60	66.00	61.50	65.20	65.00	63.50
TiO ₂	0.54	0.70	0.69	0.60	0.65	0.49	0.54
Al ₂ O ₃	13.80	14.80	14.00	13.80	13.40	15.00	13.00
Fe ₂ O ₃ *	5.64	5.77	5.43	4.99	6.63	5.55	6.34
MnO	0.14	0.13	0.20	0.14	0.29	0.41	0.18
MgO	1.68	2.30	1.96	2.54	1.29	1.09	1.44
CaO	1.43	3.41	1.26	4.50	2.90	2.02	2.53
Na ₂ O	3.62	4.49	5.20	3.51	2.64	4.80	2.88
K ₂ O	1.54	1.09	1.29	1.28	2.59	3.89	2.04
P ₂ O ₅	0.14	0.18	0.19	0.14	0.19	0.24	0.12
LOI	3.40	4.10	1.60	6.35	5.00	1.90	4.70
TOTAL	95.60	98.57	97.82	99.35	99.88	100.39	97.27

Trace Elements
(ppm)

Cu	42	36	32	26	28	60	36
Pb	5	10	9	9	7	17	7
Zn	110	90	54	70	66	35	72
Co	22	20	12	15	9	8	17
Ni	49	40	42	41	30	38	45
Mn	1200	1150	1550	1250	2590	3800	1700
Ag	0.2	<0.1	0.1	<0.1	0.1	<0.1	0.2
Au (ppb)	<5	<5	<5	<5	<5	<5	<5
As	17	5	9	3	18	10	14
Ba	368	631	348	440	589	1178	494
Rb	65	40	50	17	80	153	73
Sb	<1	<1	<1	<1	<1	<1	<1
Sn	8	2	1	6	12	27	4
Sr	238	415	277	343	225	734	192
V	111	130	111	105	66	56	110
Zr	159	139	156	127	190	325	135
S (wt. %)	0.190	0.014	0.043	0.026	0.029	0.039	0.017
CO ₂ (wt. %)	2.58	3.61	0.37	5.06	4.20	2.12	3.36
Density	2.73	2.74	2.72	2.73	2.77	2.74	2.76

TABLE 7 CONTD.

Sample No.	022	023	024	025	026	027	028
Field Rock							
Name	DA	DA	PA	MB		GW	GW
<u>Oxide (wt. %)</u>							
SiO ₂	62.00	56.10	65.00	51.10		64.60	70.20
TiO ₂	0.66	0.63	0.48	0.75		0.49	0.51
Al ₂ O ₃	14.00	12.90	14.40	13.30		14.80	15.80
Fe ₂ O ₃ *	6.49	7.72	5.00	18.90		7.63	2.83
MnO	0.18	0.30	0.18	0.15		0.12	0.07
MgO	1.57	2.24	1.54	7.52		1.87	0.87
CaO	3.00	5.98	3.56	0.13		1.87	0.47
Na ₂ O	2.95	2.62	3.95	<0.01		0.10	2.83
K ₂ O	2.08	1.89	2.66	0.17		3.01	1.99
P ₂ O ₅	0.14	0.15	0.20	0.04		0.06	0.05
LOI	4.45	8.50	1.20	9.80		5.40	3.35
TOTAL	97.52	99.04	98.14	101.86		99.95	98.97

Trace Elements
(ppm)

Cu	29	40	28	4700		2250.	295
Pb	11	12	11	20		20	9
Zn	80	69	70	1550		950	240
Co	20	13	9	111		44	13
Ni	58	37	23	184		57	21
Mn	1700	2600	1450	1100		950	580
Ag	0.2	<0.1	0.1	0.1		0.1	<0.1
Au (ppb)	<5	<5	<5	95		45	10
As	3	9	5	416		116	22
Ba	576	391	1051	28		495	384
Rb	72	60	77	22		105	85
Sb	<1	<1	<1	3		<1	<1
Sn	2	5	2	1		13	4
Sr	215	250	841	7		17	200
V	149	126	64	338		97	65
Zr	145	119	130	47		136	186
S (wt. %)	0.025	0.015	0.026	0.020		0.027	0.048
CO ₂ (wt. %)	2.34	8.10	1.46	0.04		0.28	0.11
Density	2.83	2.76	2.73	2.80		2.77	2.69

TABLE 7 CONTD.

Sample No.	029	030	031	032	033	034	035
Field Rock Name	DO	DO	DO	DO	MB	MB	MB
Oxide (wt. %)							
SiO ₂	36.80	48.70	47.10	48.70	49.80	41.40	48.34
TiO ₂	1.22	1.19	0.93	0.96	0.75	0.61	0.58
Al ₂ O ₃	15.90	14.30	13.60	14.90	14.70	12.10	12.40
Fe ₂ O ₃ *	15.60	13.40	13.30	13.00	16.60	28.30	24.91
MnO	0.17	0.27	0.24	0.30	0.28	0.14	0.11
MgO	7.50	5.32	9.45	6.35	5.01	4.59	3.93
CaO	8.10	10.10	10.40	11.10	0.32	0.67	0.21
Na ₂ O	0.06	2.47	1.30	1.67	<0.01	<0.01	<0.01
K ₂ O	1.42	0.26	0.26	0.56	0.57	0.42	0.84
P ₂ O ₅	0.10	0.13	0.09	0.10	0.05	0.04	0.04
LOI	11.40	1.40	2.20	1.90	10.25	10.90	9.00
TOTAL	98.27	97.54	98.87	99.84	98.33	99.17	100.36

Trace Elements
(ppm)

Cu	136	200	205	113	1400	6300	980
Pb	7	4	4	5	9	41	17
Zn	70	89	62	76	4000	2750	6000
Co	37	30	29	33	353	146	146
Ni	129	37	56	136	187	185	201
Mn	1350	1275	1725	925	2400	1275	1050
Ag	<0.1	<0.1	<0.1	0.5	1.4	1.5	0.1
Au (ppb)	5	<5	5	5	75	90	100
As	126	16	23	5	209	649	208
Ba	150	195	268	206	131	165	150
Rb	45	11	16	10	22	12	41
Sb	<1	<1	<1	<1	<1	5	<1
Sn	3	<1	<1	<1	1	<1	1
Sr	48	127	164	124	14	15	9
V	371	277	259	217	379	346	341
Zr	69	71	56	42	43	30	33
S (wt. %)	0.120	0.180	0.130	0.074	0.016	0.019	0.023
CO ₂ (wt. %)	5.50	1.16	1.19	1.68	0.30	0.18	0.32
Density	2.90	3.02	3.03	3.04	2.82	3.01	3.00

TABLE 7 CONTD.

Sample No.	036	037	038	039	040	041	042
Field Rock Name	MB	MB	MB	MB	MB		MB
<u>Oxide (wt. %)</u>							
SiO ₂	52.90	49.60	48.10	49.50	52.71		53.03
TiO ₂	0.80	0.66	0.89	1.00	0.91		0.92
Al ₂ O ₃	15.50	11.60	13.70	13.80	15.33		14.20
Fe ₂ O ₃ *	19.50	23.10	22.00	22.40	19.95		16.70
MnO	0.20	0.21	0.22	0.06	0.04		0.13
MgO	3.79	4.77	5.83	6.36	2.61		6.95
CaO	0.07	0.13	0.07	0.03	0.07		0.06
Na ₂ O	<0.01	0.02	<0.01	<0.01	0.26		<0.01
K ₂ O	0.75	0.30	0.03	0.06	1.28		0.07
P ₂ O ₅	0.05	0.04	0.06	0.09	0.14		0.06
LOI	7.50	9.15	9.45	7.80	7.25		7.95
TOTAL	100.96	99.54	100.26	100.10	100.55		100.07
<u>Trace Elements (ppm)</u>							
Cu	3550	1850	4900	1800	7300		1650
Pb	21	17	11	15	110		389
Zn	715	3650	790	315	780		400
Co	323	125	102	10	23		34
Ni	157	218	151	92	76		99
Mn	1600	1600	1550	380	263		970
Ag	0.7	0.6	0.3	0.5	1.8		1.0
Au (ppb)	155	90	25	45	125		110
As	605	76	869	1480	>2000		429
Ba	292	85	76	46	320		39
Rb	29	28	4	5	46		1
Sb	21	12	18	71	161		4
Sn	5	11	<1	<1	6		1
Sr	6	7	3	4	47		5
V	389	287	421	428	382		426
Zr	51	47	50	49	42		42
S (wt. %)	0.037	0.029	0.015	0.036	0.016		0.017
CO ₂ (wt. %)	0.19	0.25	0.31	0.17	0.13		0.13
Density	2.89	2.88	2.90	2.92	2.93		2.84

TABLE 7 CONTD.

Sample No.	043	044	045	046	047	048	049
Field Rock Name	MB	MB	MB	MB	MB	MB	MB
Oxide (wt. %)							
SiO ₂	43.58	46.07	48.90	46.00	53.30	51.90	47.50
TiO ₂	1.01	0.67	0.82	0.77	0.81	0.91	0.84
Al ₂ O ₃	11.87	12.90	14.70	13.80	15.70	15.60	13.70
Fe ₂ O ₃ *	24.57	24.23	20.10	23.50	12.80	15.60	15.60
MnO	0.60	0.22	0.06	0.11	0.20	0.20	0.20
MgO	8.22	6.99	7.08	7.14	7.78	6.55	6.62
CaO	0.09	0.09	0.08	0.06	0.03	0.75	3.76
Na ₂ O	<0.01	<0.01	0.02	0.03	0.02	0.02	0.23
K ₂ O	0.08	0.49	0.84	0.82	0.17	0.09	0.13
P ₂ O ₅	0.06	0.08	0.09	0.10	0.07	0.10	0.11
LOI	8.80	8.15	8.10	7.45	7.55	9.65	8.85
TOTAL	98.88	99.89	100.79	99.78	98.43	101.37	97.54

Trace Elements
(ppm)

Cu	5800	11700	3800	3200	1850	3600	7000
Pb	281	101	109	70	10	20	49
Zn	4200	5100	1340	940	285	985	550
Co	575	407	18	36	37	94	26
Ni	134	131	72	101	121	114	84
Mn	4325	1500	345	665	1500	1375	941
Ag	1.4	0.4	0.3	0.4	0.7	2.5	2.4
Au (ppb)	80	50	180	135	130	95	45
As	384	224	1440	>2000	396	473	572
Ba	281	288	208	220	<15	65	94
Rb	1	14	14	20	1	2	2
Sb	4	7	9	12	<1	3	7
Sn	<1	<1	1	1	<1	1	<1
Sr	5	3	8	6	7	1	30
V	426	354	379	401	428	407	342
Zr	42	37	62	54	59	49	48
S (wt. %)	0.018	0.027	0.077	0.096	0.021	0.180	0.260
CO ₂ (wt. %)	0.14	0.18	0.28	0.35	0.13	0.16	0.08
Density	2.93	2.98	2.92	2.95	2.80	2.84	3.00

TABLE 7 CONTD.

Sample No.	050	051	052	053	054	055	056	057
Field Rock Name	FC			FC	MB	MB	QP	GW
<u>Oxide (wt. %)</u>								
SiO ₂	78.70			73.24	54.80	52.40	69.10	67.90
TiO ₂	0.03			0.11	0.94	0.87	0.55	0.66
Al ₂ O ₃	0.40			1.07	15.84	14.13	15.10	13.60
Fe ₂ O ₃ *	18.80			20.81	10.90	15.85	3.83	7.36
MnO	0.09			0.10	0.12	0.18	0.08	0.11
MgO	0.13			0.09	3.90	5.80	0.82	2.98
CaO	0.07			0.05	0.03	0.09	0.21	0.09
Na ₂ O	<0.01			<0.01	<0.01	0.30	4.29	0.06
K ₂ O	0.13			0.28	3.76	2.44	2.59	3.07
P ₂ O ₅	0.10			0.16	0.09	0.10	0.09	0.10
LOI	1.55			2.95	7.10	8.30	2.65	4.05
TOTAL	100.00			98.86	97.51	100.46	99.31	99.98

Trace Elements
(ppm)

Cu	465			144	430	300	148	690
Pb	10			33	10	11	25	14
Zn	840			92	200	225	88	545
Co	16			2	32	36	11	20
Ni	15			15	181	170	20	124
Mn	740			620	1100	1425	610	675
Ag	8.7			0.1	<0.1	0.1	<0.1	0.2
Au (ppb)	20			10	<5	45	40	20
As	506			152	55	192	82	40
Ba	58			109	394	260	588	575
Rb	4			4	140	42	84	125
Sb	2			<1	<1	<1	<1	<1
Sn	<1			5	<1	1	<1	4
Sr	2			9	12	27	594	26
V	<2			35	398	373	87	103
Zr	6			28	60	49	178	271
S (wt. %)	0.023			0.054	0.043	0.023	0.036	0.008
CO ₂ (wt. %)	ND			0.02	0.02	ND	0.05	ND
Density	2.88			2.86	2.80	2.77	2.70	2.73

TABLE 7 CONTD.

Sample No.	058	059	060	061	062	063	064
Field Rock Name	GW	GW	GW	MB	MB	GO	GO
<u>Oxide (wt. %)</u>							
SiO ₂	74.26	75.26	67.52	50.60	51.00	43.60	39.80
TiO ₂	0.47	0.23	0.39	0.61	0.57	0.58	0.25
Al ₂ O ₃	11.47	10.71	13.64	12.60	13.10	4.34	2.92
Fe ₂ O ₃ *	5.09	4.79	5.18	21.20	15.20	39.40	46.40
MnO	0.10	0.04	0.07	0.04	0.04	0.06	0.07
MgO	2.77	1.87	3.93	6.92	8.94	0.23	0.09
CaO	0.02	0.11	0.02	0.09	0.09	0.02	0.12
Na ₂ O	0.02	0.07	0.08	<0.01	<0.01	<0.01	<0.01
K ₂ O	2.95	2.42	2.79	0.14	0.10	0.49	0.42
P ₂ O ₅	0.09	0.03	0.02	0.05	0.06	0.19	0.14
LOI	2.90	3.10	4.20	8.00	8.15	7.45	8.10
TOTAL	100.14	98.63	97.90	100.25	97.25	96.36	98.31

Trace Elements (ppm)

Cu	390	950	1880	8200	9400	4700	7000
Pb	6	12	26	36	61	3940	574
Zn	310	148	350	920	330	240	235
Co	12	7	5	27	18	15	8
Ni	54	23	46	254	278	18	17
Mn	945	245	505	344	280	465	400
Ag	<0.1	0.2	<0.1	12.3	1.0	14.3	10.4
Au (ppb)	15	15	10	25	45	2465	4005
As	49	164	168	891	858	>2000	>2000
Ba	541	693	697	102	15	227	183
Rb	92	83	88	2	1	1	4
Sb	1	4	1	1	32	294	132
Sn	7	5	4	6	6	113	128
Sr	26	24	30	11	8	24	8
V	71	43	72	304	333	124	80
Zr	198	133	174	30	35	75	31
S (wt. %)	0.009	0.005	0.010	0.010	0.004	0.110	0.067
CO ₂ (wt. %)	ND	0.14	0.04	0.12	ND	ND	0.05
Density	2.73	2.72	2.76	2.96	2.92	3.29	3.33

TABLE 7 CONTD.

Sample No.	065	066	067	068	069	070	071
Field Rock Name	MB	MB	MB	GW	GW	GW	GW
<u>Oxide (wt. %)</u>							
SiO ₂	56.90	53.40	51.45	72.93	64.00	70.20	65.52
TiO ₂	0.53	0.57	0.59	0.40	0.59	0.44	0.54
Al ₂ O ₃	12.30	10.40	9.78	11.88	16.00	12.30	14.99
Fe ₂ O ₃ *	11.50	13.60	19.70	6.53	8.17	6.94	7.83
MnO	0.05	0.04	0.07	0.11	0.07	0.10	0.07
MgO	11.70	14.20	7.28	2.01	0.56	1.17	0.48
CaO	0.03	0.09	0.30	3.08	0.04	0.08	0.05
Na ₂ O	<0.01	<0.01	<0.01	0.03	0.13	0.09	0.09
K ₂ O	0.23	0.25	0.34	2.45	3.13	2.63	3.42
P ₂ O ₅	0.04	0.09	0.07	0.18	0.05	0.05	0.09
LOI	7.25	6.75	9.30	2.60	4.65	3.25	4.10
TOTAL	100.63	99.31	98.88	99.20	97.39	97.25	99.99

Trace Elements
(ppm)

Cu	4850	10600	3000	300	201	220	360
Pb	100	69	18	8	11	10	28
Zn	185	265	915	345	68	134	140
Co	37	29	80	5	13	15	8
Ni	259	300	325	40	28	61	41
Mn	325	225	555	915	545	765	484
Ag	0.3	0.2	0.3	0.3	0.2	0.3	0.3
Au (ppb)	50	15	95	5	30	10	75
As	594	760	1440	34	45	40	152
Ba	<15	27	60	502	535	550	568
Rb	<1	2	6	83	115	83	102
Sb	39	1	10	<1	1	1	1
Sn	3	1	4	4	6	5	6
Sr	4	9	8	45	21	25	24
V	275	267	281	68	112	73	99
Zr	30	31	35	161	149	147	162
S (wt. %)	0.040	0.008	0.001	0.011	0.011	0.010	0.010
CO ₂ (wt. %)	ND	0.14	0.06	ND	ND	0.07	0.03
Density	2.78	2.73	2.91	2.80	2.83	2.78	2.79

TABLE 2. CONTD.

Sample No.	072	073	074	075	076	077	078
Field Rock Name	GW	GW	GW	MB	GW	FC	MB
<u>Oxide (wt. %)</u>							
SiO ₂	72.80	69.70	71.20	55.40	80.10	72.50	56.80
TiO ₂	0.44	0.41	0.51	0.85	0.26	0.05	1.08
Al ₂ O ₃	12.60	15.00	13.50	15.20	8.16	0.60	16.50
Fe ₂ O ₃ *	6.92	5.88	5.06	14.40	4.81	23.00	13.40
MnO	0.09	0.03	0.14	0.27	0.07	0.17	0.20
MgO	0.32	1.42	1.22	7.19	1.16	0.08	3.53
CaO	0.08	0.03	0.07	0.13	0.16	0.10	0.13
Na ₂ O	0.10	0.08	0.14	1.27	1.08	<0.01	0.10
K ₂ O	3.24	4.06	3.66	0.62	1.51	0.07	2.10
P ₂ O ₅	0.05	0.06	0.06	0.04	0.07	0.18	0.10
LOI	3.35	4.10	3.45	7.40	2.40	2.80	7.10
TOTAL	99.99	100.77	99.01	102.77	99.78	99.54	101.04

Trace Elements
(ppm)

Cu	390	161	70	370	175	100	369
Pb	70	22	5	8	30	13	6
Zn	480	205	75	765	144	90	420
Co	18	7	4	58	7	4	49
Ni	19	33	66	241	35	17	125
Mn	715	210	1100	2000	525	1100	1550
Ag	0.2	0.1	<0.1	<0.1	0.3	0.6	0.4
Au (ppb)	15	5	5	15	<5	470	65
As	72	144	120	232	16	495	13
Ba	569	502	288	232	164	18	212
Rb	83	148	131	15	64	1	84
Sb	<1	<1	<1	<1	<1	<1	<1
Sn	8	8	7	3	3	14	4
Sr	20	20	22	28	43	14	18
V	76	79	83	358	43	<2	401
Zr	169	192	164	48	108	9	67
S (wt. %)	0.024	0.014	0.016	0.045	0.009	0.008	0.007
CO ₂ (wt. %)	0.04	0.04	0.02	ND	ND	ND	ND
Density	2.80	2.79	2.76	2.81	2.71	2.96	2.87

TABLE 7 CONTD.

Sample No.	079	080	081	082	083	084	085
Field Rock							
Name	DO	DO	DO	DO	DO	DO	DO
Oxide (wt. %)							
SiO ₂	49.35	49.80	49.00	54.00	45.20	48.60	50.00
TiO ₂	0.94	1.23	0.75	0.71	0.90	1.00	1.03
Al ₂ O ₃	12.60	15.60	12.50	14.10	13.50	13.30	13.90
Fe ₂ O ₃ *	12.31	13.60	12.80	11.10	12.90	12.60	13.90
MnO	0.24	0.19	0.18	0.26	0.23	0.26	0.25
MgO	7.96	5.99	9.95	6.10	9.21	8.17	8.05
CaO	11.84	8.50	12.00	8.44	10.60	11.00	11.00
Na ₂ O	1.78	2.53	0.97	2.30	1.15	1.88	1.80
K ₂ O	0.25	0.33	0.27	1.22	0.49	0.19	0.20
P ₂ O ₅	0.09	0.14	0.09	0.12	0.06	0.11	0.12
LOI	1.80	3.55	2.75	1.45	3.25	1.50	1.40
TOTAL	99.16	101.46	101.26	99.80	97.49	98.61	101.65
Trace Elements (ppm)							
Cu	170	71	180	82	202	100	168
Pb	4	5	5	7	8	5	2
Zn	42	365	46	52	53	44	69
Co	25	28	34	22	42	24	30
Ni	51	57	142	44	146	72	81
Mn	957	865	745	1175	1000	1050	950
Ag	0.2	0.3	0.3	<0.1	<0.1	0.1	0.3
Au (ppb)	5	20	15	<5	5	<5	5
As	5	17	11	2	5	6	6
Ba	139	172	127	412	235	142	117
Rb	7	11	14	37	15	7	6
Sb	<1	<1	<1	<1	<1	<1	<1
Sn	<1	<1	<1	3	1	2	<1
Sr	115	166	130	205	154	131	160
V	227	264	200	162	237	239	223
Zr	42	60	39	66	22	53	51
S (wt. %)	0.051	0.013	0.029	0.014	0.140	0.032	0.100
CO ₂ (wt. %)	0.20	ND	0.42	0.20	0.46	0.17	0.10
Density	3.07	2.97	3.06	2.98	3.03	3.03	3.05

TABLE 7 CONTD.

Sample No.	086	087	088	089	090	091	092
Field Rock Name	MW	GW	GW	GW	GW	GW	GW
<u>Oxide (wt. %)</u>							
SiO ₂	66.10	67.40	68.29	66.64	66.55	69.10	69.30
TiO ₂	0.50	0.51	0.58	0.60	0.72	0.61	0.54
Al ₂ O ₃	16.20	13.40	17.70	15.35	17.55	15.70	14.91
Fe ₂ O ₃ *	4.92	4.94	3.05	5.14	5.11	2.93	3.63
MnO	0.31	0.15	0.14	0.16	0.14	0.11	0.25
MgO	1.06	1.67	0.43	1.48	1.42	0.79	0.70
CaO	1.64	1.15	0.95	0.58	0.28	0.29	0.38
Na ₂ O	7.81	4.16	6.08	4.09	1.01	2.15	4.21
K ₂ O	0.86	0.96	1.66	1.29	3.18	2.50	1.81
P ₂ O ₅	0.15	0.10	0.07	0.10	0.03	0.05	0.06
LOI	1.20	2.90	1.95	3.70	5.40	3.80	2.40
TOTAL	100.75	97.34	100.90	99.12	101.39	98.03	98.19

Trace Elements
(ppm)

Cu	175	66	74	128	220	96	54
Pb	8	7	6	10	14	7	6
Zn	42	340	131	295	420	315	445
Co	28	23	11	16	12	11	28
Ni	85	93	32	54	38	28	38
Mn	2550	1150	1050	1275	890	905	1850
Ag	0.1	0.1	<0.1	<0.1	0.1	0.1	0.3
Au (ppb)	10	5	<5	<5	75	10	5
As	72	10	8	21	13	4	19
Ba	128	782	456	321	629	322	451
Rb	18	34	48	53	120	97	60
Sb	<2	<1	<1	<1	<1	<1	<1
Sn	<2	5	4	9	3	2	10
Sr	280	206	344	262	111	186	207
V	74	92	68	96	87	69	77
Zr	170	179	191	184	198	182	175
S (wt. %)	0.810	0.004	0.010	0.022	0.034	0.013	0.015
CO ₂ (wt. %)	0.73	0.01	0.03	0.05	ND	0.09	0.13
Density	2.69	2.71	2.69	2.72	2.73	2.73	2.69

TABLE 7 CONTD.

Sample No.	093	094	095	096	097	098	099	100
Field Rock Name	GW	MB	GW		MB	MB	MB	MB
<u>Oxide (wt. %)</u>								
SiO ₂	71.89	50.58	70.12		40.40	46.50	44.50	48.26
TiO ₂	0.43	0.77	0.65		1.10	0.88	0.87	0.83
Al ₂ O ₃	10.76	12.44	15.47		18.16	15.00	14.80	17.78
Fe ₂ O ₃ *	6.92	19.5	3.19		19.88	14.20	19.60	15.37
MnO	0.10	0.08	0.08		0.16	0.23	0.19	0.25
MgO	1.96	5.59	0.63		5.48	6.89	6.86	3.14
CaO	0.04	0.07	0.19		2.90	7.79	0.30	2.03
Na ₂ O	0.04	0.01	1.80		<0.01	0.21	<0.01	0.21
K ₂ O	2.58	1.31	1.99		0.87	0.58	0.15	0.32
P ₂ O ₅	0.05	0.07	0.04		0.11	0.10	0.10	0.06
LOI	3.55	6.65	4.40		10.80	6.80	9.40	13.40
TOTAL	98.32	97.11	98.56		99.86	99.18	96.77	101.65
<u>Trace Elements (ppm)</u>								
Cu	1800	2750	485		>2000	15800	7150	6450
Pb	18	25	28		25	6	8	6
Zn	375	5200	430		730	870	1900	4100
Co	16	160	26		31	28	80	149
Ni	39	120	124		85	56	143	144
Mn	724	520	503		685	580	1100	1700
Ag	1.0	0.3	0.2		2.1	0.2	0.5	0.4
Au (ppb)	10	15	30		5	10	40	30
As	517	814	168		660	92	328	70
Ba	449	189	472		194	118	81	180
Rb	91	30	73		7	6	4	4
Sb	5	<1	<1		<1	<1	<1	<1
Sn	3	<1	1		<1	2	<1	<1
Sr	13	11	149		26	62	7	44
V	53	290	68		410	262	427	230
Zr	157	64	199		29	37	39	51
S (wt. %)	0.011	0.025	0.024		0.020	0.011	0.011	0.020
CO ₂ (wt. %)	0.05	0.14	0.06		1.41	0.77	0.77	0.09
Density	2.71	2.94	2.74		3.13	3.07	2.90	2.81

TABLE 7 CONTD.

Sample No.	101	102	103	104	105	106	107
Field Rock Name	DA	DA	DA	DA	DA	DA	DA
<u>Oxide (wt. %)</u>							
SiO ₂	69.58	66.70	71.60	66.50	64.60	65.30	71.90
TiO ₂	0.47	0.47	0.54	0.47	0.48	0.44	0.31
Al ₂ O ₃	13.91	14.20	13.90	12.60	13.70	14.40	8.32
Fe ₂ O ₃ *	3.32	3.92	4.02	3.06	2.93	2.24	4.42
MnO	0.09	0.12	0.14	0.21	0.19	0.11	0.13
MgO	0.74	1.00	0.77	2.17	2.03	1.48	1.99
CaO	1.19	3.01	1.76	6.10	5.22	5.05	4.42
Na ₂ O	2.47	3.07	3.17	3.51	3.73	3.82	2.03
K ₂ O	3.21	2.80	3.07	1.85	2.49	2.63	1.06
P ₂ O ₅	0.20	0.27	0.27	0.22	0.25	0.28	0.20
LOI	2.85	3.95	2.90	6.15	5.40	5.35	4.55
TOTAL	98.03	99.51	102.14	102.84	101.02	101.10	99.33
<u>Trace Elements (ppm)</u>							
Cu	54	37	67	16	25	51	45
Pb	10	10	11	28	13	37	20
Zn	100	57	36	79	80	715	115
Co	10	5	5	6	9	6	11
Ni	19	16	14	22	25	18	38
Mn	690	970	874	1400	1225	990	1175
Ag	<0.1	<0.1	<0.1	0.2	0.1	0.2	0.3
Au (ppb)	35	15	240	185	160	775	13550
As	98	136	61	21	49	27	82
Ba	620	815	818	632	781	859	358
Rb	91	70	75	48	61	78	29
Sb	<1	<1	<1	<1	<1	<1	<1
Sn	1	<1	<1	2	<1	<1	<1
Sr	253	337	359	468	593	549	304
V	56	50	58	48	49	54	45
Zr	220	196	205	157	190	193	102
S (wt. %)	0.011	0.017	0.040	0.037	0.051	0.064	0.140
CO ₂ (wt. %)	0.50	1.75	0.96	4.21	3.65	3.68	3.33
Density	2.74	2.72	2.72	2.71	2.72	2.73	2.72

TABLE 7 CONTD.

Sample No.	108	109	110	111	112	113	114
Field Rock							
Name	DA	DA	DA	DA	DA	DA	DA
Oxide (wt. %)							
SiO ₂	69.60	63.10	70.80	68.70	64.40	63.70	64.80
TiO ₂	0.52	0.53	0.52	0.52	0.49	0.52	0.51
Al ₂ O ₃	13.30	14.40	13.40	14.40	15.70	13.60	13.70
Fe ₂ O ₃ *	2.38	3.52	2.53	3.79	3.67	3.86	4.73
MnO	0.09	0.12	0.10	0.09	0.09	0.12	0.10
MgO	0.97	1.62	0.70	0.95	1.35	1.48	1.35
CaO	3.24	5.23	2.93	3.82	4.81	4.60	3.97
Na ₂ O	3.50	3.62	3.69	4.27	4.48	4.23	3.43
K ₂ O	2.45	2.42	2.44	2.34	2.38	1.72	2.25
P ₂ O ₅	0.28	0.31	0.27	0.28	0.27	0.28	0.28
LOI	3.85	5.10	3.20	3.75	4.30	4.65	4.40
TOTAL	100.18	99.97	100.58	101.91	97.46	98.76	99.52
Trace Elements (ppm)							
Cu	29	25	34	26	30	61	29
Pb	23	8	7	5	9	8	11
Zn	1150	74	72	49	103	86	65
Co	7	10	5	10	12	11	12
Ni	27	38	24	35	44	67	48
Mn	795	874	840	670	840	905	1005
Ag	<0.1	<0.1	<0.1	<0.1	<0.1	<0.3	0.1
Au (ppb)	65	1025	30	35	15	255	15
As	35	30	41	33	32	8	32
Ba	897	785	829	839	796	677	583
Rb	74	69	78	67	62	56	67
Sb	<1	<1	<1	<1	<1	<1	<1
Sn	<1	3	<1	<1	<1	<1	<1
Sr	450	525	506	526	495	555	490
V	58	74	66	72	75	70	81
Zr	166	152	163	170	153	147	136
S (wt. %)	0.110	0.110	0.160	0.11	0.038	0.026	0.030
CO ₂ (wt. %)	2.23	3.73	2.21	2.14	2.72	3.21	2.58
Density	2.72	2.73	2.71	2.72	2.71	2.73	2.71

TABLE 7 CONTD

Sample No.	115	116	117	118	119	120	121
Field Rock Name	DA	DA	DA	DA	DA	DA	DA
<u>Oxide (wt. %)</u>							
SiO ₂	56.10	56.40	60.06	61.50	63.10	59.10	63.01
TiO ₂	0.63	0.56	0.53	0.57	0.53	0.43	0.46
Al ₂ O ₃	14.00	12.30	13.34	14.20	12.80	12.60	13.50
Fe ₂ O ₃ *	4.72	5.38	5.51	4.60	5.03	4.89	3.54
MnO	0.13	0.14	0.18	0.16	0.22	0.11	0.11
MgO	3.31	3.45	2.93	2.62	2.08	3.05	1.87
CaO	8.63	7.00	5.48	5.27	4.41	6.85	4.63
Na ₂ O	4.18	2.96	3.76	4.67	3.73	3.40	4.03
K ₂ O	2.00	2.11	2.03	2.01	2.27	1.37	1.96
P ₂ O ₅	0.42	0.37	0.27	0.49	0.35	0.15	0.16
LOI	7.10	7.65	5.40	5.30	4.20	7.55	6.20
TOTAL	101.22	98.32	99.49	101.39	99.72	99.56	99.47
<u>Trace Elements (ppm)</u>							
Cu	12	25	204	36	29	23	23
Pb	12	9	5	3	6	7	5
Zn	43	68	54	47	48	83	65
Co	1	13	42	13	10	12	11
Ni	2	59	164	52	55	35	36
Mn	100	1550	1100	1350	1800	1000	1100
Ag	0.1	0.1	0.1	<0.1	0.1	<0.1	<0.1
Au (ppb)	15	5	5	<5	10	<5	<5
As	6	4	5	26	7	5	5
Ba	893	668	949	1469	973	384	755
Rb	57	53	52	47	63	41	59
Sb	<1	<1	<1	<1	<1	<1	<1
Sn	<1	<1	1	2	12	5	1
Sr	1051	768	1068	1061	752	424	517
V	77	91	75	104	77	49	61
Zr	177	143	143	195	140	115	131
S (wt. %)	0.018	0.009	0.012	0.059	0.017	0.010	0.015
CO ₂ (wt. %)	4.96	5.34	3.51	4.30	2.99	5.87	4.89
Density	2.76	2.75	2.75	2.74	2.75	2.74	2.72

TABLE 7 CONTD.

Sample No.	122	123	124	125	126	127	128
Field Rock							
Name	DA	DA	DA	DA	DA	DA	DA
Oxide (wt. %)							
SiO ₂	60.20	57.10	68.10	70.04	66.10	66.60	61.59
TiO ₂	0.59	0.57	0.44	0.50	0.53	0.58	0.48
Al ₂ O ₃	14.60	14.60	13.90	15.96	14.00	16.90	16.43
Fe ₂ O ₃ *	4.26	4.42	8.72	4.39	3.62	5.85	10.26
MnO	0.16	0.11	0.21	0.15	0.09	0.26	0.66
MgO	3.02	3.02	0.73	0.66	2.74	0.66	0.56
CaO	4.08	4.82	0.13	0.15	3.66	0.14	0.27
Na ₂ O	5.99	3.87	0.27	1.33	5.88	2.49	1.57
K ₂ O	0.65	2.27	2.98	3.44	0.69	2.71	2.28
P ₂ O ₅	0.42	0.41	0.05	0.04	0.41	0.03	0.04
LOI	4.30	7.55	5.65	3.30	3.95	4.00	6.00
TOTAL	98.27	98.74	101.18	99.96	101.67	100.22	100.14

Trace Elements
(ppm)

Cu	48	31	48	74	43	18	46
Pb	13	7	25	14	16	17	47
Zn	146	92	124	45	144	24	28
Co	14	15	27	20	16	23	69
Ni	49	48	29	26	42	28	50
Mn	1300	963	1650	1075	919	1850	5400
Ag	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Au (ppb)	10	45	20	10	45	140	15
As	5	3	122	122	5	51	168
Ba	2046	1415	787	798	2126	916	1239
Rb	19	87	120	113	18	77	70
Sb	<1	3	<1	<1	<1	<1	<1
Sn	<1	5	3	5	3	2	6
Sr	1291	790	64	142	1287	239	132
V	86	86	73	64	89	77	112
Zr	220	206	255	235	230	225	234
S (wt. %)	0.043	0.037	0.011	0.005	0.049	0.013	0.026
CO ₂ (wt. %)	2.63	6.28	ND	ND	2.58	ND	ND
Density	2.70	2.77	2.80	2.72	2.69	2.75	2.79

TABLE 7 CONTD

Sample No.	129	130	131	132	133	134	135
Field Rock Name	DA	DA	DA	DA	DA	DA	DA
Oxide (wt. %)							
SiO ₂	71.50	59.70	77.20	66.30	61.70	70.06	66.71
TiO ₂	0.50	0.42	0.34	0.55	0.57	0.59	0.57
Al ₂ O ₃	14.40	12.80	10.90	16.00	15.10	16.99	15.20
Fe ₂ O ₃ *	3.36	4.90	4.45	5.47	4.96	4.36	5.24
MnO	0.19	0.12	0.34	0.26	0.16	0.14	0.21
MgO	0.56	2.97	0.44	0.86	2.44	0.74	0.75
CaO	0.33	6.94	0.20	0.29	3.86	0.31	0.28
Na ₂ O	3.09	3.38	1.93	3.09	4.15	2.72	1.93
K ₂ O	2.38	1.30	1.64	2.49	2.03	2.81	2.37
P ₂ O ₅	0.08	0.14	0.05	0.03	0.27	0.03	0.03
LOI	2.95	7.50	2.60	4.15	5.90	3.75	5.00
TOTAL	99.34	100.17	100.09	99.49	100.14	102.50	98.29

Trace Elements
(ppm)

Cu	26	61	27	21	48	38	21
Pb	8	5	12	30	9	9	8
Zn	27	77	14	52	136	35	27
Co	8	10	28	30	15	14	28
Ni	21	33	29	39	48	36	37
Mn	1350	1000	2550	1900	1000	995	1450
Ag	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Au (ppb)	10	<5	<5	<5	<5	<5	<5
As	122	11	50	352	26	21	19
Ba	941	378	710	1228	1162	975	830
Rb	72	41	59	79	76	89	83
Sb	<1	<1	<1	<1	<1	<1	<1
Sn	5	1	8	3	5	<1	2
Sr	375	448	284	335	571	268	180
V	53	46	44	84	83	84	98
Zr	182	121	142	208	189	194	189
S (wt. %)	0.012	0.011	0.011	0.055	0.076	0.016	0.011
CO ₂ (wt. %)	0.01	5.87	ND	ND	4.36	ND	0.03
Density	2.72	2.72	2.73	2.72	2.76	2.73	2.74

A P P E N D I X C

Analytical procedures, precision and accuracy

All samples were chemically analysed by Bondar-Clegg & Co. Ltd., Ottawa.

Detection limits for analyses are as follows: Major elements 0.01%; Ag: 0.1 ppm; Cu, Zn, Co, Mn, Rb, Sb, Sn, Sr, and Zr: 1 ppm; Pb, Ni, As, and V: 2 ppm; Au: 5 ppb; Ba: 15 ppm.

Seven samples were analysed in duplicate and accuracy was checked by inserting three reference standard samples (Tables 8 and 9). As shown, precision is good for majors except SiO_2 . Trace and minor elements exhibit mostly good precision. As for accuracy, SiO_2 and Al_2O_3 register lower values than recommended but others are good. Accuracy of Cu, Pb, Zn, Co, Ni, and Mn is erratic suggesting that the acid extraction technique is poor. Generally, a high standard of analysis was achieved.

Brief descriptions of the analytical procedures and techniques (from W. Wong, Written Communication, 1983)

Major elements (plasma emission) (SiO_2 , TiO_2 , Al_2O_3 , Fe_2O_3^* , MnO, MgO, CaO, Na_2O , K_2O , P_2O_5). 0.2 g of -100 mesh material was fused with 1.5 g of lithium metaborate. The fused material was dissolved in 100 ml of 5% nitric acid solution,

then analysed by atomic emission. The instrument used was a Spectrametrics Spectraspan IIIB equipped with a D.C plasma excitation source. The instrument was calibrated using the CANMET reference materials SY-2, SY-3, and MRG-1. The accuracy of the method is $\pm 3\%$ (relative) for any one of the whole rock determinations.

Trace elements (atomic absorption)

(Cu, Pb, Zn, Ni, Mn, Ag, Co). 0.5 g of material was digested with a mixture of acids (3 parts HNO_3 to 1 part HCl) in a hot water bath for 2 hours, then diluted to a test volume of 10 ml. This test solution was then analysed by atomic absorption. The instrument used was a Varian AA875 with deuterium background correction. The accuracy and precision are $\pm 10\%$ at 10 times detection level.

Minor elements (X-ray fluorescence)

(Rb, Sr, Zr, Ba, Sn, V, Sb). The elements in this group were determined by a dry powder pellet-XRF technique. 5-8 g of -100 mesh material was compressed to produce a pellet with a smooth surface. The determinations were then performed on this pellet using XRF technique. The instrument used was a Siemens SR5 Spectrometer with an auto sample system. For each determination, the calibration involved the preparation of a curve of concentration vs peak to back-

ground ratio with materials of known composition. The accuracy is $\pm 10\%$ (relative) at concentrations of 10 times detection limit.

Arsenic (hydride generation-colorimetry)

0.2 g of material was treated with a mixture of nitric and perchloric acids, then heated until the perchloric fumes were visible. The sample was then diluted with 10% HCl and treated with stannous chloride to reduce As(5) to As(3). Zinc metal was added liberating AsH_3 gas (arsine) which was then bubbled into a cell containing a solution of silver diethyldithio-carbamate (S.D.D.C), which form a coloured complex with arsine. The absorption of the coloured complex was measured in a Spectrophotometer to determine the concentration of arsenic. The accuracy is $\pm 15\%$ (relative) at 10 times detection limit.

Gold (fire assay preconcentration atomic absorption)

10 g of material were fused with a mixture of lead oxide, sodium carbonate and borax to produce a lead metal button, the collecting medium for gold, which serves to separate the gold from other substances in the sample.

When the lead button was obtained, it was then put through a cupellation process where the lead was absorbed into bone-ash, leaving a precious metal bead (dore).

The doré bead was then dissolved in aqua regia, and the solution analysed for gold by a Varian AA875 atomic absorption Spectrophotometer. The accuracy is $\pm 20\%$ at a gold concentration of 50 ppb.

S and CO₂ (gravimetric)

Sulfur was determined by precipitating the sulfate with barium as barium sulfate. 0.5 g of sample were fused with sodium peroxide, dissolved in HCl. Barium chloride solution was added to precipitate the barium sulfate. The BaSO₄ was then collected on a filter, ignited and weighed. The accuracy is $\pm 50\%$ relative.

CO₂ was determined by collecting the CO₂ in an ascarite medium. 0.5 g of sample was reacted with phosphoric acid and heated to liberate CO₂, which was then drawn into a preweighed tube containing ascarite and then reweighed. The gain in weight is due to CO₂. The accuracy is $\pm 10\%$ (relative) at concentrations less than 1%.

TABLE 8 Duplicate Analyses

ANALYSIS NO.	025	DUP	029	DUP	044	DUP	083	DUP
Oxide (wt. %)								
SiO ₂	51.10	49.30	36.80	37.10	46.07	45.30	45.20	48.30
TiO ₂	0.75	0.73	1.22	1.24	0.67	0.69	0.90	0.93
Al ₂ O ₃	13.30	13.30	15.90	16.20	12.90	12.50	13.50	14.10
Fe ₂ O ₃ *	18.90	18.20	15.60	15.90	24.23	23.60	12.90	13.70
MnO	0.15	0.14	0.17	0.18	0.22	0.21	0.23	0.26
MgO	7.52	7.41	7.50	7.64	6.99	6.84	9.21	9.51
CaO	0.13	0.14	8.10	8.18	0.09	0.08	10.60	11.00
Na ₂ O	0.01	0.03	0.06	0.04	0.01	0.01	1.15	1.15
K ₂ O	0.17	0.19	1.42	1.36	0.49	0.41	0.49	0.60
P ₂ O ₅	0.05	0.05	0.10	0.10	0.08	0.06	0.06	0.11
LOI	9.80	9.70	11.40	11.45	8.15	8.25	3.25	3.15

Trace Element (ppm)

Cu	4700	4700	136	144	11700	11600	202	204
Pb	20	18	7	8	101	93	8	4
Zn	1550	1550	70	74	5100	5300	53	58
Co	111	110	37	34	407	427	42	44
Ni	184	196	129	123	131	117	146	157
Mn	1100	1150	1350	1300	1500	1550	1000	1100
Ag	0.1	0.1	0.1	0.4	0.4	0.1	0.1	0.2
Au (ppb)	95	85	5	5	50	50	5	5
As	416	384	126	136	224	232	5	5
Ba	28	95	150	160	288	300	235	249
Rb	22	21	45	46	14	13	15	20
Sb	3	1	1	1	7	6	1	1
Sn	1	1	3	1	1	1	1	1
Sr	7	6	48	52	3	5	154	181
V	338	351	371	360	354	339	237	232
Zr	47	42	69	59	37	37	22	24
S (wt. %)	0.009	0.020	0.120	0.150	0.027	0.063	0.140	0.20
CO ₂ (wt. %)	0.140	0.040	5.50	7.30	0.180	0.80	0.460	0.40

TABLE 8 CONTD.

ANALYSIS NO.	114	DUP	103	DUP	006	DUP
<u>Oxide (wt. %)</u>						
SiO ₂	64.80	64.30	71.60	68.70	43.70	45.40
TiO ₂	0.51	0.55	0.54	0.49	1.06	1.09
Al ₂ O ₃	13.70	13.50	13.90	13.80	12.50	13.20
Fe ₂ O ₃ *	4.73	4.71	4.02	3.85	12.50	13.00
MnO	0.10	0.10	0.14	0.10	0.19	0.20
MgO	1.35	1.35	0.77	0.75	6.01	6.09
CaO	3.97	3.91	1.76	1.77	8.03	8.28
Na ₂ O	3.43	3.29	3.17	3.08	2.77	2.97
K ₂ O	2.25	2.42	3.07	2.72	0.04	0.08
P ₂ O ₅	0.28	0.27	0.27	0.28	0.12	0.11
LOI	4.40	4.60	2.90	3.25	10.15	10.40

Trace Element (ppm)

Cu	29	59	67	71	70	68
Pb	11	7	11	9	8	12
Zn	65	82	36	35	76	72
Co	12	10	5	7	24	24
Ni	48	69	14	13	71	62
Mn	1005	870	874	900	1550	1425
Ag	0.1	0.1	0.1	0.1	0.1	0.1
Au (ppb)	15	5	240	140	5	5
As	32	34	61	56	43	47
Ba	583	618	818	772	106	97
Rb	67	60	75	78	3	4
Sb	1	1	1	1	1	1
Sn	1	1	1	1	1	1
Sr	490	435	359	379	149	164
V	81	70	58	69	312	322
Zr	136	138	205	201	59	55
S (wt. %)	0.030	0.050	0.040	0.047	0.092	0.074
CO ₂ (wt. %)	2.580	2.870	0.960	0.870	7.060	7.30

TABLE 9 COMPARISON OF BOTH MAJOR AND MINOR ELEMENT
CONTENTS WITH USGS STANDARD ROCKS

USGS Standard Rocks	GSP-1		W-1		G-1	
Oxide (wt.%)	This Study	Recommended* Values after Flanagan (1972)	This Study	Recommended Values after Flanagan (1972)	This Study	Recommended Values after Flanagan (1972)
SiO ₂	65.90	67.38	53.20	56.64		
TiO ₂	0.67	0.66	1.06	1.07		
Al ₂ O ₃	13.50	15.25	13.90	15.00		
Fe ₂ O ₃ *	4.36	4.33	10.70	11.09		
MnO	0.04	0.042	0.17	0.17		
MgO	0.97	0.96	6.54	6.62		
CaO	1.80	2.02	10.30	10.96		

Na₂O
5.17
K₂O
0.27
P₂O₅

Trace Elements

(ppm)

Cu 42
Pb 34
Zn 106
Co 4
Ni 6
Mn 200
Ag 0.1
Au ND
As 2
Ba 803
Rb 222
Sb 1
Sn 8
Sr 207
V 60
Zr 535
S (wt%) 0.030

33.3
51.3
98
6.4
22.5
331
0.1
1.6
0.09
1300
254
3.1
6.3
233
52.6
500
0.0162

120
6
27
7
14
115
0.3
ND
3
131
21
1
11
168
257
77
0.043

110
7.8
86
47
76
1278
0.081
3.7
1.9
160
21
1.0
3.2
190
264
105
0.0123

31
8
72
18
47
200
0.1
10
2
1014
255
1
1
299
4
226
ND

13
48
45
2.4
1
195
0.01
4
0.5
1200
220
0.31
3.5
250
17
210
ND

Fig. 4

Sample locality map - Macalder

1/0F

Line

7

.092
091
.090
089
.088
087

3a

.068
069
.070
071
.072

3b

031•

•030

080•

7

029•

•028

3a

1

3a

Main Open-pit

097•

•098

099•

•100

•027

025•

•033

034•

•035

036•

•037

038•

•039

044•

045•

•046

047•

•048

049•

•050

Outline of mine working

7

Dolerite older

3b

Interlayered wackes & mudstones

3a

Graywacke

2

Ferruginous chert

1

Metabasalt & pillow lavas

Geological boundary

100m

053•

•054
055•
•056

1

3a

3a

1

2 or 2

Fig. 2

Geology of area surrounding M

Symbols

- Strike and dip of bedding
- Bedding (vertical)
- Bedding (overturned)
- Cleavage (S₁)
- Cleavage (S₂)
- Trend and plunge of lineation
- Pillows, top direction
- Fault
- Contact observed, inferred
- Prospect
- Roads
- Motorable tracks
- Shaft
- Outcrop

N

100
7

OX64 thin section samples

116

Core, trench
samples for chemical analysis

2021

Fig. 3.

Surface Geology --

2021

Symbols

- Strike and dip of bedding
- Bedding (overturned)
- Bedding (vertical)
- Pillows, top direction
- Outcrop
- Open pit
- Contact, inferred, observed
- Vesicular basalt
- Shaft

100 m

END

1 2 0 6 8 6

FIN