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**Field Relationships, Petrology, Geochemistry, and Petrogenesis of Quartz Dioritic
Magmas, Whistle Offset, Sudbury Structure, Canada**

by

Wanda M. Carter

A thesis submitted to the Faculty of Science
In partial fulfillment of the requirements
For the degree of Master of Science

Department of Earth Sciences

Carleton University
Ottawa-Carleton Geoscience Centre
Ottawa, Ontario
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Abstract

The radial Whistle Offset structure strikes northeast off the northeastern corner of the Sudbury Igneous Complex, intruding Archean gneisses, granites, gabbros, and Matachewan diabase dykes. The Whistle Offset contains Footwall Breccia, an *in situ* impact breccia with composition reflecting the Archean footwall rocks, and three "quartz dioritic" phases, which are generally granodioritic in composition.

The Leucocratic Quartz Diorite intruded the offset structure first, and represents the most primary composition of the impact melt sheet. Common disequilibrium textures such as stellate amphibole, granophyric intergrowths, and elongate fluorapatite with axial melt inclusions and irregular REE zoning reflect rapid crystallization induced by volatile loss through change of pressure associated with readjustment of the crater. A second pulse of Inclusion Quartz Diorite intruded, and through local irregular heating, pods of Quartz Diorite developed within this magma. Disequilibrium textures in these rocks indicate a second crater readjustment, inducing crystallization.

Chlorine-rich fluids hydrothermally remobilized Cu and PGE, precipitating these metals as veins in areas of low pressure, permeability and constricted flow, and creating hydrous alteration halos in the host rocks.

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Chapter 1. Introduction

1.1 Introduction

The stripping of overburden from approximately 0.2 km across and almost 1 km along the length of the Whistle Offset provided an excellent opportunity to study the relationships of the silicate rocks associated with ore at surface. Not only was an extensive area of the Offset stripped, it was pressure washed, and in some areas sandblasted, allowing clear and unobstructed observations of the various rock types and their interrelationships; other Offset Dykes of the Sudbury Igneous Complex (SIC) are partially covered by overburden, and many areas that do outcrop are stained black due to early ore processing practices. Access to the property was granted by FNX Mining Company Ltd., as were logs of exploration drill holes, assay values, and partial costs of chemical analyses.

1.2 Purpose

This study focuses on the silicate rocks of the Whistle Offset and attempts to determine 1) relative timing of the quartz dioritic rocks, 2) compositional variation of the quartz diorites and Footwall Breccia along the first kilometre of the length of the Offset through petrography and lithogeochemistry, 3) the relationship between the quartz diorites and the Footwall Breccias, 4) alteration assemblages affecting the Offset rocks, 5) protoliths for the various quartz diorites and percentage of protolith rock contributions and 6) implications for ore-forming processes. It is hoped that this study will not only add to the general understanding of the Sudbury Structure in the Whistle Offset area, but also provide some relevant information with respect to ore deposits through the study of silicate assemblages. [*A glossary of terms and acronyms is available in Appendix A.*]

1.3 Methodology

A base map produced by J. Fedorowich, of FNX Mining Company, was instrumental in selecting areas along the Whistle Offset for detailed mapping (available through FNX Mining Company Ltd.). Mapping was carried out over three months during the field season of 2003. Proximal, Intermediate and Distal Zones were selected along the offset in order to compare and contrast the rocks over an approximate 1 km length section of the offset (Figure 1-1). The Proximal Zone is closest to the Whistle Embayment where rocks of the SIC are exposed, and where INCO's Whistle open-pit mine was in production from 1988 to 1991, and again from 1994 to 1997 (sulphides in this zone are disseminated to blebby). The Distal Zone encompasses the North Zone where the stripping of the overburden revealed massive chalcopyrite-rich veins at surface. The Intermediate Zone was selected approximately half way between the two end zones, where veinlets of sulphide mineralization begin to develop.

Within each zone areas were selected for detailed mapping (Figure 1-2). In the Proximal Zone four areas were mapped at 1:100 scale, a fifth area was mapped in greater detail at 1:20 scale, and a small cross-section was produced (1:100 scale). Three areas were mapped at 1:100 scale in the Intermediate Zone, and one large map at 1:100 scale was produced for the Distal Zone. Effort was made to select map areas in each zone where Quartz Diorite, or a variant thereof, occurred.

Approximately 200 specimens were collected during the field season, and included representative samples of country rocks, as well as the dyke rocks, and nine mineralized samples that were assayed. Specimens were cut and 118 thin sections and polished thin sections were produced for petrographic analysis.

Scanning electron microscopy and electron microprobe analyses were carried out at Carleton University. All analytical data were produced from the Cameca Camebax MBX EPMA (electron probe micro analyzer) equipped with four WDX x-ray spectrometers, EDS detector, BSE detector, and a 4 Pi x-ray and digital imaging system. The polished thin sections were coated with 250 Å of carbon. Silicates were analyzed at a 15 kV accelerating potential with a beam current of 20 nA, and a beam diameter of 1-2 µm. Major elements were analyzed for 15 to 40 seconds or until 40,000 counts had been accumulated, depending on which was achieved first. Raw x-ray data were reduced to elemental weight percent by the Cameca PAP matrix correction program. *See Appendix B for a list of elements, x-ray lines, and standards.* The JEOL 6400 digital SEM equipped with a Link Systems XL energy dispersive (EDS) x-ray analyzer, Robinson and JEOL backscattered electron detector and a Semages PC based digital image capture system was used to scan for PGM and other precious metals.

Whole rock geochemistry was carried out at the Geological Survey of Canada (GSC). Major elements were analyzed by XRF (x-ray fluorescence), trace elements by ICPMS (inductively coupled plasma emission mass spectrometry), and F and Cl by IC (ion chromatography) (*see Appendix B for details*). Lithogeochemical samples were pulverized to < 100 mesh powder at Carleton University by D. Smith.

Figure 1-1: Plan view of the Whistle Offset and Embayment Structure after FNX Mining Company Ltd. The 2000 and North Deposits are projected to surface, and the past-producing Whistle open pit mine is outlined in black. The Proximal, Intermediate, and Distal Zones are outlined by the black boxes.

Map locations along the Whistle Offset.

(Whistle Offset outline from FNX Mining Company Ltd. map by J. Fedorowich). See larger maps for legend. Scale bar refers to all the detailed maps. Grid spacing on the offset structure is 500 metres.

Intermediate

Distal

000181

Chapter 2. Regional Geology

2.1 Archean and Early Proterozoic Rocks of the North Range

The Sudbury Structure straddles the Archean Superior Province and the Proterozoic Southern Province, and is located about 15 km northwest of the Grenville Front of the Grenville Province (Figure 2-1). In the North Range of the Sudbury Structure, the Archean rocks are primarily gneisses (the Levack Gneiss Complex), migmatites, and granitic intrusions, with lesser amounts of metavolcanic rocks (felsic through mafic), mafic intrusions, and diabase dykes.

The Levack Gneiss Complex underlies and collars the North Range of the Sudbury Igneous Complex (e.g. Card, 1994; Wodicka, 1997). It is believed to be the uplifted core of a "magmatic" dome developed due to rifting during the late-Archean to early-Paleoproterozoic prior to 1850 Ma (Rousell et al., 1997), or uplifted due to the Sudbury Event at 1850 Ma (Grieve et al., 1991). The complex has been dated with a zircon age of 2711 ± 7 Ma (Krogh *et al.*, 1984). A pegmatite in the gneissic complex is 2647 ± 2 Ma (Krogh *et al.*, 1984). More recent U-Pb dating by Card and Wodicka (Ames et al., 2005) reveals much younger plutonic rocks intruding the complex circa 2669-2668 Ma (granodiorite) and 2657 ± 3 Ma (monzodiorite). It has attained upper amphibolite- to granulite-facies metamorphism (James et al., 1991). Zircons from the Nipissing Diabase of the Early Proterozoic have been dated as approximately 2150 Ma (Van Schmus, 1965; Fairbairn *et al.*, 1969); more recent age analyses by Corfu and Andrews (1986) indicate an age of 2219.4 ± 3.6 -3.5 Ma. Other mafic dykes assumed to be part of the Matachewan swarm are 2450 Ma (Heaman, 1989).

Table 2-1 outlines the tectonic, magmatic, and mineralization events in the Sudbury area; Rousell et al. (1997) provide a thorough history of the Sudbury region, discussing two periods of continental extension and closure (Wilson cycles) as the mechanism by which the geology of the region evolved.

2.2 The Sudbury Event and Sudbury Structure

The Sudbury Event has been the topic of intense debate since the mid-sixties, when R.S. Dietz proposed that a meteorite impact was the mechanism by which the Sudbury Structure, Sudbury Igneous Complex (SIC) and Onaping Formation were produced (Figure 2-2). The publishing of Dietz's 1964 *Sudbury Structure as an Astrobleme*, was contradictory to the original hypothesis that the Sudbury Structure and Onaping Formation were the products of massive explosive volcanism (e.g. Stevenson, 1972; Muir, 1984), with the SIC interpreted as the intrusive equivalent. Current consensus supports the interpretation that the Sudbury Structure is the deformed and deeply eroded remnants of a peak-ring, or multi-ring impact basin, of approximately 200-250 km original diameter (e.g. Stöffler et al., 1989, 1994; Grieve et al., 1991; Deutsch and Grieve, 1994). Grieve et al. (1991) suggest that a 100 km transient crater would be a ringed basin without a central peak, and have a final gravity-modified diameter of 200 km. The impacting body is calculated to have been approximately 10 km in diameter with an impact velocity of about 25 km/s (Grieve, 1994) and approximately 8-9.5 km of Huronian cover rocks are believed to have been eroded due to the impact event (Golightly, 1994, and references there in). The Sudbury Event occurred at 1.85 Ga (Krogh et al., 1984), and the Sudbury Structure is composed of the SIC and Sudbury Basin, as well as the brecciated (and shatter-coned) country rocks of the Superior and

Southern Provinces which surround the Complex (e.g. Card et al., 1984; Rousell et al., 1997). The assumptions and interpretations in the remainder of the thesis are based on the meteorite impact theory.

The Sudbury Breccia (SdBx) is a highly variable and heterogeneous rock type, produced by *in situ* brecciation (Legault et al., 2003) due to the intense cataclasis (comminution) and melting in reaction to the immense compressive and decompressive energies associated with the shock wave (Thompson and Spray, 1994; Kenkmann et al., 2000); the rock type is referred to as pseudotachylite. The target rocks are variably reduced in grain size from blocks and mega blocks (mm- to tens of metres in scale) to rock flour. The heat associated with the shock wave energy caused the rock flour to melt locally, and subsequently become the aphanitic matrix material enclosing the larger clasts. The breccia matrix and clasts are the same compositions, as they were derived from the same original rock; however, Sudbury Breccia does vary in whole rock composition about the Sudbury Structure in response to the different target rock units. Sudbury Breccia occurs irregularly and discontinuously about the SIC with the greatest abundance within a 50-km radius of the Sudbury Structure. Sudbury Breccia has been recognized as far away as Lake Temagami, 80 km north of the SIC (Simony, 1964; Peredery and Morrison, 1984; Dressler, 1984; Thompson and Spray, 1994).

Immediately after the shock wave energy created the Sudbury Breccia, the impact energy created the Footwall Breccia (FwBx, also known as Leucocratic Breccia, Granite Breccia, and Late Granite Breccia in mine terminology). The Footwall Breccia is heterogeneous, and can be best described as an '*in situ* impact breccia'. It occurs as irregular and discontinuous zones of material between the Sublayer and the Footwall

rocks in the North and East Ranges (Coats and Snajdr, 1984; Rousell et al., 1997; McCormick et al., 2002), where the matrix is generally composed of plagioclase, quartz, pyroxene, amphibole, biotite, and granophyric quartz-feldspar intergrowths in varying proportions, and has undergone contact metamorphism in response to cooling of the overlying SIC. Grieve (1994) refers to the FwBx as a thermally metamorphosed polymict breccia, though it may vary from igneous to metamorphic-textured (Farrow and Lightfoot, 2002). The composition varies about the Sudbury Structure and is directly related to the original country rocks. In the South Range where metasedimentary and metavolcanic rocks were the target, the composition of the Footwall Breccia reflects these protoliths.

The immediate target rocks were variably brecciated, melted, or completely vaporized with the impact and ejected from the crater forming a plume (Ames and Gibson, 1995; Ames et al., 1997; Ames, 1999; Ames et al., 2002; Mungall et al., 2004). Collapse of the transient cavity produced discontinuous mass-flow deposits at the base of the Onaping Formation, upon which the fallback breccia, and finer plume collapse units fell (Ames and Gibson, 1995; Ames et al., 1997; Ames, 1999; Ames et al., 2002; Mungall et al., 2004). The meteorite (or comet) is believed to have impacted into a shallow marine basin in the foreland of the Penokean Orogen (Mungall et al., 2004; Peredery and Morrison, 1984). This is interpreted by the abundance of carbonaceous clasts (mudstone) in the upper kilometre of the Onaping Formation (Ames, 1999; Mungall et al., 2004).

The Onwatin, Vermilion, and Chelmsford Formations along with the Onaping Formation make up the Whitewater Group (Figure 2-2). The Onaping Formation is the lowest unit of the basin-fill sequence, followed by the Vermilion (carbonates and

turbidites), the Onwatin (carbonaceous shales), and the Chelmsford (greywacke turbidites) Formations (Rousell, 1984b). Cowan and Schwerdtner (1994) suggested that the deposition of the Onwatin and Chelmsford Formations occurred within 6 Ma of the Sudbury Event.

2.3 Sudbury Igneous Complex

The Sudbury Igneous Complex (SIC) has been interpreted as a completely endogenic, crustally contaminated, mantle-derived differentiated magma (Naldrett and Hewins, 1984; Naldrett et al., 1986), to an impact-induced crustal melt sheet (Dietz, 1964). Variations on these two 'end-member' hypotheses include partial impact melt and partial mantle melt (Dence, 1972; Dressler et al., 1987; Chai and Eckstrand, 1994), and impact-triggered magmatism (French, 1970). Current consensus generally supports the interpretation that the SIC is an impact-generated melt (a crustal melt sheet) (e.g. Deutsch et al., 1995; Marsh and Zieg, 1999), which underwent closed-system fractional crystallization (e.g. Therriault et al., 1996). Interpretation of high resolution seismic reflection data from the LITHOPROBE transect through the area (1991-1994) does not indicate a 'hidden mafic mass' or a feeder dyke system below the SIC (e.g. Milkereit et al., 1992; Milkereit et al., 1994; Deutsch and Grieve, 1994; Boerner et al., 2000). Isotopic studies reveal a crustal signature (e.g. Deutsch, 1994; Dicken et al., 1999), and the ratio of melt volume to diameter is consistent with the impact melt model (Grieve et al., 1991). Grieve (1994) suggests that the original volume of impact melt was greater than 10^4 km^3 .

The crustal melt sheet is interpreted to have been superheated with vigorous convection cells developing in and homogenizing the felsic and mafic layers (granophyre

and norite, respectively), and cooling the magma to its liquidus (Zieg, 2001). Further cooling is interpreted to be through normal conductive processes, causing the norite to cool from the base up, and the granophyre to cool from the top down (Zieg, 2001).

Marsh and Zieg (1999) calculated that the impact instantaneously melted the target rocks at approximately 1900 °C, which subsequently took about 100,000 years to solidify, while Ivanov and Deutsch (1999) believe the SIC was superheated to approximately 2000°C and took up to 2 Ma to cool.

The Sudbury Igneous Complex is divided into two units: the Main Mass and the Sublayer. Previously the Sublayer had been further subdivided into Contact and Offset Sublayer (Collins, 1937, Giblin, 1984). Recent work by Lightfoot et al. (1997b) considers the offsets as composite systems where the unmineralized- and inclusion-poor offset quartz diorite (QD) is related to the Main Mass, while the mineralized- and inclusion-bearing offset quartz diorite (IQD) may be related to the Sublayer. The varying phases of offset quartz diorite are believed to represent multiple pulses of magma injection into offset structures, with the unmineralized- and inclusion-poor quartz diorite representing a very early and primary magma injection, followed by a second mineralized- and inclusion-bearing quartz diorite magma injection (Farrow and Lightfoot, 2002).

The Main Mass is composed of the Norite, which is stratigraphically overlain by the Quartz-Gabbro transition zone, and the Granophyre on top (Figure 2-2). The Granophyre varies in thickness from approximately 1000 m in the North Range, to approximately 700 m in the South Range. It is composed of quartz-feldspar micrographic intergrowth (granophyric intergrowth), and plagioclase in a 3:1 ratio, with lesser biotite,

amphibole, augite, and accessory oxides, apatite and titanite (Naldrett et al. 1970; Naldrett and Hewins, 1984). The Granophyre contact with the Quartz-Gabbro is gradational, and the mineral proportions vary with slightly greater mafic content (Naldrett and Hewins, 1984). Therriault et al. (1998, 2002) attempted to subdivide the SIC further by introducing a second 'transition zone', an approximately 200 m unit occurring between the granophyre and the quartz-gabbro, followed by the norite and sublayer. Their proposed transition zone unit represents a gradational zone through which the SiO_2 content increases due to removal of iron due to precipitation of Fe-Ti oxides (magnetite $\pm$ ilmenite) (Therriault et al., 1998).

The thickness of the traditional Quartz-Gabbro transition zone is approximately 200 m in both the North and South Ranges. The mineralogy, from greatest to least abundance, is plagioclase, quartz-feldspar granophyric intergrowth, augite, biotite, amphibole, oxides, apatite, and titanite. The lower contact of the Quartz-Gabbro with the Norite is also gradational.

The Norite may be subdivided into 'Felsic Norite' and 'Mafic Norite' in North Range (950 m and 250 m thick, respectively), and 'South Range Norite' and 'Quartz-rich Norite' in the South Range (1050 m and 350 m thick, respectively), and these subdivisions are directly related to the degree of contamination from the immediate country rock. Norite is generally composed of plagioclase, quartz-feldspar granophyric intergrowth, hypersthene, augite, and biotite and primary amphibole (Naldrett et al., 1970, and Naldrett and Hewins, 1984). In the North Range the Mafic Norite is composed of hypersthene, plagioclase, and quartz-feldspar granophyric intergrowth in roughly equivalent proportions, with lesser augite. The Felsic Norite is composed of plagioclase,

quartz-feldspar granophyric intergrowth, hypersthene and augite in a 4:2:1:1 ratio. An idealized stratigraphic column comparing the mineral compositions of the North and South Ranges is found in OGS Special Volume 1, page 238.

At the base of the Norite is the irregular rock unit known as the Contact Sublayer; this is the unit that contains the original discovery of Ni-Cu ore made by Slater and A. Murray in 1856, receiving little interest until 1883 when T. Flanagan made a similar discovery which was then acquired and developed by T. Murray as the Murray Mine (Giblin, 1984). The Contact Sublayer has three components: silicates, sulphides, and inclusions. The silicate component of the Contact Sublayer is norite, composed of hypersthene, augite, and plagioclase with lesser amounts of quartz, quartz-feldspar granophyric intergrowths, and Fe-oxides (Naldrett et al., 1984). Nickel-copper-iron sulphides vary from trace to greater than 60 modal % (Naldrett et al., 1984). The inclusion types are commonly locally derived, but exotic mafic and ultramafic inclusions that have no observed footwall rock equivalents had provoked hypotheses of a 'hidden zone' of the SIC from which these rock types were derived (Naldrett and Kullerud, 1967); as mentioned earlier, the LITHOPROBE transect through the area does not indicate a 'hidden zone' of mafic/ultra mafic material (e.g. Milkereit et al., 1992; Milkereit et al., 1994; Deutsch and Greive, 1994). The Contact Sublayer generally occupies large (km-scale) embayment structures or depressions (e.g. Rousell et al., 1997) such as the Levack Embayment or the Whistle Embayment, where large deposits of Ni-Cu ore have been mined.

The quartz diorite Offsets are found as irregular dykes emanating radially from the Contact Sublayer, or emplaced concentrically about the Sudbury Structure. The

Offset Dykes are composed of what has traditionally been termed Quartz Diorite (QD), but actually varies between quartz monzonite and granodiorite (Grant and Bite, 1984; Lightfoot et al., 1997; Wood and Spray, 1998). Compositionally, the Offset QD are most similar to the Felsic Norite of the Main Mass (Grant and Bite, 1984; Lightfoot et al., 1997a, 1997b), and the compositional variation between North and South Range QD is believed to be due to assimilation (contamination) of wall rocks local to offset structures by the QD magmas (Lightfoot et al., 1997a, 1997b). Although the composition of QD varies slightly from offset to offset, the general composition of unmineralized QD is believed to represent the primary composition of the undifferentiated melt sheet (Thomson, 1935; Lightfoot et al., 1997a, 1997b).

Grant and Bite (1984) subdivided offset QD into 'Main Dyke QD', 'Offset Dyke Contact QD', and 'Contaminated QD'. The 'Main Dyke QD' of the South Range Copper Cliff Offset was further subdivided into three groups based on and named after the dominant mafic mineral: hypersthene QD, pyroxene QD, and amphibole-biotite QD (Grant and Bite, 1984). A 'spherulitic' textured QD (Offset Dyke Contact QD group) has been documented by Grant and Bite (1984), and interpreted to have developed by rapid cooling (quenching) against the country rocks. All QD types are assemblages of plagioclase, quartz, K-feldspar, quartz-K-feldspar granophyric intergrowth, mafic minerals (pyroxene, and/or primary and secondary amphibole, and/or biotite), with accessory apatite, titanite, leucoxene, and ilmenite (Grant and Bite, 1984).

The Contact and Offset Sublayer host many of the Ni-Cu-PGE deposits in the Sudbury area. These rocks were recognized as the primary hosts in the late 1800s. Footwall Breccia is the most common host to the ore in the Levack Embayment of the

North Range of the Sudbury Structure, such as at Lower Coleman, Hardy and Craig mines. Sudbury Breccia zones also host Cu-PGE-rich ore bodies, such as the Deep Copper Zone at the Strathcona Mine (Falconbridge Ltd.), and McCreedy West footwall ore zone (FNX Mining Company Ltd., formerly INCO Ltd.). Sudbury Breccia zones have become the target of new exploration as the Sublayer deposits become depleted (e.g. Big Boy vein of the Broken Hammer Zone in Wisner township (Wallbridge Mining Company), and Nickel Rim South (Falconbridge Ltd.).

2.4 Whistle-Parkin Offset

The Whistle-Parkin Offset is located approximately 32 km N-NE of the city of Sudbury in Norman township; it contains a radial dyke extending northeast from the northeastern corner of the SIC (Figure 2-2). This offset is connected to the Main Mass of the SIC through an embayment structure which contained contact-type Ni-Cu-(PGE) ore developed and mined by INCO Ltd. as the Whistle mine (Figure 1-1). The Whistle mine was in operation from 1988 to 1991, and 1994 to 1997, and produced 5.7 million tons of ore (grading 1.0% Ni and 0.3% Cu). Currently, FNX Mining Company Ltd. holds the rights to the property, which is now referred to as the Podolsky Property, (previously the Norman Property and the Whistle Property); the offset is undergoing active exploration of the 2000 Deposit and North Deposit (Figure 1-1).

Pattison (1979) described the Whistle-Parkin Offset as a "poorly defined offset dyke", as it is not a continuous quartz diorite dyke in the same sense as parts of the Copper Cliff or Worthington Offsets are. Copper Cliff and Worthington are characterized by a more or less continuous QD $\pm$ IQD body (dyke), where interpretation

suggests that the QD phase was injected into the structure first, followed by a secondary pulse of IQD, generally through the centre of the QD (e.g. Lightfoot and Farrow, 2002).

The Whistle-Parkin Offset (Figure 2-3) may be subdivided into two sections: the part of the offset emanating from the embayment structure is referred to as the Whistle Offset. At its most northerly extent (2 km from the contact), the structure is offset 2 km to the northwest along the Post Creek fault. The remaining 10 km of the dyke is referred to as the Parkin Offset (Grant and Bite, 1984); Lightfoot et al. (1997b) and Murphy and Spray (2002) provide detailed descriptions of this section of the dyke. The Whistle Offset does not contain a continuous dyke-shaped body of QD $\pm$ IQD; it contains pods of QD and LQD in IQD and heterogeneous Footwall Breccia. In contrast, the Parkin Offset does contain a continuous dyke-shaped body of QD $\pm$ IQD (Lightfoot et al., 1997b; Murphy and Spray, 2002), much like the Copper Cliff and Worthington Offsets. This being the case, the Whistle-Parkin Offset can be referred to as a "hybrid" offset (C. Farrow, Chief Geologist, FNX Mining Company Ltd., personal communication), where two different styles of QD injection exist.

The Whistle Offset is hosted by Archean granite, gneiss, gabbro, and diabase dykes, as well as Early Proterozoic Nipissing Diabase, and metasedimentary and metavolcanic rocks. The Parkin Offset is hosted by the same rock types, as well as Huronian metasedimentary rocks.

2.5 Post-Sudbury Event Metamorphism and Deformation

The Penokean Orogeny (1.7-1.9 Ga) was ongoing at the time of the Sudbury Event. Metamorphism and deformation of the Archean and Early Proterozoic rocks has been discussed in section 2.1. Essentially the rocks of the Levack Gneiss Complex

reached granulite facies due to initial burial, and were subsequently retrogressed to amphibolite facies during uplift (James et al., 1991; Boast and Spray, 2003).

At 1.85 Ga the Sudbury Event occurred and the Archean and Early Proterozoic target rocks were subjected to high temperatures initially, followed by about 100,000 years of cooling of the SIC (Marsh and Zieg, 1999), producing a metamorphic aureole in the brecciated host rocks. Dressler (1984) defined the contact metamorphic aureole surrounding the SIC radially for about 1.5 km, where the degree of metamorphism ranges outward from pyroxene hornfels through hornblende hornfels to a plagioclase recrystallization zone, which corresponds to albite-epidote hornfels facies (Boast and Spray, 2003). As the SIC continued to cool, circulation of fluids caused a final retrogression of the highest-grade rocks (including the Footwall Breccia) to greenschist facies (Boast and Spray, 2003).

The present day elliptical shape of the Sudbury Structure (30 x 60 km) is due to northwest-directed shortening along the South Range shear zone (Shanks and Schwerdtner, 1990; Cowan and Schwerdtner, 1994). The original basin/crater shape is not believed to have been circular, but elliptical with the long axis/short axis ratio estimated as 1.5 prior to deformation, and 2.2 after deformation (Rousell, 1984a). Cantin and Walker (1972), Rousell (1972, 1984a), and Rousell et al. (1997) provide evidence of the original ellipsoid-shaped basin/crater based on paleocurrent measurements in the Chelmsford Formation, however, Boener and Milkereit (1999) suggest that later deformation (shortening) may bias the paleocurrent indicators.

Cowan and Schwerdtner (1994) discuss how the originally horizontal layering of the SIC may have undergone solid-body tilting (folding) to create the elliptical basin

shape, and they proposed that the inclination may have occurred more than 2.5 Ma after impact, or possibly 3 to 10 Ma. More recent work by Cowan et al. (1999) however, reports three independent lines of structural evidence from the Sudbury Structure which suggest that the SIC was not a horizontal sheet at the time of consolidation, and that it was originally parabolic in plan view (non-circular) at this time as well.

Boerner and Milkereit (1999) acknowledge the generally undeformed state of the North Range in comparison to the South Range, and use seismic data in conjunction with geologic and geochemical data to suggest that the "North Range was somehow mechanically decoupled from collision and subsequent relaxation", and that the "decoupling may have been accomplished in zones and could be related to the high-metamorphic grade contrasts across the Murray Fault Zone."

The South Range Shear Zone (SRSZ) is considered to have been a key structure in facilitating the large-scale asymmetric folding of the rocks of the Sudbury Structure, creating the doubly plunging synform (Cowan and Schwerdtner, 1994). Cowan and Schwerdtner (1994), Rousell et al. (1997), Cowan et al. (1999), and Boerner et al. (2000) provide in-depth discussions on the tectonic evolution of the area.

Mesoproterozoic (Middle Proterozoic)

1000 Ma	<i>Grenvillian Orogeny</i>
1238 Ma	Sudbury Dike Swarm (Olivine Diabase)
1415 Ma	Hornblende (Quartz) Diabase Dikes
1475 Ma	Crocker Island Complex

Paleoproterozoic (Early Proterozoic)

1648 Ma	Gabbro Dikes
1700 Ma	Chief Lake Batholith
1700 Ma	Alkali Metasomatism ●
~1700 Ma	<i>Retrograde metamorphism and deformation of Penokean Orogeny</i>
1747 Ma	Wanapitei Complex ■
1775 Ma	North Channel Dikes
1850 Ma	Sudbury Event: Sudbury Structure: Sudbury Breccia and other shock-related features, SIC and Onaping Formation ■□
~1900 Ma	<i>Peak metamorphism and deformation of Penokean Orogeny</i>
2167 Ma	Preissac (Biscotasing) Dikes
2219 Ma	Nipissing Diabase ■▲○
2200 – 2400 Ma	<i>Bleazardian Pulse of Penokean Orogeny</i>
2200 – 2500 Ma	Huronian Supergroup ▲◇
2333 Ma	Creighton Pluton
2377 Ma	River Valley Complex ■
2452 Ma	Matachewan Dikes
2477 Ma	Murray Pluton
2480 Ma	East Bull Lake Intrusion ■
2491 Ma	Shakespeare – Dunlop Intrusion ■

Archean

2711 Ma	Levack Gneiss Complex
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Table 2-1: Outline of tectonic, magmatic, and mineralization events in the Sudbury area (after Rousell et al., 1997, with modifications from Card et al., 1984). Symbols for mineralization type are as follows: ■ Ni-Cu-(PGE), ▲ Cu, ○ Ag-(Co), ● Au, ◇ U, □ Zn-Cu-Pb.

Figure 2-1: Regional geology of the Sudbury area (after Card and Wodicka, 1996, and Card and Jackson, 1995).

Figure 2-2: Regional geologic map of the Sudbury area (after Farrow and Watkinson, 1994).

Figure 2-3:

Whistle-Parkin Offset Dyke

After Murphy and Spray, 2002.

Chapter 3. Geology of the Whistle-Norman Area

3.1 Rock Types and Textures

The macroscopic distribution and petrographic characteristics of the rock types associated with the Whistle Offset are discussed below starting with the oldest rocks. Examination of the maps (Maps 1-9) will facilitate the geological perspective.

3.1.1 Archean and Early Proterozoic Rocks

▪ Intermediate and Mafic Gneiss

Intermediate and mafic gneisses of the Levack Gneiss Complex are the most common rock type occurring in the footwall of the North Range. They are the oldest rocks in the Whistle Offset area, and are cut by every other rock type. In outcrop, the gneisses are strongly banded into mafic and felsic components, as shown in Figure 3-1. An interesting phenomenon regarding the gneisses is shown in Figure 3-2 where LQD preferentially invades specific bands within the gneiss.

▪ Granite

Granite is a common footwall rock and occurs as inclusions within the FwBx and IQD. It is composed of primary quartz, K-feldspar, plagioclase feldspar, amphibole and biotite. Alteration assemblages include chlorite, epidote, secondary amphibole and biotite. Texturally, granite ranges from primary igneous textures to partially recrystallized and slightly deformed and flattened textures (particularly obvious in the quartz grains). Figure 3-3a and b display typical mineralogy and textures observed on both fresh and weathered surfaces of a granite sample; the quartz is partially recrystallized forming anhedral blebs rimmed by a fine rim of mafic minerals. Most of the plagioclase feldspar has been altered producing an alteration assemblage rich in K-

feldspar and epidote. A granite sample of different original composition is shown in Figure 3-3d; the mafic mineral content is much greater, potassic alteration of the feldspar is extensive, and local epidote veinlets are common.

Recrystallized granite occurs as inclusions in the FwBx of the Intermediate Zone (Map 6). In hand sample, the rock is pink with a sugary texture and composite quartz grains (≤ 0.5 cm) that look like tapioca beads as shown in Figure 3-3c. From petrographic analysis, the recrystallized granite appears to be all quartz and K-feldspar; primary mafic minerals were not observed. Chlorite does occur in some places, generally in fractures, or surrounding composite quartz grains.

▪ **Gabbro**

Blocks of gabbroic rocks occur throughout the offset as inclusions and footwall intrusions. The gabbro is medium- to coarse-grained, equigranular, massive, and dark green on fresh and weathered surfaces. In Figure 3-4b and c, the gabbro is intruded by LQD, and a thick rind has developed around the outer margin in contact with the LQD. The rind is typically finer-grained and much darker than the unaffected gabbro, and variable in thickness (1-7cm).

An interesting feature of some of the gabbroic inclusions is shown in Figure 3-5, where thin chalcopyrite veins cut into the gabbro, and then virtually disappear at the Footwall Breccia interface. One explanation for this observation is that the chalcopyrite veins cut the gabbro prior to the Sudbury Event and were subsequently incorporated into the Footwall Breccia as suggested by Dressler (1984). A contrasting explanation involves the relative competency of the gabbro inclusion compared to the encompassing FwBx matrix. Due to the grain size (coarse-grained gabbro versus fine-grained FwBx

matrix), and the thermal state of the material (relatively cold gabbro block versus warm FwBx matrix), movement of sulphide-bearing fluid through these contrasting rocks would act quite differently, where fracturing and subsequent vein formation would occur in the gabbro, whereas the sulphide-bearing fluid would 'dissipate' in the FwBx matrix.

▪ **Diabase Dykes and Xenoliths**

Diabase dykes occur as footwall rock, and as variably sized inclusions (xenoliths) within Footwall Breccia and Inclusion Quartz Diorite (IQD). They are fine-grained, and vary from porphyritic to non-porphyritic hornfelsed pyroxene-magnetite-bearing diabase as described by Lightfoot et al. (1997a). In this study they are divided and referred to as plagioclase porphyritic diabase (PPD) and non-porphyritic diabase (NPD) (anhedral porphyry is used for PPD by FNX Mining Company Ltd. geologists).

Unbrecciated segments of diabase dykes adjacent to the offset are generally only a few metres wide (5 metres is at the high end), and vary in length. Figure 3-6a shows a good example of a flow differentiated PPD dyke in the Intermediate Zone (Map 7). The dyke was flow differentiated; that is, plagioclase phenocrysts are concentrated in the centre of the dyke, where the flow velocity would have been greater. In the same image, the knife-sharp contact of the diabase dyke is demonstrated quite spectacularly cutting the Intermediate Gneiss. Figure 3-6b shows the diabase dyke being cut by LQD; the contact is not sharp, and appears to be more of a gradational, uneven assimilation type contact, or a diffusion front, where equalization between the two rock types is occurring through a 'solid' state transfer process.

The plagioclase phenocrysts formed early in the evolution of the diabase magma, and were carried up with the melt in the zones of greatest flow velocity when the diabase

was injected into the Archean crust. Zoning of the plagioclase phenocrysts is quite apparent on weathered surfaces (Figure 3-6c). The groundmass is generally fine- to medium-grained, interlocking crystals of plagioclase and amphibole. The amphibole occurs as a fibrous aggregate or mass; possible pyroxene pseudomorphs were observed petrographically, supporting the idea of uralitization (replacement of pyroxene by amphibole), a consequence of deuteric alteration (Shelley, 1993). Petrographically, these diabase dykes resemble the Matachewan dyke swarm (2.45-2.47 Ga) as described by Phinney and Halls (2001).

Where the diabase is present as inclusions within the Footwall Breccia, it is quite variable in fragment size (see Maps; referred to as Matachewan), and the distinction between plagioclase porphyritic and non-porphyritic inclusions is difficult, as fragments from the edge of a porphyritic dyke would naturally be devoid of phenocrysts.

Lightfoot et al. (1997a) report that variably anhedral plagioclase porphyritic diabase make up < 30% of the inclusion population in the igneous textured Sublayer matrix (ITSM) in the Whistle Embayment.

▪ **Other Rocks**

Quartz monzodiorite (Figure 3-3e) was observed only as inclusions within the offset dyke units, specifically the FwBx and IQD. Petrographic examination of the quartz monzodiorite reveals that it is medium- to coarse-grained with a slight foliation, and composed of a fine-grained recrystallized quartz and plagioclase groundmass, with local patches of granophyric intergrowths, extensively chloritized amphibole, less extensively chloritized biotite, accessory apatite (commonly occurring in the granophyric patches), magnetite, and albite+hematite alteration veinlets; a sample was submitted for

chemical analysis. The granophyric patches are secondary and are spatially associated with chlorite and albite+hematite alteration assemblage.

3.1.2 Sudbury Event Related Rocks

▪ Sudbury Breccia

A belt of Sudbury Breccia (SdBx) oriented roughly parallel to the Whistle embayment structure is cut perpendicularly by the Whistle Offset (Figure 1-1). R. Poulin mapped this breccia belt in 2003 for FNX Mining Company Ltd. Within the offset dyke, SdBx is not common, though does occur as discrete, irregular pods or lenses (see Intermediate Zone, Map 7), and has undergone significant thermal metamorphism due to the heat from the SIC. Typical textures and mineralogy occurring in the Sudbury Breccia are available in *Appendix C*. As discussed in Chapter 2, section 2.2, the shock wave associated with the Sudbury Event released enormous amounts of energy into the various target rocks, and comminuted them to variable degrees. Thus the mineralogy is a function of the target rock, and the textures are a function of heat and energy; energy reduced grain size (comminution), while heat melted rock flour sized particles, and thermally metamorphosed the new rock type (SdBx).

▪ Footwall Breccia

Footwall Breccia is a heterogeneous unit that occurs irregularly and discontinuously at the base of the SIC and variably throughout offsets (e.g. Coats and Snajdr, 1984; Rousell et al., 1997; Lightfoot et al., 1997b; Wood and Spray, 1998; Murphy and Spray, 2002; McCormick et al., 2002). Spatially, with respect to the Whistle Offset, the FwBx occurs around the base of the Whistle embayment and defines the width

of the offset, as shown on Figure 1-2. The length of the offset is defined by the occurrence of quartz diorite intrusive facies. Morphologically, it is very irregular and discontinuous with a highly variable composition (Dressler, 1984; McCormick et al., 2002), as it is basically an *in situ* breccia produced by the energy associated with the impact event as discussed in section 2.2.

The clasts, or fragments, in the breccia vary in size from microscopic to megaclasts (20x30 metres, for example), and are composed of the previously discussed rock types (gneiss, granite, gabbro, diabase, SdBx). Point counts of the clast population reveal variable degrees of roundness, from rounded to angular, and a greater proportion of felsic igneous and metamorphic clasts relative to other clast types; this is assumed to be a function of the higher concentration of those rock types in the footwall of the area.

The matrix is composed of plagioclase, quartz, potassium feldspar, variably chloritized amphibole, pyroxene and biotite, and accessory apatite, titanite, sulphides, magnetite and ilmenite. McCormick et al. (2002) described the FwBx in the Strathcona embayment structure: the variability in colour generally relating to the felsic:mafic mineral content, and the variability in texture from granular to igneous, a function of metamorphic coarsening is due to proximity of the Sublayer and SIC (the heat source), as well as location relative to the centre (or core) of the embayment structure.

Several samples of FwBx were submitted for lithogeochemistry, and 28 thin sections were produced for petrographic examination. The main characteristic of the FwBx in thin section is the heterogeneous inclusion content in a non-igneous-textured groundmass. In places, the FwBx has undergone albite alteration, replacing calcic

plagioclase with sodic plagioclase. Zones of albite alteration are typically light pink such as in Figure 3-7a, b and c; this colouration is due to fine-grained hematite.

▪ Quartz Diorite

There are three types of quartz diorite that occur in the Whistle Offset: Quartz Diorite (QD), Leucocratic Quartz Diorite (LQD), and Inclusion Quartz Diorite (IQD). Examples of the three quartz dioritic phases are shown in Figure 3-8, and the distribution is shown on the maps. QD bodies occur as discrete pods of varying size ($0.5 \times 1 \text{ m}^2$ to $5 \times 12 \text{ m}^2$), hosted in IQD or FwBx within the offset. QD is more abundant in the Intermediate and Distal Zones, but does occur in the Proximal Zone, such as in Map 5.

As a whole, QD is fine- to medium-grained, equigranular, and massive-textured. The primary silicate mineralogy of QD from the Whistle Offset includes quartz, plagioclase, amphibole, $\pm$ biotite, and accessory apatite and ilmenite. Secondary deuteric alteration minerals are saussurite (Na-plagioclase $\pm$ zoisite $\pm$ epidote), chlorite, biotite and amphibole and titanite.

Radiating, needle-like amphiboles are a common feature in the QD and LQD, and the texture is referred to as stellate (Figure 3-9). Stellate describes an aggregate of crystals in a star-like arrangement, as opposed to spherulite, which describes a rounded mass of acicular crystals, commonly feldspar, radiating from a central point (Bates and Jackson, 1984). Petrographic observation reveals stellate features, and not spherulitic ones. Pattison (1979) described "*quench-textured igneous sublayer*" from the Whistle Offset. Comparison of "*quench-textured igneous sublayer*" (Pattison, 1979, p. 267) to stellate-textured QD and LQD clearly shows that they are one and the same.

Needle-like amphibole grains imply very rapid crystal growth in one direction, and indicate dis-equilibrium conditions during crystal growth (Shelley, 1993). This occurs when diffusion rates are slow relative to growth rates, that is, ions of the appropriate elements are not as abundant locally about the growing grain, thus the grain "reaches out" to scavenge a greater area (Shelley, 1993).

As mentioned above, Pattison (1979) described these rocks as "*quench-textured*"; "*quench-textures*" are dis-equilibrium textures, and these develop due to changes in pressure and/or temperature. Granophyric intergrowths of quartz and feldspar are also dis-equilibrium textures and are typically the product of volatiles being driven off inducing rapid crystallization (Barker, 1970; Shelley, 1993); this is generally a function of pressure change (Shelley, 1993). Considering that the stellate amphibole and granophyric intergrowths occur throughout the quartz-dioritic phases, it can be assumed that at least a pressure change occurred to create these textures.

▪ **Leucocratic Quartz Diorite**

Leucocratic Quartz Diorite (LQD) bodies occur as irregular pods in the Proximal and Intermediate Zones of the Offset. LQD pods are much greater in size than QD pods at surface (see Maps and Table 3-1). Mineralogically, LQD is much the same as QD with greater potassic-feldspar content. Very elongate and thin stellate amphibole is common around the outer margins of the LQD pods, with amphibole grains generally less stellate (stubbier) near the centre of the LQD pods (see Figure 3-8f); this is likely a function of pod size (in combination with rapid crystallization due to volatile loss), as stellate amphibole is quite common throughout QD pods which are generally smaller. In any case, the occurrence of stellate amphibole in LQD is compatible with a quench origin as

discussed above. Table 3-1 outlines the similarities and differences between the quartz dioritic phases.

Table 3-1

	QD	LQD	IQD
Primary Mineralogy	qtz, plag, granophyre, amph $\pm$ bt	qtz, ortho, plag, granophyre, amph $\pm$ bt	qtz, plag, granophyre, amph $\pm$ bt (+ inclusions)
Accessory Mineralogy	apt + ilm + hem	apt + ilm + hem	apt + ilm (+ hem)
Deuteric Alteration Mineralogy	chl Na-plag $\pm$ zoisite $\pm$ ep titanite Fe-oxyhydroxide	chl Na-plag $\pm$ zoisite $\pm$ ep titanite Fe-oxyhydroxide	chl Na-plag $\pm$ zoisite $\pm$ ep titanite Fe-oxyhydroxide
Textures	Fine- to medium-grained; equigranular with local stellate features	Medium- to coarse-grained; equigranular with local stellate features	Fine- to medium-grained; inequigranular to variably equigranular
Spatial Association	Pods within IQD and FwBx	Abuts footwall rocks; partial contact with IQD	Irregular bodies within the offset structure
Morphology	Small, irregular pods (0.5x1 m ² to 5x12 m ²)	Large, irregular pods (2-4x larger than QD pods)	Large, irregular pods (larger than QD & LQD); gradational into FwBx

▪ Inclusion Quartz Diorite

Inclusion Quartz Diorite (IQD) is essentially inclusion-bearing QD. Stellate-textures are not observed in IQD, but the mineralogy is generally identical to that of QD (as outlined in Table 3-1). The inclusions are generally locally derived footwall rocks, and vary in size over a range from microscopic to mega-clastic (tens of metres) (Figure 3-8g-i). Point counts of inclusion types reveal a variable degree of roundness from rounded to sub-rounded, and with felsic igneous and metamorphic clasts as the dominant inclusion

type (granitoids and gneisses) followed by mafic igneous clasts. Due to the great inclusion content, contamination of the igneous melt through assimilation processes undoubtedly occurred. Geochemical results will be discussed in the following chapter.

3.1.3 Post Sudbury Event Rocks

▪ Sudbury Olivine Diabase Dyke

A single olivine diabase dyke, approximately 6 metres wide, cuts west-northwest across the Whistle Offset structure and country rocks in the Intermediate Zone (Map 6). The dyke is steeply dipping to near vertical (approximately 70° or greater), and is more or less continuous except where it has been offset approximately 60 metres to the north by a late fault on the east side of the Whistle Offset structure (Figure 1-2).

The Sudbury Olivine Diabase Dykes are a post Sudbury Event intrusive facies, as demonstrated by cross cutting relationships. Van Schmus (1965) and Fahrig and Wanless (1963) dated the dykes at approximately 1250 ± 50 Ma (the Middle Proterozoic) using radiometric K-Ar and Rb-Sr. More recent work by Krogh et al. (1987) date the olivine diabase dykes at 1238 ± 4 Ma.

The Sudbury Olivine Diabase Dykes are commonly medium- to coarse-grained, and composed of plagioclase, augite, olivine, and biotite (Dressler, 1984); accessory apatite is also present. The Olivine Diabase Dykes are characteristically moderate to strongly magnetic due to high magnetite content. See *Appendix C* for images of typical textures and mineralogy.

3.2 Petrography and Mineral Chemistry

Petrographic observation and description of the Archean and Early Proterozoic rocks, the Sudbury Breccia, and post-Sudbury Event rocks are briefly discussed above. As these rocks are not the focus of the project, limited petrographic descriptions and no mineral chemical analyses were performed. The quartz dioritic rocks and the Footwall Breccia are the focus of the study and therefore extensive mineral chemical analyses were performed on these rock types.

▪ Feldspar, Quartz, and Granophyric Intergrowths

Plagioclase feldspar ($\text{NaAlSi}_3\text{O}_8$ - $\text{CaAl}_2\text{Si}_2\text{O}_8$) is common throughout all quartz diorite phases and the FwBx. It is generally lath shaped, colourless in plane-polarized light, and varies in grain size from medium to coarse. Albite twinning is common, though it becomes less obvious where alteration has affected the grains, obliterating the twinning to varying degrees. The alteration products of calcic plagioclase are characteristically sodic plagioclase $\pm$ zoisite $\pm$ epidote, which appear as a heterogeneous grey speckled mixture under plane polarized light. Under cross-polarized light, the alteration appears as many tiny flecks in multiple colours; Figure 3-10 shows examples of the alteration.

Potassic feldspar (KAlSi_3O_8) is also a common constituent of the quartz diorite phases and FwBx. It is commonly colourless to very pale pinkish-brown under plane-polarized light, and is typically intergrown with quartz as granophyre. Eleven K-feldspar grains were analyzed with the electron microprobe (see *Appendix D*, data Table 1); the grains analyzed were all granophyrically intergrown with quartz (except LQD5A-4), and

are very similar in composition. Figure 3-11 shows the analyses plotted on K-Ca-Na and Si-Al-Fe ternary diagrams.

Quartz (SiO_2) is a common mineral in all the rocks types. It occurs as discrete irregularly shaped grains, but more importantly as granophyric intergrowths with feldspar (Figure 3-12). Simultaneous coupled growth of quartz and alkali feldspar to produce granophyric intergrowths occurs in near surface conditions at low water pressures due to the loss of volatiles, producing rapid undercooling and freezing (Shelley, 1993). The quartz intergrown with feldspar is optically continuous, coming to extinction as a single grain would. The granophyric material is often found having nucleated on a pre-existing plagioclase phenocryst (Figure 3-10e and f), the product of earlier slow cooling (and/or pre-cotectic crystallization) (Shelley, 1993). Quartz-feldspar granophyric intergrowth dis-equilibrium textures are quite common in QD and LQD, and occur locally in IQD and FwBx.

▪ Amphibole

Fifty-two electron microprobe analyses were made on amphibole grains from QD, LQD, IQD and FwBx samples from along the length of the offset. Original data, sample recalculations, classification tables, and back-scattered electron (BSE) images are presented in *Appendix D*. All amphiboles analyzed were calcic in composition, as shown by Figure 3-13a. Further classification, using the average of the 15eNK and 13eCNK recalculation methods (Appendix x), shows that the majority of the amphibole analyzed is magnesio-hornblende, with lesser actinolite, edenite, and ferro-actinolite compositions (Figures 3-13b and c).

Table 3-2 lists the chemical formulae per amphibole composition. The six analyses of edenite all occur on the east side of the offset in the Proximal Zone (Proximal #3 and #5 areas).

Table 3-2

Name	Chemical Formulae
<i>Amphibole Formula Unit</i>	$(\text{Ca, K, Na})_2(\text{Fe, Mg, Al, Ti})_5(\text{Si, Al})_8\text{O}_{22}(\text{OH})_2$
Magnesio-hornblende	$\square\text{Ca}_2[\text{Mg}_4(\text{Al, Fe}^{3+})]\text{Si}_7\text{AlO}_{22}(\text{OH})_2$
Actinolite	$\text{Ca}_2(\text{Mg, Fe}^{2+})_5\text{Si}_8\text{O}_{22}(\text{OH})_2$
Edenite	$\text{NaCa}_2\text{Mg}_5\text{Si}_7\text{AlO}_{22}(\text{OH})_2$
Ferro-actinolite	$\square\text{Ca}_2\text{Fe}^{2+}_5\text{Si}_8\text{O}_{22}(\text{OH})_2$

Relatively unaltered, homogeneous amphibole grains were sought for electron microprobe analysis. Alteration of amphibole grains is variable throughout the sample suite, with chloritic mottling developed along cleavage planes to various degrees (Figure 3-14). Zoning is irregularly developed in amphibole, with ferro-actinolitic zones near oxides or sulphides (Figure 3-14b).

A plot of $[\text{Fe}/(\text{Fe}+\text{Mg})]$ versus $\text{Na}+\text{K}$ (Figure 3-15) shows a general positive correlation between the variables, and suggests some degree of potassic and sodic alteration of the amphiboles.

Figure 3-16a is a Cl versus F graph where the analyses have been grouped with respect to zones from which the samples were collected. A 1:1 chlorine to fluorine line has been added to the diagram, and clearly shows that the amphibole from all zones is generally enriched in F relative to Cl. Figure 3-16b shows a regression line and correlation coefficient when all the data are plotted as a group.

The F-Cl-OH ternary diagram (Figure 3-17) shows the distribution of the halogen species in the OH site; OH was calculated using the formula $2-(\text{F}+\text{Cl})$. Chlorine ranges

from 0.000 to 0.095 atomic % with an average value of 0.049 atm.%, and fluorine ranges from 0.012 to 0.342 atomic % with an average of 0.121 atm. % in the samples analyzed.

Chlorine correlates positively with Fe (Figure 3-18: Fe# vs. Cl#), as does Mn (Figure 3-19: Fe# vs. Mn).

▪ Biotite

As biotite is a rare mineral in the quartz dioritic phases, only four analyses were obtained (data table in *Appendix D*). Fluorine ranges from 0.45-0.47 wt. %, while chlorine ranges from 0.17-0.38 wt. %.

▪ Chlorite

Selective alteration of primary mafic minerals (amphibole and biotite) by chlorite $[(\text{Mg}, \text{Fe}^{2+}, \text{Fe}^{3+})_6\text{AlSi}_3\text{O}_{10}(\text{OH})_3]$ is quite extensive as shown in Figure 3-8.

Approximately 10% of primary amphibole remains unaltered (or partially altered) by chlorite. Primary biotite is a rare mineral phase in the QD and LQD, but where present it is generally partially or completely altered to chlorite.

Twenty-seven electron microprobe analyses were performed on chlorite grains; data and BSE images are in *Appendix D*. The chlorite is clearly more F-rich relative to Cl (Figure 3-20); chlorine ranges from 0.00-0.08 wt. % with an average value of 0.02 wt. %, while fluorine ranges from 0.00-0.17 wt. % with an average value of 0.08 wt. %.

Figure 3-21 shows the data plotted on a Fe/(Fe+Mg) versus Mn graph. The data cluster closely and the relationship is close to 1:1.5.

▪ Apatite

Apatite $[\text{Ca}_5(\text{PO}_4)_3(\text{F}, \text{Cl}, \text{OH})]$ is a common accessory mineral in the quartz diorite phases of the offset. The apatite crystals are fine-grained ($\leq 1\text{ mm}$), elongate (in some

cases with an aspect ratio of 1:40), and characteristically pale green, with high relief and a pebbly surface texture. They commonly occur in quartz-feldspar granophyric intergrowths, and occasionally contain axial melt inclusions of quartz-feldspar granophyric material (Figure 3-22). The crystal habit in association with the granophyric intergrowths is compatible with rapid growth and crystallization from a volatile-rich magma.

Sixty-six electron microprobe analyses were carried out on apatite grains from quartz-dioritic phases at different intervals along the Whistle Offset; electron microprobe data and back-scattered electron images are found in *Appendix D*. The analyses consistently show that the apatite is fluorian (Figures 3-23 and 3-24), suggesting that most of the Cl in the magma was exsolved in the fluid/volatile phase. Boudreau et al. (1986) and Farrow and Watkinson (1999) reported that Cl is generally less soluble than F in silicate melts in the presence of aqueous fluid. This Cl may have been available to act as a ligand for copper and precious metal element transport, and their subsequent precipitation as veins (such as in the Distal Zone). Halogen site species average 3.14 wt. % F and 0.04 wt. % Cl in composition. These are quite comparable to apatite compositions from other offset dykes, where fluorine and chlorine values generally range from 2.39-3.45 wt. % and 0.00-0.05 wt. %, respectively (Stewart, 2002; Magyarosi, 2002). No distinction in apatite composition within the different quartz dioritic phases or within the different zones was observed. F-rich apatite compositions are typical throughout the SIC (Farrow and Watkinson, 1999).

Back-scattered electron imagery reveals that apatite grains are generally homogeneous or more commonly irregularly mottled with respect to REE concentrations

(Figure 3-25). Typical core-margin crystallographic-axis zonation patterns are not common. Cerium, neodymium, and lanthanum vary the greatest in these zones, and it is through coupled substitution with Si and Na ions for Ca and P sites that the charges are compensated for and the zonations occur [$\text{REE}^{3+} + \text{Na}^+ \rightarrow \text{Ca}^{2+} + \text{Ca}^{2+}$ and $\text{REE}^{3+} + \text{Si}^{4+} \rightarrow \text{Ca}^{2+} + \text{P}^{5+}$] (Roeder et al., 1987; Hughes and Cameron, 1991). In addition to REE, Na, Sr, and Mn may substitute for Ca, while Si most commonly substitutes for P (Roeder et al., 1987). Due to very low diffusion rates of REE in apatite, zoning is preserved reflecting the variability (chemical and physical) of the magmatic environment (Roeder et al., 1987).

Average compositions of the REE oxides are as follows: 0.28 wt. % Ce_2O_3 , 0.15 wt. % Nd_2O_3 , and 0.14 wt. % La_2O_3 . Figure 3-26a demonstrates the relationship between (Si+Na) and the REE. A line representing a 1 to 1 ratio between (Si+Na) and REE clearly shows the general proportionality between them. The analyses plot slightly below the line where only the elements La+Ce+Pr+Nd+Sm are considered, but the addition of yttrium pulls the analyses closer to the idealized 1 to 1 substitution (Figure 3-26b). Figure 3-27 shows the same graphs and data, however regression lines and confidence intervals have been applied to the data per zone; clearly the Proximal and Intermediate Zones overlap very tightly, while the wider spread of the Distal Zone data produce a lower, but still close, regression line and confidence interval.

The irregular morphology of the REE-enriched and depleted zones, in addition to the elongate habit, axial melt cavities and inclusions, and the association with granophyric intergrowths reflects the variability of the melt environment, and the rapid rate of change within that environment.

▪ Ilmenite, Titanite, Hematite, Sulphides, and Fe-oxyhydroxides

Ilmenite (FeTiO_3) is a primary accessory mineral in the quartz dioritic phases. It is generally fine-grained with an elongate habit; Figure 3-28 shows an ilmenite grain enveloped by quartz-feldspar granophyric intergrowth. The ilmenite is rimmed by titanite (CaTiSiO_5), a calcic alteration mineral that forms during hydrothermal alteration of Ti-bearing minerals (Thompson and Thompson, 1996). In the extreme close-up image (Figure 3-28c) a third mineral phase, Ti-bearing magnetite is visible between the unaltered ilmenite and the outer titanite rim, and the very irregular nature of the alteration of the ilmenite grain is apparent. More examples of titanite growing at the expense of ilmenite are shown in Figure 3-29. Farrow (1994) analyzed titanite from the Frazer Mine Epidote Zone with results showing no compositional variation with alteration intensity, and very low halogen concentrations. Titanite forms between 200-400°C (minimum), and requires a relatively high calcium activity to stabilize (Thompson and Thompson, 1996).

A relatively small amount of hematite (Fe_2O_3) blebs occur in LQD and back-scattered electron imagery reveals the presence of exsolution lamellae of ilmenite (Figure 3-30a and b). Exsolution lamellae imply a solid solution between ilmenite and hematite, and temperatures in excess of 950°C are necessary for this to occur (Klein and Hurlbut, 1985).

Fe-oxyhydroxides, possibly goethite (HFeO_2) or limonite [$\text{FeO}(\text{OH}) \cdot n\text{H}_2\text{O}$], occur as secondary alteration rims around disseminated sulphide in quartz dioritic phases. Figure 3-30d-h show the thin Fe-oxyhydroxide rims surrounding pyrite and chalcopyrite in QD and LQD.

Discrete sulphide grains and blebs occur variably throughout the quartz-dioritic phases; Figure 3-31 displays some of the typical textures and mineralogy of these magmatic sulphides.

Figure 3-1: a) Intermediate to Mafic Gneiss immediately west of the offset in the Proximal Zone. b) Intermediate Gneiss clast in Footwall Breccia (clast is approximately 2 metres across).

Figure 3-2: LQD invading Intermediate Gneiss (Intermediate Zone, Map 7). Note the preferential invasion of the LQD into specific bands within the gneiss, as well as the "rip-off" clasts. "Injection breccia" describes these features well. Diameter of coin is approximately 1.7cm.

Figure 3-3: a) Fresh (wetted) surface of partially recrystallized granite from the Proximal zone, b) weathered surface of same granite, showing elongation of some minerals. c) Recrystallized granite (sample 067) from the Intermediate Zone, Map 6. d) Granite (sample 057) from the Intermediate Zone, Map 7 area. e) Quartz monzo-diorite inclusion from the Proximal Zone, Map 3.

Figure 3-4: a) Gabbro intruded by leucocratic dike in the footwall east of Map 3 in the Proximal Zone (field of view is ~ 20 metres). b) and c) Thick alteration rim developed on gabbro intruded by LQD, Proximal Zone, Map 3.

Figure 3-5: The sequence of photos display a chalcopyrite veinlet in a large gabbroic block, an inclusion in the FwBx in the Proximal Zone, Map 1. The inclusion to the right of the gabbro and FwBx matrix is plagioclase porphyritic diabase. The pen in the upper left photo is 13.5 cm in length.

Figure 3-6: a) Plagioclase porphyritic diabase dyke (right) cutting Intermediate Gneiss in the Intermediate Zone, Map 7. The dyke margin is essentially devoid of plagioclase phenocrysts (white), which tend to concentrate in the centre of the dyke [hammer is 36 cm]. b) Same dyke as in a), is cut by LQD pod #4. Note the diffuse intrusive contact [hammer is 36 cm]. c) and d) Plagioclase phenocrysts in diabase inclusions in FwBx. c) Alteration of phenocrysts enhances original compositional zoning textures.

Figure 3-7: Footwall Breccia: a) Albitized FwBx with mafic inclusion (top left) and plagioclase phenocryst undergoing variable alteration due to primary zoning features. b) Clasts of Plagioclase Porphyritic Diabase in albitized FwBx matrix. c) Epidote and albite or K-feldspar alteration veining. d) FwBx dominated by granitic clasts ("Granite Breccia") Map 6 area. e) Diabase clasts in FwBx affected by late movement. f) Mafic clasts in relatively unaltered FwBx matrix.

Figure 3-8: a) and b) Plane-polarized and cross-polarized light photomicrographs of QD, and c) QD in contact with FwBx in the Distal Zone (coin is 1.7cm across). d) and e) Plane-polarized and cross-polarized light photomicrographs of LQD, and f) LQD from central portion of LQD Pod #3 (Map 3). g) and h) Plane-polarized and cross-polarized light photomicrographs of IQD, and i) IQD in contact with hematized granite from the Map 8 area.

Figure 3-9: Stellate textures in QD from the Distal Zone (a), and LQD from the Proximal Zone (b and c). Also note the granitic clasts in (b); these are pieces of wall rock, and in some cases it appears as though the stellate amphibole grains nucleate on the clast as in (c).

Figure 3-10: a) Plane polarized and b) cross-polarized light images of relatively fresh plagioclase grains in LQD. c) Plane polarized and d) cross-polarized light images of variably altered plagioclase in LQD. e) Invasive alteration along twinning planes of plagioclase. f) "Disseminated" alteration homogeneously throughout plagioclase. Field of view is 7mm across for a-d, and 5mm across for e and f.

Figure 3-11: Potassic feldspar analyses plotted on
a) K-Ca-Na ternary, and
b) Si-Al-Fe ternary diagram.

Figure 3-12: Granophyric intergrowths. Commonly nucleating on plagioclase phenocrysts (a, b, c, d), which have been variably altered. Field of view for all images is 5mm across.

Figure 3-13: Amphibole classification diagrams of
a) the four principal groups using the average of 15-NK and 13-CNK (minimum and maximum Fe³⁺, respectively),
b) classification of the calcic group where ANa+AK < 0.5 and Ti < 0.5, and
c) classification of the calcic group where ANa+AK > 0.5 and Ti < 0.5, and Fe³⁺ < Al^{VI}.

Legend

- ▼ Proximal Zone
- Intermediate Zone
- Distal Zone

Figure 3-14: Back-scattered electron images of silicates. Locations of electron microprobe analyses are shown by arrows. a) Chlorite overgrowing amphibole; note Ti-bearing mineral (white) in the chlorite. b) Actinolitic-hornblende with ferro-actinolitic zone at bottom, near chlorite alteration. c) Anhedral amphibole altering to chlorite. d) Partially chloritized amphibole in quartz and altered plagioclase matrix. [Samples 27 and 53 are from the Intermediate Zone, Map 8 area, and LQD-17 and LQD-5B are from the Proximal Zone, Maps 1 and 2, respectively.]

Figure 3-16: Cl versus F (atomic %) a) per zone, and b) as a single group with regression lines, confidence intervals and prediction intervals plotted.

Figure 3-17: Amphibole analyses plotted on a F-Cl-OH ternary diagram.

Figure 3-18: Fe-number versus Cl-number a) per zone, and b) as a single group with regression line, confidence intervals and predictions intervals plotted.

Figure 3-19: Fe-number versus Mn a) per zone, and b) as a single group with regression line, confidence intervals and prediction intervals plotted.

Figure 3-20: Chlorite analyses plotted on Cl versus F graphs a) per zone, and b) as a single group with regression line and confidence intervals plotted.

Figure 3-21: Fe-number versus Mn in chlorite a) per zone, and b) as a single group with regression line and confidence intervals plotted.

Figure 3-22: Photomicrographs of apatite crystals in quartz dioritic rocks.

a-b) Plane-polarized and cross-polarized light images of apatite with axial melt inclusion of granophyric material that is optically continuous with the granophyre surrounding the grain (altered plagioclase laths contain the granophyre). Field of view is 1mm across.

c-d) Plane-polarized and cross-polarized light images of relatively stubby apatite crystals in granophyre. Field of view is 1 mm across.

e-f) Plane-polarized and cross-polarized light images of extremely elongate apatite crystals in granophyric material. Field of view is 1 mm across.

g) Cross-polarized light image of many tiny apatite crystals in granophyre. Field of view is 2 mm across.

h) Cross-polarized light image of apatite crystal with axial melt inclusion of quartz, occurring in quartz-feldspar granophyric material. Field of view is 0.5 mm across.

Figure 3-22

Figure 3-23: Both a) and b) show analyses of halogen content in apatite per zone.

Figure 3-24: Electron microprobe analyses of apatite plotted on a F-CI-OH ternary diagram reveal their fluorian nature. Variation with respect to zone is not observed.

Figure 3-25: Back-scattered electron images of apatite in false colour to enhance the irregular REE-zoning patterns. In Figures a-c and e-g, areas of bright yellow = greater REE content, while areas that are orangish-yellow = less REE. In Figures d and h, dark blue = greater REE content, and light blue = less REE.

Figure 3-26: a) Si+Na versus REE, and b) Si+Na versus REE+Y for apatite analyses. Rare earth element content is generally proportional to (Si+Na).

Figure 3-27: a) Si+Na versus REE and, b) Si+Na versus REE+Y for apatite analyses. Regression lines and confidence intervals are plotted per zone, with tables displaying the calculated coefficients.

Figure 3-28: Series of back-scattered electron images of an ilmenite grain rimmed by titanite. Between the ilmenite and titanite is a patchy area of Ti-bearing magnetite. Ilmenite is in a granophyric groundmass. Sample is from the Intermediate Zone (LQD-20A).

Figure 3-29: Back-scattered electron images of (a-b) Ilmenite with an alteration rim of titanite in LQD from the Proximal Zone, Map 1 (sample LQD-12). (c) ilmenite has been irregularly replaced by titanite in LQD from the Intermediate Zone, Map 6 (sample LQD-18). (d-e) Ilmenite with alteration rim of titanite in QD from the Distal Zone (sample 91).

Figure 3-30: Back-scattered electron images of:

a-c) Exsolution lamellae of ilmenite in hematite disseminations in LQD from the Proximal Zone, Map 2 area (sample LQD-5a).

d-h) Fe-oxyhydroxide rimming sulphide minerals in LQD and QD (d: sample LQD-5a, e-f: sample LQD-18, Intermediate Zone, Map 6, and g-h: sample 91, Distal Zone).

Figure 3-30

Figure 3-31: (a-b) Pyrite in LQD (LQD-12, Proximal Zone, Map 1, and LQD-18, Intermediate Zone, Map 6 area, respectively). (c-e) Pyrite blebs with lesser chalcopyrite in LQD and QD (c - LQD-12, Proximal Zone, Map 1, and d+e - 91, Distal Zone, respectively). f) Disseminated chalcopyrite, and g) adjoined pyrite and Ni-S grains in QD (89, Intermediate Zone, Map 6).

Chapter 4. Geochemistry

Whole rock geochemical sampling and analyses were primarily carried out in order to classify QD, LQD, IQD and FwBx compositions, and to distinguish compositional variations and possible relationships between the different phases. Less emphasis was placed on classifying diabase dyke and xenolith compositions to determine their source and whether they are segments and fragments of the Matachewan dyke swarm, or part of the SIC as proposed by Corfu and Lightfoot (1996).

Seventy-three samples were submitted to the Geological Survey of Canada Laboratories for whole rock geochemistry. Major elements were analyzed by XRF (x-ray fluorescence), trace elements by ICPMS (inductively coupled plasma emission mass spectrometry), and F and Cl by IC (ion chromatography). *Methods are discussed in Appendix B.*

4.1 Classification

Classification of the samples using whole rock lithogeochemical analyses was aided by the use of variation diagrams. Figure 4-1a is used to classify the samples based on SiO_2 versus $\text{Na}_2\text{O} + \text{K}_2\text{O}$ content (Cox et al., 1979). The Footwall Breccia samples fall into the diorite, quartz-diorite (granodiorite), syeno-diorite categories, with SiO_2 content ranging from 55.30 – 64.80 wt. %. The QD samples plot entirely within the diorite category, as does the LQD with the exception of a single sample plotting in the syeno-diorite category. The IQD plots within the diorite, syeno-diorite, and gabbro categories. The SiO_2 content of the quartz dioritic phases range from 49.30 – 61.90 wt. % for QD, 57.80 – 61.90 wt. % for LQD, and 50.50 – 58.90 wt. % IQD; clearly the SiO_2 content in the LQD is higher due to the higher proportion of felsic silicate minerals in the rock. A

comparison to this classification scheme is presented in Figure 4-1b, where a QAP (quartz-alkali feldspar-plagioclase) diagram with divisions and nomenclature from Streckeisen (1976) is used, classifying the QD as granodiorite with one sample plotting as a tonalite, the LQD as granodiorite, monzogranite, quartz-monzodiorite to quartz diorite, and the IQD as quartz-monzodiorite with one sample each plotting as monzodiorite and granodiorite. Greater emphasis is placed on the QAP diagram classification scheme than the SiO_2 versus $\text{Na}_2\text{O} + \text{K}_2\text{O}$ classification scheme. [In order to produce the QAP diagram, calculation of a norm from the bulk chemical analyses had to be carried out. Fe_2O_3 Total was used in the calculations; this will be discussed further in Chapter 5.] The variation in chemical composition is believed to be a function of contamination. Table 4-1 shows chemical compositions of other North Range offset dyke quartz dioritic magma compositions.

Table 4-1

<i>Offset</i>	<i>Chemical Composition (from QAP diagram)</i>
Whistle QD	Granodiorite to tonalite
Whistle IQD	Quartz-monzodiorite, monzodiorite, to granodiorite
Whistle LQD	Granodiorite, monzogranite, quartz-monzodiorite to quartz diorite
Parkin QD and IQD (Murphy and Spray, 2002)	Granodiorite, tonalite, quartz monzodiorite, and quartz monzonite
Hess QD (Wood and Spray, 1998)	Granodiorite, quartz monzodiorite, and tonalite
Foy QD and IQD (Tuchscherer and Spray, 2002)	Granodiorite, quartz monzodiorite, and tonalite

Jenner (1996) stated that alteration and metamorphism often makes major element geochemistry suspect and invalid, therefore greater emphasis is placed on the mineral chemistry over the whole rock geochemistry. Also, many of the classification schemes

were developed to classify glasses or other aphanitic rocks (and their metamorphic and/or altered equivalents). The grain size of the study rocks is sufficiently large enough to classify the rocks petrographically, as was discussed in Chapter 3.

In any case, the whole rock geochemistry does classify the rocks well, and clearly shows the association between the mafic and felsic parental components (diabase and gabbros, and granites and gneisses) and the resultant quartz diorite and Footwall Breccia compositions.

4.2 Major Elements

Figures 4-2 and 4-3 present some of the major element data on Harker Diagrams (where $x = \text{SiO}_2$). Positive correlations are very loosely defined for Na_2O , K_2O , and Al_2O_3 with SiO_2 , whereas negative correlations are very strong between MgO , MnO , Fe_2O_3 , CaO , TiO_2 and SiO_2 (P_2O_5 correlates weakly with SiO_2). These trends may reflect mixing between the mafic and felsic footwall rocks, which were subsequently variably melted due to the Sudbury Event and mixed to form the QD suite. [*With respect to Harker diagrams in general: they tend to be limited due to the oxide data totaling 100% producing an "artificial" trend.*]

Histograms showing the distribution of TiO_2 , Na_2O , K_2O and P_2O_5 in the whole rock samples are shown in Figures 4-4 and 4-5; the diagrams on the left display the frequency distribution per rock type per bin, while the diagrams on the right display a stacked frequency distribution of all the quartz dioritic phases together. Titanium is assumed to be primarily locked-up in the accessory mineral ilmenite (FeTiO_3) and other Ti-oxides. A bimodal distribution may be interpreted from the histogram, where the QD and LQD represent one population and the IQD represents a second, contaminated

population. It is assumed that mafic contaminants would contain Ti-oxides with greater TiO_2 content than those produced in the QD and LQD magmas.

The Na_2O histogram (Figure 4-4c-d) may be interpreted as a normal curve; more analyses may have produced a more distinct bell-shape. Plagioclase feldspar, $(\text{Na,Ca})\text{Al}(\text{Si,Al})\text{Si}_2\text{O}_8$, is the main mineral in the QD phases where sodium occurs, (hornblende $(\text{Ca,Na})_{2-3}(\text{Mg,Fe}^{+2},\text{Fe}^{+3},\text{Al})_5(\text{Al,Si})_8\text{O}_{22}(\text{OH})_8$ also contains sodium, however most of the hornblende has been altered to chlorite $(\text{Mg,Fe}^{+2},\text{Fe}^{+3})_6\text{AlSi}_3\text{O}_{10}(\text{OH})_8$). From petrographic observation, it is clear that all of the plagioclase feldspar in the QD phases has undergone some degree of alteration (saussuritization). "Saussurite", a term that has fallen into disuse, refers to "a tough, compact mineral aggregate consisting of a mixture of albite (or oligoclase) and zoisite or epidote... and it is produced by alteration of calcic plagioclase" (Bates and Jackson, 1984). Thus, it can probably be inferred that the slightly irregular density distribution of Na_2O in the whole rock analyses reflects the various degrees of alteration of the plagioclase feldspar.

The K_2O histogram (Figure 4-5a-b) displays a near normal distribution curve. Potassium primarily occurs in potassium feldspar (K-feldspar: KAlSi_3O_8) in the QD phases.

Phosphorus chiefly occurs in the accessory mineral apatite $[\text{Ca}_5(\text{PO}_4)_3(\text{F,OH,Cl})]$ throughout the QD phases. The P_2O_5 histogram (Figure 4-5c-d) displays an abnormal curve, and can be interpreted as a percent phosphorus contained within the apatite structure.

4.3 Rare Earth and Trace Elements

4.3.1 Quartz Dioritic Phases and Footwall Breccia

The rare earth element data reveal intimate similarities between the quartz dioritic phases and the FwBx rocks. Figure 4-6 shows the three quartz dioritic phases as well as the FwBx samples normalized to chondrite (Nakamura, 1974) and plotted on REE diagrams (the colours correspond to the zone from which the rocks were sampled: red = Proximal Zone, yellow = Intermediate Zone, and green = Distal Zone); the trends of all the rock types are essentially identical, with pronounced LREE enrichment relative to HREE depletion and a slight negative Eu anomaly. HREE depletion generally represents garnet in source rocks, (as garnet tends to concentrate HREE); in this case it, as well as the LREE enrichment and negative Eu anomaly, probably reflect inherited signatures from the Archean and Proterozoic target rocks. A different option with respect to Eu, could be related to alteration lowering concentrations of the element. Comparison with REE-data from the Parkin Offset (Murphy and Spray, 2002) reveals the same characteristic slope, with LREE enrichment relative to HREE depletion.

Figure 4-7 shows the same analyses as Figure 4-6, however the data has been normalized to Average North Range Felsic Norite (Lightfoot et al, 1997a). These graphs illustrate a roughly 1:1 relationship between the quartz dioritic phases and the Felsic Norite, with the relative enrichment in LREE and depletion in HREE appearing more subdued than in the chondrite-normalized (and primordial mantle-normalized) graphs.

The LREE values in the FwBx samples are generally similar to the quartz dioritic phases, whereas the HREE concentrations are consistently characterized by a gentle depression (Figure 4-7d). This HREE-depression is also observed in LQD sample LQD-11, and to a lesser extent LQD-5; both samples occur very close to LQD pod margins and

are in direct contact with unbrecciated granitic footwall rocks. Some of the IQD samples display similar, but more subdued HREE-depressions; this may suggest contamination from footwall rocks and inclusions.

Average Felsic Norite-normalized extended REE plots are shown in Figure 4-8 and were created in order to compare with data collected by Lightfoot et al. (1997, p.134) from both the Whistle and Parkin segments of the offset. [Normalizing to Average Felsic Norite was necessary for comparison with other researchers data, but it is based on the assumption that the norite was derived from a heavily contaminated mantle magma (Chai and Eckstrand, 1994), and that that magma was in a liquid state, much like the QD offsets have been interpreted to have been. *Acknowledging* these assumptions, normalizing to Average Felsic Norite should allow direct comparison of the quartz dioritic offset facies with a genetically related rock type.] All of the quartz dioritic phases exhibit a roughly 1:1 trend with respect to incompatible elements relative to Average Felsic Norite, thus the quartz diorite phases are chemically identical to the Average Felsic Norite (the QD samples from the Intermediate Zone, Figure 4-8a, are a very good example of this), confirming the genetic relationship. Slight enrichment in P, Zr and Ti are assumed to reflect apatite, zircon, and ilmenite content respectively. Variable Ba, Rb, Th, U, K, Nb and Ta values are believed to reflect the major contribution of continental crust to the SIC magma. [Continental crust signatures are apparent when Th and Nb are normalized to Primordial Mantle (McDonough et al., 1992), emphasizing the greater concentration of Th relative to Nb, a feature which is not obvious in the Felsic-Norite normalized extended REE plot (figure not shown).]

Figures 4-8h-j show the FwBx samples on the same Felsic Norite-normalized REE plot. It should be restated that care was taken to avoid inclusions in the FwBx specimens and only sample the matrix, however inclusions may have been present, influencing the geochemistry. The samples from all the Zones have virtually identical trends, with pronounced U and Ta depletion and Ba and K enrichment, variable Sr and P, and slight Zr ($\pm$ Hf) and Ti, and Y peaks. Uranium (+Th) and Ta (+Nb) depletion and the Ba and K enrichment are indicative of significant continental crust contribution. Strontium, like Eu mentioned earlier, likely reflects inherited signatures from the target rocks. Again, the P, Zr and Ti levels are most likely related to apatite, zircon, and ilmenite content respectively. Hafnium variability may reflect diabasic components (contamination/assimilation) in the FwBx matrix, as Lightfoot et al. (1997) report anomalous Hf in diabase samples from the Whistle Mine (p. 34); this is reflected in Figure 4-12c.

Lanthanum and samarium values from the quartz dioritic phases are very comparable to data from Lightfoot et al. (1997a), plotting in the same field as quartz diorite from the Parkin Offset and Main Mass felsic and mafic norites (Figures 4-9 and 4-10). The general clustering of the quartz dioritic rocks and FwBx between the fields defined for the Main Mass (Figure 4-9) may reflect that the Main Mass rocks had more time to evolve, with the La and Sm values of the quartz dioritic rocks reflecting concentrations of these elements in the initial composition of the melt sheet. Lanthanum increases in the residual melt as fractionation proceeds. Table 4-2 compares La/Sm, La/Nb and Th/Zr ratios of this study with those of Lightfoot et al. (1997a, 1997b) from the Parkin Offset, Whistle Embayment and Main Mass.

Figure 4-10a the analyses are plotted on a La/Sm versus Gd/Yb diagram with fields from Lightfoot et al. (1997a). The LQD and QD analyses cluster around the fields defined for the Main Mass, QD of the Manchester Offset, and QD of the Parkin Offset. The IQD analyses have a wider spread, and the variation in composition is attributed to contamination from xenolithic material.

Table 4-2

Rock Type	La/Sm	La/Nb	Th/Zr	n
QD	6.3	4.0	0.04	8
LQD	6.7	4.6	0.04	14
IQD	5.8	5.1	0.03	7
FwBx	6.6	6.8	0.02	14
<i>QD from Parkin Offset</i>	6.3	4.5	0.05	43
<i>Leucocratic Norite from Whistle Embayment</i>	6.2	5.0	0.02	?
<i>Main Mass (felsic norite, quartz-gabbro, and granophyre)</i>	4.5 - 7	2.8 - 4.2	0.04 - 0.05	?

Footwall Breccia analyses, shown on Figures 4-9a and 4-10b, cluster around the field defined for the array of Main Mass compositions (Lightfoot et al., 1997a); this is expected as the FwBx and the crustal melt sheet are essentially derived from the same source rocks, but have undergone different degrees of melting.

Copper and nickel are found in trace amounts in the quartz dioritic phases, with the ratio of Ni:Cu generally high (greater than 1) as outlined in Table 4-3.

Table 4-3

Rock Type	Zone	Ni/Cu	n	range
QD	Proximal	3.40	1	-
	Intermediate	2.92	4	2.08 - 4.43
	Distal	4.72	4	0.13 - 17.87
LQD	Proximal	1.32	7	0.19 - 3.39
	Intermediate	2.19	7	0.18 - 3.74
IQD	Proximal	2.35	5	1.43 - 3.30
	Intermediate	7.93	1	-
	Distal	0.41	1	-
FwBx	Proximal	2.48	4	1.79 - 3.26

	Intermediate	3.15	8	0.16 – 7.53
	Distal	1.18	2	0.97 – 1.39

Figure 4-11 shows the analyses plotted per a) Zone, to see if there is any variation with distance from the embayment structure, b) quartz dioritic phase, and c) all rock types analyzed. No definitive conclusions can be drawn from these divisions of the geochemical analyses, and in any case, the populations are very small. Rickard et al. (2004) reported Ni and Cu concentrations from the Lac des Iles palladium deposit, and with a very large population base they were able to define two distinct trends of data representing primary magmatic sulphides ($\text{Ni}:\text{Cu} < 1$) and secondary hydrothermally remobilized sulphides ($\text{Ni}:\text{Cu} > 1$). Dahl et al. (2002) reported the same relationship at the Coldwell Complex. Despite the relatively small sample population base of this study, the general trend of Ni:Cu ratios greater than 1 are interpreted to indicate hydrothermal remobilization of sulphides. Hydrothermal remobilization will be discussed in Chapter 5.

4.3.2 Plagioclase Porphyritic and Non-Porphyritic Diabase

When sampling the Plagioclase Porphyritic Diabase (PPD), care was taken to avoid plagioclase phenocrysts in order to attain geochemical results for the groundmass component only. In some cases, a sample was taken from a phenocryst-devoid dyke margin as well as the phenocryst-bearing centre for comparison purposes.

The PPD are thought to have formed through crystal fractionation of a mantle magma, with plagioclase phenocrysts fractionating first as shown by a negative Eu anomaly on the Primordial Mantle-normalized (McDonough et al., 1992) REE-diagrams (Figure 4-12a). Two distinct populations stand out and the fields have been highlighted in Figure 4-12b. The two populations have very similar REE trends, with Population 2

slightly more enriched in LREE than Population 1. In Figure 4-13 the diabase analyses are plotted on La/Sm versus Gd/Yb and La versus Sm graphs with selected SIC rock fields and mafic-ultramafic inclusion fields taken from the literature (Lightfoot et al., 1997a). Population 1 analyses plot within and near the field for diabase and diabase inclusions from the Whistle Mine and Parkin Offset (Figure 4-13a and b), with two of the non-porphyritic diabase (NPD) samples plotting near the upper limit of the field defined by Lightfoot et al. (1997a) in the La versus Sm graph (Figure 4-13b). The overlap of the diabase and diabase inclusions field with the orthopyroxene-rich Sublayer Norite field in Figure 4-13b, coincident with the location of the diabase analyses from this study, could be interpreted to support the hypothesis of a genetic link between the diabase xenoliths and the SIC as proposed by Corfu and Lightfoot (1996), however, this relationship does not hold over when compared in Figure 4-13a, so this study does not support the genetic link hypothesis.

Figure 4-14a-c shows more graphical examples highlighting the two distinct populations, and Figure 4-14d shows the analyses plotted with fields defining Matachewan diabase dyke swarm compositions from Phinney and Halls (2001). The total lack of overlap may suggest that the diabase dykes and xenoliths sampled in this study are not Matachewan, however the trend is roughly similar and metasomatism (alteration) could enrich the rock in certain elements through removal of other elemental constituents. Phinney and Halls (2001) reported removing veins and sulphides and using only the cleanest samples in their study, whereas the samples collected for this study were variably altered. Lightfoot et al. (1997a) acknowledge the petrographic and geochemical similarities between the diabase dyke and inclusions they sampled from the

Whistle Mine and Parkin Offset with Matachewan diabase dykes, as does this study, and the evidence indicates that the diabase dykes and xenoliths sampled in this study are indeed Matachewan.

Samples 03AV-18 and 03AV-19 are plotted together in Figure 4-15 as they sample the same dyke, but in areas of contrasting plagioclase phenocryst content. Sample 03AV-19 is more plagioclase phenocryst-bearing, whereas 03AV-18 is a less phenocryst-bearing part of the diabase dyke. There is very little separation between the samples in terms of REE, 03AV-19 being slightly depleted relative to 03AV-18, however the extended REE plot (Figure 4-15b) shows much more separation between the analyses, with 03AV-19 having a much greater U and Th depletion. Niobium and Ta, and Zr and Hf also show depleted anomalies, while a slight Sr enrichment also contrast 03AV-19, the more plagioclase phenocryst-bearing sample, from 03AV-18.

4.4 Comparison /Discussion

4.4.1 Main Mass and Footwall Rocks

The QD, LQD and IQD as well as the FwBx can all be characterized by relative enrichment in LREE compared to HREE (as seen on Chondrite normalized and/or Primordial Mantle normalized plots). This characteristic is common throughout the SIC as reported by Chai and Eckstrand (1994), Lightfoot et al. (1997a), and Therriault et al. (2002) for Main Mass rocks. It is also characteristic of the pre-Sudbury Event diabase dykes (Matachewan; Figure 4-12), and other country rocks (Archean gneiss and granite) as reported by Chai and Eckstrand (1994). Considering that the SIC and offset rocks are derived from impact-induced melting of the continental crust, it is no surprise that the REE data reflect this.

As mentioned in Section 4.3.1 with respect to La and Sm (Figure 4-9 and 4-10b), the quartz dioritic phases correlate well with felsic norite, mafic norite and Parkin Offset values, but not the granophyre and quartz-gabbro which have elevated La and Sm values (Lightfoot et al., 1997a). The correlation of the offset dyke La-Sm concentrations with the mafic and felsic norite is echoed by the least altered Onaping Formation compositions of Ames (1999) discussed below.

4.4.2 Other Offset Dykes

Lightfoot et al. (1997a; 1997b) provide a plethora of geochemical information regarding offsets from both the North and South Ranges of the SIC. A brief review of their Average Felsic Norite-normalized extended REE plots (OGS OFR 5959, p. 178-179) reveal several features in common: strong Sr depletion, with less pronounced P, Eu and Hf depletions. [Variation in phosphorus is most likely due to the amount of apatite contained within the geochemical sample.] Also, there are weak positive Y anomalies in offset samples from both Ranges. The U and K concentrations differ comparatively, where uranium is depleted with respect to potassium in North Range offsets, and visa versa for South Range offsets. Another difference is shown by the Ta anomaly, (generally weak), where tantalum concentrations are depleted in North Range offsets and enriched in South Range offsets. These characteristics are summarized in Table 4-4 below.

Table 4-4: Characteristics of North and South Range Offsets (taken from Average Felsic Norite normalized extended REE plots by Lightfoot et al., 1997a.)

Element	North Range	South Range
Sr	strong depletion	strong depletion
P, Eu, Hf	weak to moderate depletion	weak to moderate depletion
Y	weak enrichment	weak enrichment
U	depleted relative to K	enriched relative to K

K	enriched relative to U	depleted relative to U
Ta	weak enrichment	weak depletion

The geochemical analyses from this study tend to show a bit more variation with respect to the previously mentioned common offset features. Strontium is variable in all quartz dioritic phases, as well as the FwBx, with both positive and negative anomalies ranging from weak to strong. Phosphorus is variable with weak to moderate concentrations, and both positive and negative anomalies; phosphorus is by no means distinguishing as apatite is the only mineral containing significant P, and apatite is only an accessory phase within the quartz dioritic phases. Europium does adhere to the commonalities listed above; Eu is depleted in all quartz dioritic phases and FwBx, though it is generally a very weak negative anomaly. Hafnium is variable throughout all the phases, showing very weak positive and negative anomalies. Yttrium concentrations are weak to moderately elevated in all the quartz dioritic phases and the FwBx.

Uranium, K and Ta vary from weak to strong concentrations, and from positive to negative anomalies throughout all the quartz dioritic phases. This is not consistent with the general trend of North Range depletions of U and Ta, and K enrichments. In order to further assess this inconsistency the data were plotted according to the QAP derived rock name (detailed figure in *Appendix C*). Further analysis of the data reveal that the samples that plot as quartz diorite, monzodiorite and granite on the QAP diagram all adhere to the U-depletion relative to K-enrichment outlined by Lightfoot et al. (1997). Most of the samples that plot as granodiorite on the QAP diagram also adhere, though there are four samples that do not follow this trend; petrographic examination show that one sample is IQD, while the other three are LQD. These four samples likely contain or have

assimilated inclusions, which may be responsible for the opposing U and K concentrations typical of the North Range. Coincidentally, the extended REE plots of the FwBx analyses all show very well developed strong anomalies for U, K and Ta; U and Ta showing strong depletions relative to K enrichment. In general terms, the quartz dioritic phases of the Whistle Offset do adhere to the elemental characteristics for North Range offsets as defined by Lightfoot et al. (1997a).

4.4.3 Other Sudbury Melts

Some other Sudbury melts to compare data to include the Least altered Onaping Formation, and the Onaping Intrusion (or Basal intrusion).

The Onaping Formation consists of a fallback breccia, intruded by impact melt forming hydro-clastic breccias, overlain with plume collapse materials (Ames, 1999). It sits stratigraphically above the Granophyre, and is the lowest formation of the basin-fill sequence, the Whitewater Group (Muir and Peredery, 1984). The other formations of the Whitewater Group (Onwatin, Vermilion, and Chelmsford) are reworked sedimentary units (Muir and Peredery, 1984).

Ames (1999, p. 94) presents geochemical data on 'least altered' samples from the Onaping Formation. Comparison of chondrite-normalized REE plots show that QD from all the zones along the Whistle Offset match well with the values obtained by Ames (1999) from the 'less altered' Onaping Formation, as do LQD samples from the Intermediate Zone. LQD from the Proximal Zone are slightly elevated in LREE and in some cases, not all, slightly depleted in HREE relative to the 'less altered' Onaping Formation. In the case of the IQD samples, the trend again is very similar for all zones along the Offset, with slightly greater LREE concentrations than the 'less altered'

Onaping Formation. The REE values from the FwBx also exhibit the same overall trend as the quartz dioritic phases and the 'less altered' Onaping Formation, with slightly greater concentrations of LREE and lesser HREE than the 'less altered' Onaping samples.

The fact that the REE values from the QD samples match well with the 'less altered' Onaping Formation samples is excellent, as it supports the 'comagmatic', or cogenetic origin of both units (Lightfoot et al., 1997; Ames et al., 2002). The slight variations with respect to the other quartz dioritic phases likely reflect greater assimilation of footwall materials; this idea is supported by the REE values from the FwBx.

Also, the La-Sm values of the Onaping Formation overlap well with the felsic norite, mafic norite, (and to a lesser degree the Parkin Offset) fields as reported by Lightfoot et al. (1997), Ames (1999), and Ames et al. (2002); the quartz dioritic phases from the Whistle Offset also overlap with these fields.

Ames (1999) also describes the geochemistry of the Onaping Intrusion (or Basal intrusion). The Onaping intrusion is part of the Onaping Formation, however it is a clast-rich, igneous-textured melt rock which is discordant with the other units of the Onaping Formation; it is interpreted to have been a melt "pool" collecting at the base of the Onaping Formation, subsequently intruding the Onaping during the later stages of crater formation (Ames, 1999). The REE geochemistry of the Onaping intrusion is very similar if not identical to the 'less altered' Onaping Formation samples, which are very similar to the quartz dioritic phases from the Whistle Offset, therefore supporting a genetic relationship of these early melts.

Figure 4-1: All lithogeochemical data plotted on a) SiO₂ versus Na₂O+K₂O diagram (fields after Cox et al., 1979), and b) QAP (quartz-alkali-feldspar-plagioclase) diagram (created using Fe₂O₃ Total, and oxide analyses (no cation analyses used) (divisions from Streckeisen (1976))).

Figure 4-2: Harker diagrams displaying major element data. K_2O , Na_2O and Al_2O_3 loosely correlate positively with SiO_2 , whereas P_2O_5 weakly correlates negatively with SiO_2 .

Figure 4-3: Harker diagrams displaying major elements negatively correlating with SiO_2 (weight %).

Figure 4-4: Histograms showing the distribution of TiO_2 and Na_2O in the quartz dioritic phases (QD=quartz diorite, LQD=leucocratic quartz diorite, and IQD=inclusion quartz diorite).

Figure 4-5: Histograms showing the distribution of K_2O and P_2O_5 in the quartz dioritic phases (QD=quartz diorite, LQD=leucocratic quartz diorite, and IQD=inclusion quartz diorite).

Figure 4-6: Chondrite normalized REE diagrams for:

- a) QD,**
- b) LQD,**
- c) IQD, and**
- d) FwBx.**

The colours represent the zone from which the sample was collected: red = Proximal Zone, green = Intermediate Zone, and yellow = Distal Zone.

Figure 4-6

Figure 4-7: Average Felsic Norite normalized REE diagrams for:

- a) QD,**
- b) LQD,**
- c) IQD, and**
- d) FwBx.**

The colours represent the zone from which the sample was collected: red = Proximal Zone, green = Intermediate Zone, and yellow = Distal Zone.

Figure 4-7

Figure 4-8: Average Felsic Norite normalized extended REE diagrams for quartz dioritic phases and Footwall Breccia whole rock compositions.

- a) These samples are virtually geochemically identical, with trends similar to those reported by Lightfoot et al (1997a, p. 134) for the Parkin Offset. They all plot in the granodiorite field on the QAP diagram.
- b) Sample 91 has the same over all trend, but exhibits a greater Ba, Rb and K depletion than the other samples. On the QAP diagram 91 plots as a tonalite, whereas 78, 82 and 90 plot as granodiorites.
- c) LQD-14, 03AV-17, 03AV-24 and LQD-5 plot as granodiorite, LQD-4 plots as monzogranite, and 03AV-13 plots as diorite.
- d) LQD-19, LQD-20, LQD-21, 03AV-28 and LQD-18 plot in the granodiorite field, 36 plots as quartz diorite, and 35 plots as monzogranite. Sample 36 has a similar trend to the Sublayer Matrix from the Whistle Mine reported by Lightfoot et al. (1997a, p. 134).
- e) All the samples plot as quartz diorite on the QAP diagram, except IQD-14 which plots as monzodiorite.
- f) 44 plots as granodiorite.
- g) 77 plots as quartz diorite.
- h) All these samples plot as quartz diorite on the QAP diagram.
- i) 19, 23, 25, 47 and 50 plot as quartz diorite, 52 and 60 plot as granodiorite, and 63 plots as monzodiorite.
- j) Sample 85 plots as granodiorite, and 87 plots as quartz diorite.

Figure 4-8: Extended REE diagrams with Average Felsic Norite normalized analyses plotted for QD, LQD, IQD and FwBx.

Figure 4-9: Variation in La and Sm for all quartz dioritic phases of the Whistle Offset compared to other rock types of the SIC. Fields from Lightfoot et al. (1997a). FN = felsic norite, MN = mafic norite, and G + GT = granophyre and quartz-gabbro.

Figure 4-10: Quartz dioritic phases and Footwall Breccia analyses plotted on a) La/Sm versus Gd/Yb graph, and b) La versus Sm graph, with fields from Lightfoot et al. (1997a).

Figure 4-11: Cu versus Ni graphs showing concentration per a) map zone (for quartz dioritic phase analyses only), b) quartz dioritic phase, and c) all rock types analysed lithogeochemically.

Figure 4-12:

- a)** REE diagram with Primordial Mantle normalized Plagioclase Porphyritic and Non-porphyritic Diabase analyses plotted and divided into two populations.
- b)** Same as in (a), but with fields for Populations 1 and 2 drawn in.
- c)** Extended REE diagram with the two Diabase population fields defined (normalized to Average Felsic Norite).

Figure 4-12

Figure 4-13: Compositions of plagioclase porphyritic diabase (PPD) and non-porphyritic diabase (NPD) plotted on a) La/Sm versus Gd/Yb diagram, and b) La versus Sm diagram, both with fields from Lightfoot et al. (1997a).

Figure 4-14: Compositions of plagioclase porphyritic diabase (PPD) and non-porphyritic diabase (NPD) plotted on a) La/Sm versus Gd/Yb, b) Ce versus MgO, c) Ce/Nb versus Ce, and d) La/Sm versus La diagrams, with Matichewian diabase dyke fields from Phinney and Halls (2001).

Rock Sample/Primordial Mantle

Rock Sample/Felsic Norite

Figure 4-15: a) REE diagram of diabase samples from the same dyke, where 03AV-19 contains more plagioclase phenocrysts than 03AV-18, representing core and margin compositions of the dyke, respectively. b) Extended REE diagram of the same samples.

Chapter 5. Hydrothermal Alteration and Vein Emplacement

5.1 Alteration Mineralogy

This chapter deals with post quartz dioritic phase emplacement and crystallization features, specifically selective forms of alteration (veins) affecting all the rock types. Vein type alteration is prevalent throughout the map areas along the Whistle Offset; alteration minerals are listed below in Table 5-1. Vein assemblages often range from single phase to multi-phase mineralogy, for example: calcite-chlorite, quartz-epidote, epidote-amphibole-chlorite, chlorite, carbonate, epidote-carbonate, quartz-hematite, chalcopyrite-pyrite-epidote, or chalcopyrite-magnetite-chlorite.

Table 5-1: Alteration vein mineral phases

<i>Mineral</i>	<i>Chemical Formulae</i>
Epidote	$\text{Ca}_2(\text{Al,Fe})_3\text{Si}_3\text{O}_{12}(\text{OH})$
Chlorite	$(\text{Mg,Fe}^{2+},\text{Fe}^{3+})_6\text{AlSi}_3\text{O}_{10}(\text{OH})_8$
Carbonate (calcite)	$(\text{Ca,Fe,Mg})(\text{CO}_3) - \text{Ca}(\text{Mg,Fe})(\text{CO}_3)_2$
Hematite	Fe_2O_3
Quartz	SiO_2
Albite	$\text{NaAlSi}_3\text{O}_8$
Pyrite	FeS_2
Chalcopyrite	CuFeS_2
Magnetite	Fe_3O_4

Epidote (and Epidote-K-feldspar)

Epidote and epidote-K-feldspar veining are very common throughout the offset, as shown on the maps and in Figure 5-1 (also see Figure AC-5 in *Appendix C*). The veins are commonly less than 5cm wide, and generally trend N-S to NE-SW, (other orientations are observed, though these are less dominant). In thin section epidote is colourless to pale yellow under plane-polarized light, commonly occurs as euhedral, columnar crystals, and has characteristic high relief and high birefringence colours (Figure 5-2). Epidote veins are observed cutting, and being cut by other vein types,

supporting the idea of multiple phases of fluid movement through the rocks (e.g. Molnár et al., 1999, 2001; Molnár and Watkinson, 2002; Farrow and Watkinson, 1999; Watkinson, 1994, 1999).

Thompson and Thompson (1996) report that vein-fill epidote crystals are generally larger and highly prismatic (columnar crystals), and this is thought to be a function of higher temperatures during precipitation. Hydrothermal fluid with temperatures in excess of 230°C alter Ca-plagioclase to epidote and other Ca-bearing minerals (Thompson and Thompson, 1996). The alteration of plagioclase also releases aluminum, which is essential for epidote growth. Farrow and Watkinson (1999) describe intermediate temperature (200° - 850°C) hydrothermal fluids of the North Range, where fluid inclusion analyses show that the Cl-rich fluids typically contain Ca-chloride daughter minerals. The association of calcium with trapped fluids in the North Range is a function of the footwall rocks (gneisses and granitoids) (Farrow et al., 1994; Watkinson, 1994; Farrow and Watkinson, 1999; Molnár and Watkinson, 2002).

Chlorite

Chlorite alteration halos are characteristically associated with sulphide veins, a feature that is quite apparent in the Distal Zone (Figure 5-3) where the halos may be 50 cm wide. In Figure 5-2c selectively pervasive deuteritic chloritization in IQD, particularly well developed around sulphide disseminations, is cut by a later epidote vein, while in Figure 5-2d a thin chlorite veinlet cuts across an earlier fine-grained epidote vein, again attesting to multiple episodes of fluid-rock interaction (e.g. Molnár et al., 1999, 2001).

Lithological boundaries are commonly exploited as path ways for fluids as shown in Figure 5-4a where an epidote-chlorite vein associated with pyrite occurs near the intersection of Intermediate Gneiss, IQD and LQD.

Carbonate (Calcite)

Calcite veinlets are less common than epidote and chlorite veins, and much smaller in scale (mm-scale or less). Figure 5-2g,h show calcite veinlets cutting through an epidote vein in IQD; calcite often replaces other Ca-bearing minerals.

Photomicrographs in Figure 5-5a-d show that the calcite crystals are very coarse-grained with perfect rhombohedral cleavage and lamellar twins.

Farrow and Watkinson (1999) note that calcite occurring locally in the most intensely altered magnetite-rich zones of the Epidote Zone (Fraser Mine), indicate an increase in fluid pH, lessening Cu solubility in the fluid, and representing a decline of the intensity of a hydrothermal system.

Hematite (and Quartz-Hematite)

Hematite disseminations were observed particularly in the Intermediate Zone, where granitic rocks may be strongly reddened, such as in Figure 5-4c. Variable specular hematite content was observed in FwBx and IQD from the same zone where thin, metallic, basal sections of the mineral occur (Figure 5-4d).

Quartz veinlets rimmed with hematite occur locally in the Distal Zone (Figure 5-5e-h).

Albite-Hematite

Selectively pervasive albite alteration affects all rock types. Exsolution of hematite from feldspars causes the red colouration (Figure 3-3e and 3-7). Extensive, irregular zones of albite alteration are common throughout the study area.

Pyrite

Sulphide veins occur in the Intermediate Zone, and increase in thickness towards and throughout the Distal Zone. In the Intermediate Zone, sulphide veins consist of chalcopyrite, pyrite, and minor millerite; epidote alteration ($\pm$ chlorite; see Figure 5-4a) is common along the margins of these veins. An example of a highly tarnished chalcopyrite vein with large (≤ 4 cm) pyritohedrons from the Intermediate Zone is shown in Figure 5-4e and f. Pyritohedron development is dependant on time, the rate of delivery of Fe and S to the growing nucleus, and how many nuclei there are. The distribution of pyrite in veins is variable, as is the size of individual crystals.

Chalcopyrite Veins

Chalcopyrite vein development is apparent in the Intermediate Zone, where thin veins and veinlets (mm- to cm-scale) are rimmed by thick epidote alteration halos, or in some cases pegmatitic material (Figure 5-4b). The veins are much larger in the Distal Zone (mm- to m-scale), and are quite spectacular. Figure 5-3 shows morphology and features of the Distal Zone chalcopyrite veins. The veins in the Intermediate Zone appear much more linear than the irregular and anastomosing massive veins in the Distal Zone (see Maps 6 and 9). This may be a function of varying fracture development in specific rock types, utilization of contact zones, or tensional regime during which the veins were emplaced, or all of the above.

The vein mineralogy is dominantly composed of chalcopyrite with lesser pyrite and millerite, magnetite and ilmenite, and various platinum-group minerals (PGM), precious-metal minerals (PMM) and telluride species. Giroux and Benn (2005) also noted minor amounts of pyrrhotite, pentlandite, arsenopyrite, galena, titanomagnetite and hematite. In addition, Ames et al. (2003) reported the following minerals from the Podolsky property: Ag-bearing chalcopyrite, Co-bearing pyrite, marcasite (FeS_2), violarite ($\text{Fe}^{2+}\text{Ni}^{3+}_2\text{S}_4$), polydymite (NiNi_2S_4), bornite (Cu_5FeS_4), covellite (CuS), sphalerite (ZnS), cobaltite (CoAsS), gersdorffite (NiAsS), Se-bearing galena (PbS), clausthalite (PbSe), cassiterite (SnO_2), tsumoite (BiTe), tetradymite ($\text{Bi}_2\text{Te}_2\text{S}$), hauchecornite ($\text{Ni}_9\text{Bi}(\text{Sb},\text{Bi})\text{S}_8$), native Ag and Au, acanthite (Ag_2S), naumannite (Ag_2Se), matildite (AgBiS_2), bohdanowiczite (AgBiSe_2), tellurite (TeO_2), and siegenite ($\text{Ni},\text{Co}_3\text{S}_4$).

Magnetite

Magnetite rinds occur locally about the massive chalcopyrite veins in the Distal Zone (see Figure 5-3c). The rinds are generally ≤ 5 mm thick, and the magnetite is medium grained and granular. They may be a late stage alteration along the margins of the chalcopyrite veins. Magnetite has been reported adjacent to Cu-rich veins at McCreedy West, where electron microprobe analyses have shown that the magnetite is locally altered to ilmenite, and remaining magnetite is enriched in Si, Ti, Cr and Mg (Farrow, 1994). This may be the case for the magnetite rimming the chalcopyrite veins in the Distal Zone, though limited analytical work was done here and follow up would be required for confirmation.

Precious Metal Minerals and Platinum-Group Minerals

Petrographic and SEM analysis of polished thin sections from the Distal Zone chalcopyrite vein material reveal a plethora of bismuth-telluride minerals, commonly with Ag and Pd, less commonly with zinc. The Bi-telluride minerals may occur as grains of a single mineralogy, or as composite grains of multiple Bi-telluride species such as in Figure 5-6. Bi-tellurides are also observed with hessite (Ag-telluride; Figure 5-6b, d-f).

Native bismuth is also commonly observed in thin section. Under plane polarized light the grains are very bright and silvery blue in colour. All of the native bismuth observed occurs as discrete grains in chalcopyrite (Figure 5-7).

A single PGM (platinum group mineral) grain was observed in the samples collected for this study; Figure 5-6h shows the irregular intergrowth of sperrylite (PtAs_2) and michenerite (PdBiTe). Samples borrowed from Giroux and Benn (2005) were analyzed on the SEM and revealed abundant PGM and PMM, with common intergrowths of michenerite and hessite, michenerite and merenskyite, Au and Ag (Figure 5-8 and 5-9).

Malachite

Malachite [$\text{Cu}_2(\text{OH})_2\text{CO}_3$] forms by the reaction of Cu-bearing solutions with carbonate minerals and occurs under oxidizing conditions. Malachite occurs in the Intermediate Zone as irregular bright green patches coating surfaces associated with chalcopyrite veins. It is not widely distributed throughout the study area.

5.2 Hydrothermal Fluids

The presence of cross cutting veins filled with secondary minerals attests to the occurrence of multiple episodes of fluid-rock interaction. Sulphide-bearing veins

indicate that the fluids were sulphur-bearing while the presence of magnetite rinds in the Distal Zone indicates that the fluids were oxidizing. The many calcium-bearing alteration minerals indicate the Ca-bearing nature of the fluids. Farrow et al. (1994), Watkinson (1994), Farrow and Watkinson (1999), and Molnár and Watkinson (2002) discuss the partial control that local country rocks have on fluid compositions, in this case the plagioclase-rich gneisses and granitoids of the North Range contribute Ca to the fluids. Fluorine-rich apatite (discussed in Chapter 3) suggests that any chlorine associated with the magma phase was exsolved into the fluid/volatile phase.

Studies of fluid inclusions and mineral chemistry of silicate and sulphide minerals associated with Sudbury Ni-Cu-PGE deposits indicate that fluids were H-O-Cl-S-Fe-Cu-Ni-Te-Se-Bi-As-bearing, with common NaCl, CaCl₂, BaCl₂, KCl, and Fe-Mn hydroxychloride daughter minerals found in fluid inclusions, and emphasize the ability of Cl-bearing fluids to transport PGE and PMM (e.g. Farrow, 1994; Farrow et al., 1994; Farrow and Watkinson, 1992, 1997, 1999; Watkinson, 1994, 1999; Li and Naldrett, 1993; Jago et al., 1994; Molnár et al., 1997, 1999, 2001; Molnár and Watkinson, 2002; Marshall et al., 1999; Szentpéteri et al., 2005). Farrow and Watkinson (1992, 1999) note that the distance from the base of the SIC was a major control on temperature of the hydrothermal fluids, reflecting the significance of the SIC as a heat source driving hydrothermal fluids in the footwall. Later hydrothermal activity however, may have been derived from more regional heat and fluid sources (Molnár and Watkinson, 2002). The hydrothermal fluids are considered to have been composed of varying proportions of magmatic fluids and formational brines (Watkinson et al., 1991; Farrow and Watkinson, 1999).

Molnár et al. (2001) have identified three hydrothermal fluids in North Range rocks: 1) high temperature ($> 300^{\circ}\text{C}$ - 400°C), very saline (about 50 wt.% NaCl equivalent) magmatic fluid under lithostatic pressures at a depth of 4-6 km, 2) intermediate temperature (300°C - 350°C), $\text{CO}_2\text{-H}_2\text{O}$ fluids which did not remobilize ore, and 3) late stage, low temperature (150°C - 250°C), NaCl- $\text{CaCl}_2\text{-H}_2\text{O}$ -type fluids at 4-6 km depth and under variable lithostatic and hydrostatic pressures. The high temperature Cl- and heavy-metal-rich saline magmatic fluids are interpreted to have deposited Cu-PGE-rich veins after scavenging primary magmatic ores. Late stage Cl-rich saline brines are interpreted by Molnár et al. (2001) to have interacted with, and remobilized ore from primary magmatic sulphide ore bodies, creating chalcopyrite-rich veinlets and epidote and chlorite alteration. Watkinson (1999) discusses how saline fluids, specifically formational brines, are capable of dissolving significant amounts of PGE under low pH, high Eh and T conditions.

Figure 5-10 shows the analytically measured Fe_2O_3 Total (wt. %) versus the calculated ratio of $\text{Fe}^{2+}/(\text{Fe}^{2+}+\text{Fe}^{3+})$ in order to determine the degree of chemical weathering (alteration) due to oxidation. All iron data, analytical and calculated, are shown in *Appendix D*. In two cases, samples 03AV-22 and 03AV-40, Fe^{2+} could not be calculated, as there was zero FeO measured in the wet chemical process. The remainder of the samples, with exception of 03AV-66, all show calculated ferrous iron (Fe^{2+}) greater than ferric iron (Fe^{3+}), implying that oxidation is not prevalent throughout the lithogeochemical samples.

Figure 5-1: a) Epidote veining along the east side of the LQD pod in the Proximal Zone, Map 1 area (view looking north). b) and c) Epidote-K-feldspar veining in the central portion of the LQD pod, Map 1 (coin is 1.7 cm). d) and e) Epidote-K-feldspar veining in the LQD pod in the Proximal Zone, Map 2 area. f) Quartz veining in the LQD pod, Map 2 area.

Figure 5-2: Photomicrographs

a-b) Epidote veinlet cutting IQD (sample IQD-7 from Proximal Zone, Map 2 area) in plane polarized and cross-polarized light, respectively.

c) Sulphide bleb and deuteric chlorite alteration in IQD cut by later epidote vein.

d) Fine-grained epidote vein cut by thin chlorite veinlet.

e-f) Close-up view, in cross-polarized light, showing the coarse-grained nature of epidote alteration (sample FB-1, Proximal Zone, Map 2 area).

g-h) Plane polarized and cross-polarized light images of a fine-grained epidote vein cross-cut by a later carbonate veinlet in IQD.

Figure 5-2

Figure 5-3: Massive chalcopyrite-rich veins in the Distal Zone (also known as "The Yellow Brick Road"). Note the irregular nature of the veins and the chloritic alteration halo surrounding them. Rims of magnetite are local about the veins (c). Inclusions with ductile deformation (b) and 'tensional' features (a and f) are common characteristics in this zone.

Figure 5-4: Typical features of the Intermediate Zone. a) Epidote-chlorite-pyrite veining near the contact of IQD with Intermediate Gneiss. b) Tarnished chalcopyrite - pegmatite vein cutting Mafic Gneiss. c) Gradational contact between IQD and granite contact; pervasive hematite alteration colouring the granite. d) Hematite in IQD. e+f) Pyritohedrons in chalcopyrite vein (black tarnish) at the contact between FwBx and hematitized granite.

Figure 5-5: Photomicrographs

a-d) Carbonate (calcite) veinlets cross-cutting LQD from the Proximal Zone, Map 2 area and Intermediate Zone, Map 7 area (sample LQD-4 and 35, for (a-b) and (c-d) respectively), and

e-h) quartz-hematite veinlets cross-cutting (sample 8).

Figure 5-5

Figure 5-6: Back-scattered electron microprobe images of bismuth-tellurides (with varying amounts of Ag, Pd and Zn), and PGM (h) in chalcopyrite and silicate minerals, from the massive Cu-rich veins in the Distal Zone (all images from sample 'A', except (g) which is from sample 'B').

Figure 5-6

Figure 5-7: Back-scattered electron microprobe images of native bismuth in chalcopyrite from the Distal Zone veins (sample 'B').

Figure 5-8: Back-scattered electron microprobe images of PGM intergrown with hessite and other Ag-telluride species in chalcopyrite from the Distal Zone Cu-veins (a-d: sample WL-1F, and e-f: sample WL-2D). Samples provided by Giroux and Benn.

Figure 5-8

Figure 5-9: Back-scattered electron microprobe images of PGM and PMM in chalcopyrite from the Distal Zone Cu-veins. (a-d: sample WL-5B, e: sample WL-1F). f-g) Au>Ag minerals in epidote and chalcopyrite, respectively (sample WL-1B). Samples provided by Giroux and Benn.

Figure 5-9

Figure 5-10: Fe_2O_3 Total weight percent measured versus $\text{Fe}^{2+}/(\text{Fe}^{2+}+\text{Fe}^{3+})$ calculated from the lithogeochemical analyses. a) All rock types, and b) quartz dioritic phases and Footwall Breccia.

Chapter 6. Discussion

6.1 Compositional variations, relationships between, and protoliths of quartz dioritic phases and Footwall Breccia

The composition of the quartz diorite offset dykes is generally agreed to represent the primary composition of the undifferentiated SIC crustal melt sheet, where quick rapid cooling and minimal contamination through assimilation are believed to have occurred (e.g. Rousell et al., 1997; Lightfoot et al., 1997b). Ames et al. (2002) reported that the composition of quartz diorites of the offset dykes may be derived through the mixing of vitric Onaping Formation quenched shock melt with greater proportions of mafic material, occurring as pre-impact strata, sampled at deeper levels during the crater excavation. "This mafic-contaminated melt, or impact melt, developed at the base of the melt sheet and was injected into the offset dikes both prior to and contemporaneously with the earliest stages of sulfide precipitation from the Sudbury Complex" (Ames et al., 2002).

Clearly, the protoliths of the quartz-dioritic phases and the FwBx are the immediate country rocks into which the impact occurred. Figures 6-1 and 6-2 show several Primordial Mantle-normalized REE diagrams with individual analyses and rock-type fields plotted. Comparison of the QD, LQD, IQD, and FwBx fields (Figure 6-2) reveals a definite overlap in chemical composition among all four phases, but more specifically, between the QD and IQD and the LQD and FwBx. This subdivision likely reflects the felsic nature of the LQD and FwBx in comparison to QD and IQD. From the overlay of composition of the quartz-dioritic phases and Footwall Breccia onto the various country rock compositions, it is clear that QD, LQD, IQD, and FwBx fields all

have the same general trend as the Intermediate Gneiss sample, though they have slightly more elevated REE compositions. They all overlap well with the quartz-monzodiorite sample, except where europium is concerned, as the QD, LQD, IQD and FwBx are all characterized by a Eu-depletion, whereas the quartz-monzodiorite has a distinct positive Eu-anomaly. In general, the LREE characteristics of QD, LQD, IQD and FwBx all partially overlap with Population 2 diabase dyke and xenolith compositions, one of the granite samples, the quartz-monzodiorite, and in the case of QD, the intermediate gneiss. The HREE characteristics partially overlap with Populations 1 and 2 diabase dykes and xenoliths, quartz-monzodiorite, gabbro (with the exception of LQD), and intermediate gneiss in the case of LQD and FwBx.

The QD, LQD, IQD, and FwBx all can be derived, in general terms, with input from intermediate gneiss > diabase (and gabbro) > granite (> quartz-monzodiorite; the quartz-monzodiorite is only seen as inclusions and not as immediate country rock, therefore it is not considered to have contributed substantially to the offset magmas). When the compositions of the intermediate gneiss, diabase and gabbro, and granite are considered, rough percentages of 50% intermediate material, 30% mafic material, and 20% felsic material could account for the offset magmas; however, due to the small sample populations for some of the country rocks, these percentages are not strongly emphasized and should only be used as a guide line.

The compositional variations of the matrix of the quartz-dioritic phases may purely be a function of contamination through assimilation of varying quantities and compositions of footwall rocks, as well as the residence time in the source magma chamber (the undifferentiated SIC) prior to injection into the offset structure and

subsequent crystallization. Lightfoot and Farrow (2002) noted with regard to the Worthington Offset, that the assimilation of inclusions has not changed the chemical composition of the silicate matrix of IQD in comparison to QD significantly; this is also true of the composition of Whistle Offset QD and IQD. Apatite analyses show no chemical variation with distance from the embayment, nor do the amphibole analyses (although one may argue that they are slightly more F-rich in the Proximal Zone compared to the Intermediate and Distal Zones, but this is generally a matter of about 0.2 weight percent).

The relationship between the quartz-dioritic phases of the Whistle Offset with the Footwall Breccia is an intrusive one. The FwBx is an *in situ* breccia created by direct impact energy, developed around the base of the crater and as irregular fracture zones radially and concentrically about the SIC. The development of offset structures (defined by the presence of FwBx and quartz dioritic phases) is believed to have originated from pre-existing structures, such as faults, that became focal points for impact energies to disperse (causing *in situ* brecciation) laterally. The FwBx became the conduit system in which quartz diorites were intruded, providing an easy permeable pathway for silicate magmas to access, much as Sudbury Breccia provided permeable zones for migrating metal-laden fluids. Lightfoot and Farrow (2002) discussed how "the type and style of brecciation developed in the country rocks along different offset dikes controlled the continuity of the quartz diorite and the location of the orebodies". The FwBx conduit system (offset structure) is envisioned as highly irregular with heterogeneous clast content and size, directly influencing permeability and the extent and style of quartz-dioritic intrusion. A cross section and schematic block diagrams in Figure 6-3 show how

irregular the FwBx contact with IQD is envisioned to be, and the map of the Proximal #5 area reflects this concept.

Lightfoot and Farrow (2002) proposed that "the quantity of sulfide in a dike is related to the thickness of the overlying melt sheet." Variable clast content is believed to locally affect the composition of quartz dioritic phases, in some cases providing sulphur to the quartz dioritic magma and enhancing the development of sulphide mineralization (this view is supported by the relative lack of sulphide mineralization in QD, whereas IQD is commonly sulphide-bearing). Clast content and how they affect the 'flow' and morphology of sulphide liquids will be discussed in Section 6.3.

6.2 Relative Timing of offset phases

Contact relationships between the QD and IQD of the Copper Cliff and Worthington Offsets have been interpreted to represent a primary pulse of QD followed by a later pulse of IQD (e.g., Lightfoot et al., 1997a; Lightfoot and Farrow, 2002; Stewart, 2002). In contrast, Murphy and Spray (2002) have interpreted that IQD was injected into the Parkin Offset structure first, followed by later injection of QD. In both these cases, field mapping has revealed that QD generally occurs along the outer margins of these dykes, with IQD generally occupying the central portion. This is not always the case, as IQD is also observed occurring along the offset margins (Murphy and Spray, 2002) and in some cases it is the only phase present. In contrast, "pods" of QD hosted entirely within Sudbury Breccia have been described at the Kirkwood, Vermilion and Frood-Stobie Offsets (Grant and Bite, 1984; Szentpéteri, 2005). Lightfoot et al. (1997a) described these pods as dismembered portions of dykes within very mobile zones of Sudbury Breccia. Wood and Spray (1998) reported that the composition of the Hess

Offset "is most closely affiliated with an evolved Felsic Norite component of the SIC and not bulk impact melt", and interpreted that the Hess Offset was not intruded immediately following impact, but after some period of fractionation of the melt sheet, and note that the fault system which the offset occupies was active during crater modification/readjustment stages. Tuchscherer and Spray (2002) interpreted that the composition of quartz diorites from the Foy Offset reflect the bulk composition of the SIC prior to significant fractionation. Clearly, there is a lot of variation with respect to the rock types associated with offset structures, cross-cutting relationships, and the interpretations that these features provoke. In many cases, it seems that multiple processes may have been acting simultaneously, or staggered slightly with respect to one another, possibly occurring in a slightly different order in other offset structure locations about the SIC.

A feature commonly used to support primary injection of QD followed by a later pulse of IQD are inclusions of QD occurring in IQD. Stewart (2002) described cm-scale QD inclusions in IQD at the Worthington Offset, and suggested that the IQD pulse intruded consolidated or semi-consolidated QD. The mechanism and timing suggested by Stewart (2002) to produce such contact relations involves primary injection of QD from the undifferentiated SIC into the offset structure, followed by gravitational settling of inclusions and sulphides in the source magma chamber (undifferentiated SIC), with the later pulse of sulphide-bearing IQD injected into the offset structure due to tectonic readjustment or gravitational collapse of the Sudbury Structure.

The term "inclusion" generally refers to something that is fully consolidated and has become caught up in an igneous magma. Stewart (2002) suggested the QD was in a

consolidated to semi-consolidated state prior to fragmentation and incorporation into IQD. "Inclusions" of QD in IQD have been observed in the study area of the Whistle Offset, and in most cases these "inclusions" are small (cm-scale), but they increase in size (metre-scale) in the Distal Zone. Though they all generally tend to be rounded, the irregular morphology of many of the "inclusions" detracts from the interpretation of discrete inclusions fragmented and rounded by IQD injection forces. The term "pod" has been used in this study to refer to the QD and LQD bodies that occur in the offset, as their textural and morphological features suggest a "fluid" state. "Melt inclusions" could also be applied, or "melt pod". In two dimensions these features simply appear to be inclusions, but in three dimensions they may be interconnected. The pods of QD at Kirkwood, Vermilion and Froid-Stobie tend to be much larger than the pods at Whistle; one QD pod at Vermilion measures just under $300 \times 50 \text{ m}^2$ (Szentpéteri, 2005). The preference of the author is that the size of pods and their appearance as inclusions could be a function of the present erosional level.

The initial composition of the undifferentiated melt sheet is considered to be heterogeneous due to local target rock compositions (gneisses and granitoids in the North Range, and metasedimentary, metavolcanic and granitic rocks in the South Range) (Lightfoot and Farrow, 2002). Farrow and Watkinson (1999) discussed how mixing and assimilation of footwall rocks created a volatile-enriched marginal facies of the melt sheet, and suggested that this volatile-rich magma was emplaced to form the offset dykes. Assuming an initial "instantaneous" injection of the undifferentiated melt sheet into the offset structures, I propose that the LQD pods at the Whistle Offset represent the primary

volatile-rich composition of the undifferentiated melt sheet in the North Lobe area (leucocratic due to the abundance of gneiss and granitoids) (Figure 6-4a).

Field relations at the Worthington Offset lead Lightfoot and Farrow (2002) to suggest that the formation of QD and IQD "predate significant silicate differentiation or silicate gravitational segregation of the melt sheet and that the differences may record primary silicate heterogeneity of the melt sheet." At Whistle, the QD and IQD are considerably less leucocratic than the LQD, but have the same general chemical composition. It is proposed here that after the primary pulse of LQD into the offset structure, the melt sheet began to differentiate and gravitationally segregate in its magma chamber, and initiated very early stage heterogeneous contamination by assimilation of clastic debris (Figure 6-4b). Local readjustment of the crater may have caused a change in the pressure regime from lithostatic to hydrostatic, inducing rapid crystallization of the LQD magma through devolatilization, simultaneous with, or shortly followed by a second pulse of relatively undifferentiated, inclusion-bearing magma (IQD) into the offset structure, or the LQD may have been semi-consolidated at the time of the IQD intrusion (Figure 6-4c).

The QD is believed to have either been: a) injected as a third pulse, or b) derived from incongruent heating in the IQD. Incongruent heating is believed to have developed due to irregular or unevenly distributed heat energy from the overlying SIC, causing local areas within the IQD to become slightly less viscose and eject or assimilate clastic material, creating inclusion-devoid melt pods. Aligned clastic material in IQD concentrically distributed about QD pods supports this hypothesis (e.g. Proximal Zone, Map 5). The process of "nucleation" of QD pods and ejection of clastic material is not

fully understood, but is strongly believed to be related to incongruent heating. Volatiles associated with the IQD-QD system may tend to migrate into the slightly lower viscosity medium, the QD, but would not completely be lost from the IQD. Disequilibrium textures such as elongate, skeletal, or acicular minerals, irregular REE zoning in apatite, and large amounts of granophyric material are particularly well developed in QD (as in LQD), and are also present in IQD. This suggests that the mechanism to induce crystallization could again be crater readjustment, pressure drop causing a loss of volatiles, followed by rapid crystallization (Figure 6-4e).

6.3 Alteration assemblages and implications for ore-forming processes

The Nipissing Diabase dyke swarm, which is widespread in the Sudbury region, is suggested as a likely proto-ore source for the SIC (Golightly, 1994). The proto-ores in the Sudbury region were incorporated into the crustal melt sheet and re-concentrated through sulphide-silicate liquid immiscibility processes (e.g. Naldrett, 1984; Naldrett et al., 1997), and by later post-crystallization hydrothermal remobilization processes (e.g. Watkinson, 1994, 1999; Farrow and Watkinson, 1997). Examples of both these processes occur at the Whistle Offset and embayment structure; the main ore bodies of the Whistle embayment and the blebby to disseminated sulphides observed in the quartz dioritic phases of the offset represent liquid immiscibility of sulphide and silicate magmas, while the Cu-rich veins predominant in the Distal Zone represent hydrothermally remobilized ore.

Hydrothermal processes are implied by the presence of hydrous silicate alteration minerals proximal to ore, and fluid inclusions in ore and gangue minerals, in conjunction with vein morphology of the sulphide assemblage. Many of the sulphide-bearing veins,

the Distal Zone in particular, have very complicated and anastomosing features indicative of flow. Clearly these veins are post offset-emplacement features.

Giroux and Benn (2005) used magnetic anisotropy to define fabrics in the Whistle Offset rocks (sampling norite, leucocratic norite and leucocratic breccia (FwBx) in the embayment and Proximal Zone, and massive sulphides and QD from the Distal Zone) and interpret that "the flow pattern defined by that subfabric demonstrates lateral (horizontal) injection of the Whistle Offset dyke and subsequent sinking of molten massive sulphide through the dyke." Giroux and Benn (2005) reported large variations in magnetic sub-fabric orientations in the Distal Zone and interpreted "the lack of a well defined flow plane to be due to choking of the lateral flow in the vicinity of the narrow portion of the dyke", as the dyke narrows considerably just to the north of the Distal Zone.

The author does not wholly agree with the interpretations made by Giroux and Benn (2005), as their study fails to acknowledge movement of the offset since emplacement of silicate and sulphide magmas. Also, they clearly did not consider the mineralogical features of the veins in the Distal Zone, where the Cu-PGE rich sulphide assemblage in conjunction with the hydrous alteration assemblage clearly indicate hydrothermal fluid movement as the emplacement mechanism for the veins. The "lack of a well defined flow plane" (Giroux and Benn, 2005), and interpretation of flow choking can be applied to a hydrothermal interpretation, where constriction or significantly lowered permeability could cause the sulphide-bearing hydrothermal fluid to circulate in a chaotic manner with the precipitation of the dissolved sulphides recording the irregular flow.

Inclusions of clastic material may produce the choking effect described by Giroux and Benn (2005). Metal-laden hydrothermal fluids could either circulate around clasts, or hydraulically fracture clasts depending on the pressure regime. If the clast population becomes increasingly dense, this may choke the fluid flow, halting fluid migration and creating traps for economic sulphide mineralization. [Lightfoot et al. (1997b) also note a narrowing and termination of the Parkin Offset in FwBx zones; if metal-laden hydrothermal fluids traversed the distance, this zone of decreased permeability may also be a prospective mineralized area.]

Farrow and Lightfoot (2002) reported cross-cutting sulphide veins at the Levack adit and Barnet property, that are locally associated with hydrothermal minerals, where one set of veins exploits pre-existing gneissic foliation, and the second set is perpendicular. Hydrothermal alteration minerals are only associated with the second set of veins, and "mixing" with the sulphide minerals is not reported (Farrow and Lightfoot, 2002). These textural features were interpreted to indicate that the sulphide veins were emplaced in tensile fractures propagating perpendicular to the gneissic foliation, and coinciding with hydrothermal activity (Farrow and Lightfoot, 2002; Legault et al., 2003). The morphology and some of the textural features of the Cu-veins in the Distal Zone of the Whistle Offset appear tensional, while lithological contacts and clast-matrix contacts are also key features with respect to fluid movement. Farrow and Watkinson (1999) discuss how pre-existing structures or lithological contacts tend to focus volatile migration.

Lightfoot et al. (1997b) and Farrow and Lightfoot (2002) reported that the basal contact of the SIC at the Whistle embayment dips about 30° south-southwest. If the

"2000" and "North" deposits are assumed to be the same distance from the SIC contact, calculating back to horizontal yields about 45° movement of the Sudbury Structure in this area (Figure 6-5). However, Cowan (1996) and Cowan et al. (1999) cite structural evidence that the granophyre in the northeast lobe of the SIC has not undergone fold-induced strain since lithification, as radial mineral lineation patterns in unstrained norite are interpreted by Cowan (1996) to be incompatible with an initially horizontal melt sheet. Boerner et al. (2000) suspect that gravitational leveling of the melt must have occurred in an impact of such large size. The asymmetry of the SIC as revealed by seismic imaging, and the importance of post-impact shortening in the South Range and the virtual lack of deformation in the North Range lead Boerner et al. (2000) to suggest that the solid-body rotation required to expose the oblique SIC cross section required up to 25° of rotation from horizontal (assuming the base of the SIC was originally horizontal). Regardless, approximately 25° to 45° rotational movement is believed to have occurred in the northeast area of the Sudbury Structure, (if it did occur at all), and the interpretations in this thesis are based on approximately 30° S-SW movement.

The Whistle embayment represents a productive Sublayer 'throat' (the Whistle Pit) of an offset with Cu-PGE veining down offset (North Deposit) and Cu-PGE veining at depth below the Whistle Pit (2000 Deposit) (C. Farrow, Chief Geologist, FNX Mining Company Ltd., personal communication). Considering FNX Mining Company Ltd.'s recent Cu-PGE-rich Footwall Discovery at Levack 4000 feet below surface, it is possible that more economic Cu-PGE deposits exist associated with the Whistle Offset. The "2000" and "North" deposits (Figures 6-5) are both Cu-PGE-rich and hosted in variable amounts of FwBx (metabreccia) and IQD (C. Farrow, Chief Geologist, FNX Mining

Company Ltd., personal communication). Prospective exploration strategies for further economic mineralization should consider brecciated and/or inclusion-bearing rocks (FwBx, SdBx, and IQD), zones of constriction of the offset structure, and hydrous-bearing mineral alteration halos.

Lastly, it has been presumed that the Whistle and Parkin Offsets are disjointed segments of the same offset. Murphy and Spray (2002) report movement on the Post Creek and Milnet Mine fault zones (PCFZ and MMFZ, respectively) as post intrusive. The movement on the PCFZ and MMFZ may have exposed a different structural level of the Parkin Offset environment, juxtaposing it with respect to the Whistle Offset, embayment structure and the Main Mass of the SIC. Another possibility is that the Whistle and Parkin Offsets are discrete en echelon offset structures which should not be related directly as they may not be a linked system. These hypotheses should be kept in mind when exploring for sulphide deposits associated with the Parkin Offset.

Figure 6-1: Primordial Mantle normalized REE graphs with lithogeochemical analyses from a) footwall rocks, and b) footwall rocks plus the fields defined for the Matachewan diabase dykes and xenoliths in the Whistle Offset area.

Figure 6-2: Primordial Mantle normalized REE diagrams with pre-Sudbury Event rock types overlain by fields for:

- a) QD,
- b) LQD,
- c) IQD,
- d) FwBx, and
- e) all offset rocks.

Figure 6-2

REE

Figure 6-3:

a) Cross-section of FwBx-IQD contact in the Proximal Zone (Map 4).

b-d) Block diagrams displaying the irregular nature of the FwBx-IQD contact, and showing how progressive erosion may lead to the interpretation of FwBx pods in IQD, or visa versa, in plan view.

Figure 6-3

Figure 6-4: Schematic model of the emplacement of the quartz dioritic rocks of the Whistle Offset. Sections are vertically exaggerated (the SIC is ~2.5km, and the Onaping Formation is ~1.5km). Schematic Onaping Formation created with the guidance of D. Ames (Mineral Deposits Geologist, Geological Survey of Canada).

Figure 6-5: a) Generalized geological section of the Whistle deposit from Molnar and Watkinson, 2002. b) Conceptual advanced exploration model for Lens A and B, and the 2000 and North deposits of the Whistle embayment and offset structure, from FNX Mining Company Ltd. c) 3-D view looking NE along the Whistle Offset Dyke, from FNX Mining Company Ltd.

Chapter 7. Conclusions

1) Field relationships suggest that the relative timing of the quartz dioritic rock phases is LQD, intruded by IQD, followed by the development of QD. The LQD represents the most primary composition of the undifferentiated melt sheet in the area of the Whistle Offset structure. The IQD also represents an early phase of magma ejected from the melt sheet, but initiation of silicate differentiation, assimilation, and gravitational segregation processes had begun. QD was the final phase to develop locally in the IQD due to incongruent, or irregular heat associated with the system as a whole.

2) Petrographic observation and lithogeochemical analysis of the quartz dioritic phases and Footwall Breccias reveals variation due to contamination by assimilation of xenolithic materials. Due to the irregular nature of contamination, variation along the length of the Whistle Offset is irregular and cannot be rigidly constrained.

3) The relationship between the quartz dioritic phases and the Footwall Breccias begins with common parental materials, specifically the LQD and FwBx. The LQD represents the most primary composition of the undifferentiated melt sheet in the area of the Whistle Offset structure. This being the case, the LQD and FwBx are derived from the same rock types but under varying thermal regimes; the LQD magma was ejected from the superheated melt sheet, whereas the FwBx was brecciated *in situ*, and underwent a fraction of the degree of melting associated with the LQD. The wide range of compositions (scatter) of FwBx geochemical analyses is attributed to the

heterogeneous nature of the rock, compared to the LQD, which would have undergone substantial homogenization. Contact relationships indicate that the quartz dioritic phases were intrusive into the FwBx, and gradational contacts attest to the overlying heat of the entire system, dissipating from the SIC above.

4) Deuteric alteration has affected all the rock types (QD, LQD, IQD, and FwBx), with plagioclase feldspar variably altered to saussurite (sodic plagioclase $\pm$ zoisite $\pm$ epidote), amphibole and rare biotite altered to chlorite, and ilmenite may be altered to Ti-bearing magnetite and titanite. Selective alteration in the form of veins, include assemblages of epidote and epidote+K-feldspar, chlorite, hematite and quartz+hematite, albite and albite+hematite, carbonate, and pyrite, as well as metallic vein assemblages of chalcopyrite with minor amounts of pyrrhotite, pentlandite, millerite, pyrite, arsenopyrite, galena, magnetite and ilmenite, as well as PGM (michenerite, merinskyite, and sperrylite) and PMM (hessite and other Ag-Pd-(Zn)-Bi-tellurides, and native bismuth). Also, malachite is present at surface and associated with chalcopyrite veining.

5) The protoliths for the various quartz dioritic phases are intermediate gneiss > diabase (and gabbro) > granite, and percentage of protolith rock contributions is roughly estimated at 50:30:20 intermediate, mafic, and felsic material, respectively.

6) Common disequilibrium textures in the quartz dioritic phases such as stellate amphibole, granophyric intergrowths, elongate fluorapatite with axial melt inclusions

and irregular REE zoning, indicate that volatiles escaped, rapidly inducing crystallization of these magmas. These volatiles were Cl-rich and capable of transporting Cu and PGE. Metallic mineralization in the form of Cu-PGE-rich veins (Intermediate and Distal Zones), and associated hydrous silicate alteration minerals, imply hydrothermal transport and remobilization. Irregular vein morphology is attributed to clast density influencing the rate and degree of flow. Areas of high clast density may have been capable of impeding flow, causing the fluid to founder, lose heat to the surrounding rocks (creating an alteration halo), and precipitate the mineralization contained within.

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Appendix A

Glossary of Terms and Acronyms (terms directly from Giblin (1984) are in bold italics)

Disseminated sulphide: a scattered distribution of generally fine-grained metal-bearing minerals throughout a rock body, in sufficient quantity to make the deposit an ore.

East Range: a portion of the Sudbury Igneous Complex, commonly considered as an integral part of the North Range, with which it is geologically similar. It extends from the pronounced flexure of the Complex in Norman Township southward to the faulted flexure in Falconbridge Township.

Felsic norite: the major unit of the Lower Zone of the Sudbury Igneous Complex in the North Range.

Footwall Breccia (FwBx): a collective term for various breccias found in the Footwall of the Sudbury Igneous Complex, particularly on the North Range. Many textural and compositions variants can be defined locally. The breccia is characterized by abundant Footwall rock fragments, and locally by sulphide inclusions, in a contact-metamorphic matrix consisting mainly of highly variable proportions of plagioclase, quartz, pyroxene, amphibole, biotite, and granophyric intergrowth of feldspar and quartz. Sulphide may or may not be present in the matrix. The breccia comprises a major portion of the ore deposits on the North Range.

Granophyre: the major unit of the Upper Zone of the Sudbury Igneous Complex.

Ion Chromatography (IC): ion chromatography is a form of liquid chromatography that uses ion-exchange resins to separate atomic or molecular ions based on their interaction with the resin.

Inductively Coupled Plasma Emission Mass Spectrometry (ICP-MS): a type of mass spectrometry that is highly sensitive and capable of simultaneous analysis of a range of metals at below the parts per trillion level. It is based on coupling together an inductively coupled plasma as an ion source with a mass spectrometer as a method of detecting ions.

Inclusion quartz diorite (IQD): an inclusion-bearing variety of quartz diorite occurring in offset structures associated with the Sudbury Igneous Complex.

Leucocratic quartz diorite (LQD): a felsic, medium- to coarse-grained variety of quartz diorite occurring as large pods associated with the Whistle Offset of the Sudbury Igneous Complex.

Levack Gneiss Complex: a belt of mainly high-rank metamorphic gneisses adjacent to parts of the North Range of the Sudbury Igneous Complex.

Lower Zone: the lower, noritic portion of the Main Mass of the Sudbury Igneous Complex. In the North Range, it consists of the felsic norite and mafic norite; in the South Range, it consists of South Range norite and quartz-rich norite.

Mafic norite: the basal unit of the Main Mass of the Sudbury Igneous Complex in the North Range.

Main Mass: the major part of the Sudbury Igneous Complex, consisting of the Lower, Middle, and Upper Zones, and exclusive of the Sublayer.

Massive sulphide: an ore type, consisting almost entirely of sulphide minerals.

Middle Zone: the central portion of the Main Mass of the Sudbury Igneous Complex, consisting mainly of quartz-gabbro.

North Range: the northern portion of the Sudbury Igneous Complex. It is separated from the southern portion by a zone of faulting, extending from the Chicago Fault to the Cameron Creek Fault, at the western end of the Complex. Its eastern end is the pronounced faulted flexure in Falconbridge Township. The East Range is commonly considered as an integral part of the North Range.

Offset; offset dyke: a radial or concentric dyke of the Sudbury Igneous Complex, in general, consisting predominantly of quartz diorite of the Sublayer but may include significant proportions of Footwall Breccia material.

Platinum Group Elements (PGE): platinum (Pt), palladium (Pd), rhodium (Rh), iridium (Ir), ruthenium (Ru) and osmium (Os).

Platinum Group Minerals (PGM): metallic minerals containing PGE.

Precious Metal Minerals (PMM): metallic minerals including Au and Ag and PGE.

Quartz diorite (QD): a variety of the Sublayer of the Sudbury Igneous Complex.

Rare-Earth Elements (REE): the 15 lanthanide elements with atomic numbers 57 through 71: La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu. Rare-Earth Elements may be further sub-divided into Light and Heavy groups, **LREE** and **HREE** respectively; LREE are those elements with atomic numbers from 57-63, and HREE include elements with atomic numbers 64-71 plus Y and Sc.

South Range: the southern portion of the Sudbury Igneous Complex, lying south of the zone of faulting between Cameron Creek and Chicago Faults at the western end and south of the pronounced faulted flexure at the eastern end in Falconbridge Township.

Sublayer: a unit of the Sudbury Igneous Complex. Two varieties, Contact Sublayer and Offset Sublayer, are recognized.

- **Contact Sublayer:** the lowermost unit of the Sudbury Igneous Complex. It is characterized by its discontinuous and inhomogeneous nature, by the presence of 2 distinct types of inclusions set in an igneous matrix, and by the presence of

sulphides in varying amounts. The inclusions consist of footwall rock types and/or a group of mafic to ultramafic rocks.

- **Offset Sublayer:** the varieties of Sublayer which occupy the offset dykes of the Sudbury Igneous Complex. The predominant variety is quartz diorite which may be inclusion and sulphide-free or may contain 2 distinct inclusion types and sulphides as in Contact Sublayer.

Sudbury Basin: the area enclosed by the Sudbury Igneous Complex and occupied by rocks of the Whitewater Group.

Sudbury Breccia (SdBx): pseudotachylite consisting dominantly of locally derived, commonly rounded, rock fragments in a fine-grained, generally dark-coloured matrix that consists of comminuted rock and mineral fragments. In a few places, recrystallized melt matrices have been observed.

Sudbury Igneous Complex (SIC): a large differentiated layered intrusion with which the nickel-copper-precious metals deposits of the Sudbury district are associated. The Complex is sub-divided into a Main Mass (consisting of Lower, Middle, and Upper Zones) and a Sublayer unit.

Sudbury Event: the event (or events) leading to formation of the Sudbury Structure at 1.85 Ga.

Sudbury Structure: a collective term of a feature consisting of 3 main elements:

- (1) the Sudbury Igneous Complex
- (2) the Sudbury Basin
- (3) the brecciated country rocks of the Superior and Southern Provinces which surround the Complex.

Upper Zone: the uppermost portion of the Sudbury Igneous Complex, consisting of the granophyre and plagioclase-rich granophyre units.

Whistle Offset: a radial offset structure occurring off of the northeast margin of the Sudbury Igneous Complex.

X-Ray Fluorescence (XRF): a non-destructive, analytical method whereby a powdered sample is exposed to x-rays of relatively high energy. The photons are capable of exciting (ejecting) the electrons in the core levels of the material under investigation. The induced excited state relaxes under emission of an x-ray photon with a smaller energy. This emitted light is analyzed in a spectrometer which indicates which chemicals are present and their relative proportions.

Abbreviations:

atm. %: atomic percent

wt. %: weight percent

Mineral Abbreviations

amph = amphibole

apt = apatite

bt = biotite

ccp = chalcopyrite

chl = chlorite

ep = epidote

grano = granophyric intergrowths of quartz and feldspar

hem = hematite

k-spar = K-feldspar

ilm = ilmenite

mgt = magnetite

Ni-S = nickel sulphide

plag = plagioclase

py = pyrite

pyx = pyroxene

qtz = quartz

sil = silicate

tit = titanite

Appendix B

Microprobe Analysis and Techniques

Quantitative analyses were made on an automated four-spectrometer Camebax MBX electron probe by the wavelength dispersive x-ray analysis method (WDX) at Carleton University by P.C. Jones. Operating conditions for silicate minerals (excluding apatite) were 15kV accelerating potential and a beam current of 20 nano-amperes (η A). Peak counting times for each analyzed element were 15-40 seconds or 40,000 accumulated counts. Background measurements were made at 50% peak counting time on each side of the analyzed peak. Raw x-ray data were converted to elemental weight % by the Cameca PAP matrix correction program. A suite of well characterized natural and synthetic minerals and compounds were used as calibration standards. Analyses are accurate to 1-2 % relative for major elements, 3-5 % relative for minor elements (< 1 wt %). Element, x-ray line, and standards are listed below.

<i>Element</i>	<i>X-Ray Line</i>	<i>Standard</i>	<i>Type</i>
Si	K α	wollastonite	natural
Al	K α	anorthite	synthetic
Mg	K α	olivine	natural
Na	K α	albite	natural
K	K α	microcline	USNM
Ca	K α	wollastonite	natural
Ti	K α	ilmenite	USNM
Cr	K α	Cr ₂ O ₃	synthetic
Mn	K α	MnTiO ₃	synthetic
Fe	K α	fayalite	synthetic
Ni	K α	NiO	synthetic
Ba	L α	barite	natural
Cl	K α	tugtupite	natural
F	K α	Lithium fluoride	synthetic
Zn	K α	gahnite	USNM

The analytical methods employed for analyzing apatite were similar to those of Piccoli and Candela (1994): 15kV accelerating potential, 15 η A beam current, electron

beam rastered over an area of 5 x 5 to 10 x 10 microns, and 200Å (angstrom) carbon coating for samples and standards, avoiding significant problems of diffusion and volatilization of halogens (described by Stormer et al., 1991). Counting times were either 30-50 seconds or 40,000 counts, depending upon the element, with 0.5 seconds background on each side of the peak (see table below). Fluorine was counted for 60 seconds while REE were counted for 50 seconds. X-ray ray lines were chosen to minimize or eliminate possible elemental interferences (Roeder, 1985; Roeder et al 1987). A suite of well characterized natural and synthetic minerals and compounds were used as calibration standards. Analyses are accurate to 1-2 % relative for major elements (>10 wt %), and 3-10 % relative for minor elements (0.5-10 wt %). Relative error approaches 100% for trace elements (<0.5 wt %) as minimum detection limit (MDL) is approached.

<i>Element</i>	<i>X-Ray Line</i>	<i>Standard</i>	<i>Type</i>	<i>Counting Times</i>
F	K α	Durango apatite	USNM	60 seconds
P	K α	Durango apatite	USNM	20
Ca	K α	Durango apatite	USNM	15
Mn	K α	MnTiO ₃	Synthetic	15
Na	K α	tugtupite	Natural	15
Cl	K α	tugtupite	Natural	20
Ce	L α	CeO ₂	Synthetic	40
Nd	L α	NdAlO ₃	Synthetic	40
Sr	L α	celestite	Natural	20
S	K α	celestite	Natural	20
La	L α	LaAlO ₃	Synthetic	40
Fe	K α	Y ₃ Fe ₅ O ₁₂	Synthetic	15
Si	K α	tugtupite	Natural	15
Y	L α	Y ₃ Fe ₅ O ₁₂	Synthetic	20
Sm	L β	SmAlO ₃	Synthetic	40
Pr	L β	PrF ₃	Synthetic	40
Ba	L α	BaFe ₁₂ O ₉	Synthetic	20
As	L α	NiAs	Natural	15

Digital BSE (back-scattered electron) images were collected with an Electron Optic Services digital imaging system at 512 x 512 resolution with a Lamont 4 element solid state BSE detector and BSE Quad Summing Amplifier interfaced to a 4Pi Analysis Inc. digital imaging and EDX x-ray system and Power Macintosh computer.

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Lithogeochemical Techniques

Whole rock geochemistry was carried out at the Geological Survey of Canada Laboratories in Ottawa. Analytical Chemistry Services guidelines are available at http://gsc.nrcan.gc.ca/labs/chem_e.php.

X-ray Fluorescence (XRF)

Major elements were determined by fused disc wavelength dispersive XRF. The table below lists the major elements and their limit of determination (from GSC Laboratories, http://gsc.nrcan.gc.ca/labs/chem_e.php).

Analyte	Limit of Determination (%)
SiO ₂	0.50
TiO ₂	0.02
Al ₂ O ₃	0.40
Cr ₂ O ₃	0.02
Fe ₂ O ₃ total	0.10
MnO	0.01
MgO	0.10
CaO	0.10
Na ₂ O	0.50
K ₂ O	0.05
P ₂ O ₅	0.02

Inductively Coupled Plasma Mass Spectrometry (ICP-MS)

Trace elements were determined "based on total dissolution of the sample using nitric, perchloric and hydrofluoric acids followed by a lithium metaborate fusion of any residual material" (from GSC Laboratories), followed by ICP-MS and ICP-ES (emission spectrometry). The tables below list the element and limit of determination (from GSC Laboratories).

Trace elements (ICP-ES)

Element	Limit of Determination (ppm)	Element	Limit of Determination (ppm)
Ag	5	Pb	10
Ba	10	Sc	0.5

Be	0.5	Sr	5
Co	5	V	5
Cr	10	Y	5
Cu	10	Yb	0.5
La	10	Zn	5
Ni	10	Zr	10
Mo	5		

Rare-earth elements (ICP-MS)

Element	Limit of Determination (ppm)	Element	Limit of Determination (ppm)
Ce	0.1	Nd	0.1
Dy	0.02	Pr	0.02
Er	0.02	Sm	0.02
Eu	0.02	Tb	0.02
Gd	0.02	Tm	0.02
Ho	0.02	Y	0.02
La	0.1	Yb	0.05
Lu	0.02		

Other trace elements (ICP-MS)

Element	Limit of Determination (ppm)	Element	Limit of Determination (ppm)
Ag	0.1	Pb	2
Bi	0.5	Rb	0.05
Cd	0.2	Sn	0.5
Cs	0.02	Ta	0.2
Ga	0.1	Th	0.02
Hf	0.05	Tl	0.02
In	0.05	U	0.02
Mo	0.2	Zr	0.5
Nb	0.05		

Ion Chromatography (IC)

Fluorine and chlorine were determined using a pyrohydrolysis method followed by ion chromatography. Detection limits for F and Cl are 50 ppm and 100 ppm, respectively. This method has a 1% upper limit of determination.

Appendix C

Figure AC-1: Photomicrographs of Sudbury Breccia (in plane polarized light) typical of the Whistle Offset area. a) Recrystallized quartz inclusions in fine-grained quartz-feldspar-unidentifiable mafic groundmass. b) Rounded mafic inclusion in fine-grained groundmass. c) Rounded quartz-feldspar inclusions in fine-grained groundmass, with ragged biotite porphyroblasts or inclusions? d) Close-up view of biotite inclusion. e) Close-up view of quartz inclusion with fragments of mafic minerals. f) Apatite in fine-grained groundmass.

Figure AC-2: Sudbury Olivine Diabase Dyke. a) Hand sample displaying colour and texture on fresh surface. b) Typical mineralogy and texture of Olivine Diabase. c) Olivine crystals (dark green) in plagioclase, pyroxene (augite; dark grey), and magnetite (light grey). d) Needle-shaped magnetite grain. e) and f) Cross-sectional cuts through skeletal magnetite grains. [Images b) through f) were taken through a binocular microscope with transmitted light.]

Figure AC-3: Photomicrographs of Sudbury Olivine Diabase. a) Plane polarized light (ppl) image of olivine crystals (centre, light green) with pyroxene (brownish-pink) and plagioclase feldspar. b) Crossed-polarized light (xpl) image of a). c) and d) Pyroxene in plagioclase in ppl and xpl, respectively. e) Apatite (long, light green, needles) with pyroxene and plagioclase (ppl). f) Skeletal magnetite grain in plagioclase.

Figure AC-4: Created using Fe₂O₃ Total and oxide analyses (no cation analyses used). Generalized IUGS classification.

Figure AC-5: Geological features in the Sudbury Breccia belt parallel to the Whistle embayment, cut perpendicularly by the Whistle Offset. a-b) SdBx in granite. c-f) Epidote-K-feldspar alteration veins in SdBx (coin is 1.7 cm). g) Pegmatitic development cut by later epidote veinlet.

Appendix D

Table 1: Electron Microprobe Data – Potassium Feldspar

Basis 16 oxygen(s) formula

Analyses	Zone	Rock Type	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	K ₂ O	CaO	Na ₂ O	BaO	TOTAL	Si	Al	Fe	SUBT	K	Ca	Na	Ba	SUBT
LQD12-5	Prox. #1	LQD	65.16	18.90	0.03	15.99	0.05	0.19	0.39	100.71	5.980	2.044	0.002	8.026	1.872	0.005	0.035	0.014	1.926
LQD5A-4	Prox. #2	LQD	66.48	18.71	0.33	16.62	0.03	0.08	0.11	102.36	6.004	1.991	0.023	8.018	1.914	0.003	0.014	0.004	1.935
LQD-14-4	Prox. #3	LQD	65.69	18.62	0.14	16.43	0.03	0.29	0.15	101.35	5.996	2.003	0.010	8.009	1.913	0.003	0.051	0.005	1.972
LQD-8-4	Prox. #3	LQD	66.23	18.36	0.20	14.72	0.18	1.10	0.22	101.01	6.025	1.968	0.014	8.007	1.709	0.017	0.193	0.008	1.927
LQD-15A-4	Prox. #5	LQD	65.85	18.91	0.02	16.58	0.05	0.27	0.00	101.68	5.985	2.025	0.002	8.012	1.923	0.005	0.048	0.000	1.976
LQD15B-2	Prox. #5	LQD	64.92	18.77	0.16	16.00	0.12	0.28	0.57	100.82	5.968	2.034	0.011	8.013	1.876	0.011	0.050	0.020	1.957
LQD20A-3	Int. #1	LIQD	64.48	18.37	0.03	16.06	0.11	0.31	0.22	99.58	5.991	2.011	0.002	8.004	1.903	0.011	0.057	0.008	1.979
LQD-21-4	Int. #2	LIQD>LQD	64.98	19.00	0.22	15.84	0.12	0.45	0.51	101.12	5.952	2.051	0.015	8.018	1.851	0.012	0.080	0.018	1.961
53-4	Int. #3	FwBx	65.27	19.00	0.15	16.40	0.03	0.19	0.31	101.35	5.964	2.046	0.011	8.021	1.912	0.003	0.034	0.011	1.960
77-6	Distal	IQD	65.44	18.81	0.30	16.46	0.01	0.31	0.57	101.90	5.966	2.021	0.021	8.008	1.914	0.001	0.055	0.020	1.990
QD-4	Distal	QD	66.27	18.35	0.06	16.35	0.03	0.33	0.20	101.59	6.028	1.967	0.004	7.999	1.897	0.003	0.057	0.007	1.964
maximum			66.48	19.00	0.33	16.62	0.18	1.10	0.57		6.028	2.051	0.023		1.923	0.017	0.193	0.020	
minimum			64.48	18.35	0.03	14.72	0.01	0.08	0.00		5.952	1.967	0.002		1.851	0.001	0.014	0.004	
average			65.52	18.71	0.15	16.13	0.07	0.35	0.30		5.99	2.01	0.01		1.88	0.01	0.06	0.01	

*All of the K-feldspar analyzed is in granophyric intergrowth with quartz, except LQD5A-4 which is completely surrounded by chlorite.

Amphibole Classification

- Leake, B.E. et al., 1997, Nomenclature of Amphiboles: Report of the Subcommittee on Amphiboles of the International Mineralogical Association, Commission on New Minerals and Mineral Names. *The Canadian Mineralogist*, vol. 35, pp. 219-246.
- The classification is based on the chemical contents of the standard amphibole formula $AB_2^{VI}C_5^{IV}T_8O_{22}(OH)_2$.
- The components of the formula conventionally described as *A*, *B*, *C*, *T* and "OH" correspond to the following crystallographic sites:

<i>A</i>	One site per formula unit
<i>B</i>	Two M4 sites per formula unit
<i>C</i>	A composite of five sites made up of 2 M1, 2 M2 and 1 M3 sites per formula unit
<i>T</i>	Eight sites, in two sets of four
"OH"	Two sites per formula unit

- The ions considered *normally* to occupy these sites are in the following categories:

□ (empty site) and K	at <i>A</i> only
Na	at <i>A</i> or <i>B</i>
Ca	at <i>B</i> only
<i>L</i> -type ions: Mg, Fe ²⁺ , Mn ²⁺ , Li and rarer ions of similar size, such as Zn, Ni, Co	at <i>C</i> or <i>B</i>
<i>M</i> -type ions: Al	at <i>C</i> or <i>T</i>
Fe ³⁺ and, more rarely, Mn ³⁺ , Cr ³⁺	at <i>C</i> only
High-valency ions: Ti ⁴⁺	at <i>C</i> or <i>T</i>
Zr ⁴⁺	at <i>C</i> only
Si	at <i>T</i> only
Anions: OH, F, Cl, O	at "OH"

- Fluorine substitutes more easily for OH than chlorine:

Element/Molecule	Atomic Weight/Molecular Weight
O / OH	16.00 / 17.00
F	19.00
Cl	35.45

- Ferrous (Fe^{2+}) versus Ferric (Fe^{3+}) Iron: use 13eCNK (maximum Fe^{3+}) if the rocks are oxidized.

Fe^{2+}	All ferrous iron (Fe^{2+})
15eNK	Minimum estimate of the proportion of ferric iron (Fe^{3+}).
15eK	
13eCNK	Maximum estimate of the proportion of ferric iron (Fe^{3+}).
Average (15eNK and 13eCNK)	Average of the minimum and maximum estimates for ferric iron.

- **15eNK:** data normalized so that the sum of the cations Si through Ca = 15, exclusive of Na and K.
- **15eK:** data normalized so that the sum of the cations Si through Na = 15, exclusive of K.
- **13eCNK:** data normalized so that the sum of the cations Si through Mn = 13, exclusive of Ca, Na and K.

Table 2: Electron Microprobe Data -- Amphibole

SAMPLE	Zone	Rock	SiO ₂	Al ₂ O ₃	TiO ₂	Cr ₂ O ₃	FeO	MnO	MgO	NiO	K ₂ O	CaO	Na ₂ O	Cl	F	TOTAL	TOT-O
LQD1-1	Prox. #1	LQD	47.02	6.33	0.99	0.10	18.43	0.31	11.42	0.06	0.70	10.87	1.33	0.35	0.19	98.10	97.94
LQD1-2	Prox. #1	LQD	51.59	3.06	0.03	0.04	17.33	0.43	12.80	0.01	0.18	11.67	0.50	0.16	0.06	97.86	97.80
LQD12-1	Prox. #1	LQD	49.31	5.33	0.89	0.05	14.59	0.23	12.86	0.00	0.48	11.44	1.10	0.25	0.35	96.88	96.68
LQD12-3	Prox. #1	LQD	48.78	5.36	0.88	0.10	16.57	0.23	13.02	0.03	0.53	11.02	1.32	0.21	0.47	98.52	98.27
LQD17-1	Prox. #1	LQD	48.81	4.31	1.36	0.09	17.39	0.33	12.45	0.01	0.38	10.65	0.92	0.18	0.14	97.02	96.92
LQD17-2	Prox. #1	LQD	45.46	7.01	1.63	0.02	17.60	0.21	11.64	0.05	0.94	10.87	1.53	0.28	0.29	97.53	97.34
LQD17-3	Prox. #1	LQD	47.37	5.46	0.62	0.10	17.81	0.29	12.20	0.00	0.54	10.82	1.12	0.24	0.15	96.72	96.60
LQD17-4	Prox. #1	LQD	51.73	2.51	0.22	0.07	14.95	0.32	13.85	0.00	0.19	11.54	0.55	0.10	0.16	96.19	96.10
LQD17-5	Prox. #1	LQD	47.44	5.84	0.93	0.10	17.55	0.33	11.73	0.00	0.56	10.85	1.10	0.24	0.23	96.90	96.75
LQD5A-1	Prox. #2	LQD	48.31	6.58	1.73	0.01	12.94	0.20	14.33	0.01	0.93	10.97	1.56	0.27	0.45	98.29	98.04
LQD5A-5	Prox. #2	LQD	49.64	5.82	1.40	0.00	13.48	0.25	14.48	0.04	0.75	11.06	1.30	0.24	0.43	98.89	98.65
LQD-5B-1	Prox. #2	LQD	49.85	4.90	0.76	0.00	14.21	0.59	14.16	0.04	0.43	11.41	0.97	0.16	0.12	97.60	97.51
LQD-8-1	Prox. #3	LQD	47.90	6.25	1.27	0.01	13.03	0.15	14.45	0.02	1.01	11.36	1.54	0.15	0.73	97.87	97.53
LQD-8-2	Prox. #3	LQD	47.22	6.66	1.65	0.03	14.27	0.19	13.55	0.02	1.01	11.24	1.52	0.20	0.40	97.96	97.75
LQD-8-3	Prox. #3	LQD	46.94	6.50	1.59	0.01	14.41	0.25	13.54	0.02	0.94	11.29	1.48	0.19	0.43	97.59	97.37
LQD-14-1	Prox. #3	LQD	46.28	6.26	1.55	0.01	19.05	0.33	10.83	0.01	0.84	10.96	1.51	0.29	0.39	98.31	98.08
LQD-14-3	Prox. #3	LQD	46.75	6.92	1.58	0.00	17.77	0.24	11.28	0.00	0.96	11.08	1.55	0.37	0.22	98.72	98.54
LQD4-1	Prox. #3	LQD	46.63	6.77	1.60	0.01	14.35	0.14	14.12	0.00	1.14	11.27	1.48	0.09	0.51	98.11	97.87
LQD17-1	Prox. #3	LQD	51.61	3.89	0.25	0.00	14.98	0.43	14.21	0.01	0.28	10.69	0.76	0.07	0.35	97.53	97.37
LQD17-2	Prox. #3	LQD	52.34	2.54	0.11	0.01	18.50	0.35	11.42	0.00	0.15	11.08	0.46	0.16	0.10	97.22	97.14
LQD-15A-1	Prox. #5	LQD	46.23	6.87	1.48	0.03	17.19	0.24	11.79	0.00	1.06	11.18	1.66	0.32	0.53	98.58	98.28
LQD-15A-2	Prox. #5	LQD	50.74	4.70	0.37	0.38	13.78	0.26	15.13	0.00	0.52	11.22	1.04	0.17	0.46	98.77	98.54
LQD-15A-5	Prox. #5	LQD	46.08	6.83	1.55	0.03	17.28	0.20	11.79	0.00	0.99	11.23	1.47	0.28	0.47	98.20	97.94
LQD15B-1	Prox. #5	LQD	49.53	5.57	0.26	0.01	17.46	0.25	13.98	0.09	0.21	9.66	0.30	0.07	0.11	97.50	97.44
LQD-18-1	Int. #1	LQD	47.89	5.69	1.00	0.01	17.55	0.37	12.27	0.03	0.61	11.11	1.31	0.29	0.24	98.37	98.20
LQD-18-2	Int. #1	LQD	49.41	3.59	0.00	0.02	23.58	0.58	7.84	0.01	0.13	11.38	0.28	0.05	0.10	96.97	96.92
LQD-18-5	Int. #1	LQD	47.57	5.72	0.95	0.05	18.15	0.29	12.00	0.00	0.54	10.47	1.14	0.32	0.21	97.41	97.25
LQD-19-1	Int. #1	LQD	49.77	4.40	1.17	0.00	16.55	0.42	13.21	0.04	0.35	10.61	0.92	0.16	0.20	97.80	97.68
LQD20B-2	Int. #1	LQD	49.18	4.95	0.69	0.00	15.92	0.33	13.51	0.04	0.45	11.21	1.08	0.15	0.27	97.78	97.63
LQD20A-2	Int. #1	LQD	48.53	5.60	1.01	0.02	16.62	0.38	12.48	0.03	0.55	11.14	1.26	0.19	0.17	97.98	97.87
LQD20A-4	Int. #1	LQD	54.56	1.90	0.41	0.01	13.75	0.09	14.84	0.00	0.15	12.11	0.42	0.00	0.23	98.47	98.37
LQD20A-5	Int. #1	LQD	47.85	6.21	1.05	0.00	16.93	0.34	12.43	0.05	0.64	10.99	1.40	0.21	0.25	98.35	98.20
LQD-21-2	Int. #2	LQD>LQD	49.19	5.55	0.90	0.10	16.13	0.36	13.73	0.01	0.58	10.38	1.19	0.20	0.21	98.53	98.40
LQD-22-1	Int. #2	LQD	46.64	6.40	1.24	0.05	17.67	0.34	11.74	0.00	0.73	11.21	1.26	0.32	0.14	97.74	97.61

Table 2 cont'd: Electron Microprobe Data -- Amphibole

SAMPLE	Si	Al	SUBT	Al	Ti	Cr	Fe	Mn	Mg	Ni	SUBT	K	Ca	Na	SUBT	Cl	F	SUBT	OH calc.
LQD1-1	7.070	0.930	8.000	0.192	0.112	0.012	2.317	0.039	2.559	0.007	5.238	0.135	1.752	0.387	2.274	0.090	0.091	0.181	1.819
LQD1-2	7.619	0.381	8.000	0.153	0.004	0.005	2.140	0.054	2.817	0.001	5.174	0.034	1.847	0.142	2.023	0.039	0.028	0.067	1.933
LQD12-1	7.333	0.667	8.000	0.268	0.099	0.006	1.815	0.029	2.851	0.000	5.068	0.091	1.824	0.317	2.232	0.063	0.166	0.229	1.771
LQD12-3	7.220	0.780	8.000	0.155	0.098	0.012	2.051	0.029	2.872	0.003	5.220	0.100	1.747	0.378	2.225	0.054	0.218	0.272	1.728
LQD17-1	7.323	0.677	8.000	0.084	0.153	0.011	2.182	0.042	2.784	0.001	5.257	0.073	1.711	0.268	2.052	0.046	0.065	0.111	1.889
LQD17-2	6.888	1.112	8.000	0.140	0.186	0.002	2.230	0.026	2.628	0.006	5.218	0.181	1.765	0.449	2.395	0.072	0.141	0.213	1.787
LQD17-3	7.178	0.822	8.000	0.152	0.070	0.012	2.257	0.037	2.755	0.000	5.283	0.103	1.756	0.330	2.189	0.062	0.074	0.136	1.864
LQD17-4	7.688	0.312	8.000	0.128	0.025	0.008	1.858	0.041	3.068	0.000	5.128	0.036	1.837	0.160	2.033	0.025	0.073	0.098	1.902
LQD17-5	7.168	0.832	8.000	0.208	0.106	0.012	2.218	0.042	2.643	0.000	5.229	0.108	1.756	0.324	2.188	0.061	0.108	0.169	1.831
LQD5A-1	7.074	0.926	8.000	0.210	0.190	0.001	1.584	0.025	3.127	0.001	5.138	0.173	1.721	0.443	2.337	0.066	0.209	0.275	1.725
LQD5A-5	7.209	0.791	8.000	0.205	0.153	0.000	1.638	0.030	3.135	0.004	5.165	0.139	1.722	0.366	2.227	0.059	0.195	0.254	1.746
LQD-5B-1	7.328	0.672	8.000	0.176	0.084	0.000	1.747	0.073	3.102	0.005	5.187	0.081	1.797	0.275	2.153	0.041	0.057	0.098	1.902
LQD-8-1	7.078	0.922	8.000	0.166	0.141	0.001	1.610	0.019	3.182	0.003	5.122	0.191	1.798	0.441	2.430	0.038	0.342	0.380	1.620
LQD-8-2	6.999	1.001	8.000	0.162	0.184	0.004	1.768	0.023	2.992	0.003	5.136	0.191	1.785	0.436	2.412	0.051	0.185	0.236	1.764
LQD-8-3	6.993	1.007	8.000	0.135	0.178	0.001	1.795	0.031	3.007	0.003	5.150	0.178	1.803	0.429	2.410	0.047	0.203	0.250	1.750
LQD-14-1	7.000	1.000	8.000	0.116	0.176	0.001	2.410	0.042	2.442	0.001	5.188	0.163	1.776	0.443	2.382	0.073	0.185	0.258	1.742
LQD-14-3	6.917	1.083	8.000	0.203	0.177	0.000	2.219	0.031	2.510	0.000	5.140	0.183	1.773	0.448	2.404	0.093	0.105	0.198	1.802
IQD4-1	7.565	0.435	8.000	0.237	0.027	0.000	1.836	0.053	3.105	0.001	5.259	0.052	1.679	0.217	1.948	0.017	0.161	0.178	1.737
IQD17-1	7.789	0.211	8.000	0.234	0.013	0.002	2.302	0.044	2.533	0.000	5.128	0.029	1.767	0.133	1.929	0.040	0.048	0.088	1.912
IQD17-2	6.936	1.064	8.000	0.151	0.167	0.004	2.157	0.031	2.636	0.000	5.146	0.204	1.797	0.483	2.484	0.083	0.252	0.335	1.665
LQD-15A-1	7.364	0.636	8.000	0.169	0.041	0.044	1.673	0.032	3.272	0.000	5.231	0.096	1.745	0.293	2.134	0.041	0.210	0.251	1.749
LQD-15A-2	6.932	1.068	8.000	0.143	0.176	0.003	2.174	0.025	2.644	0.000	5.155	0.190	1.810	0.430	2.430	0.072	0.222	0.294	1.706
LQD-15A-5	7.312	0.688	8.000	0.281	0.029	0.001	2.156	0.031	3.076	0.010	5.584	0.039	1.528	0.085	1.652	0.017	0.052	0.069	1.931
LQD15B-1	7.142	0.858	8.000	0.142	0.113	0.001	2.189	0.047	2.727	0.004	5.223	0.117	1.775	0.378	2.270	0.073	0.112	0.185	1.815
LQD-18-1	7.594	0.406	8.000	0.244	0.000	0.002	3.031	0.076	1.797	0.002	5.152	0.025	1.875	0.083	1.983	0.014	0.049	0.063	1.937
LQD-18-2	7.164	0.836	8.000	0.179	0.108	0.006	2.286	0.037	2.694	0.000	5.310	0.103	1.689	0.332	2.124	0.081	0.101	0.182	1.818
LQD-18-5	7.362	0.638	8.000	0.129	0.130	0.000	2.048	0.052	2.913	0.005	5.277	0.066	1.682	0.265	2.013	0.040	0.094	0.134	1.866
LQD-19-1	7.286	0.714	8.000	0.150	0.077	0.000	1.973	0.042	2.983	0.005	5.230	0.084	1.779	0.311	2.174	0.037	0.128	0.165	1.835
LQD20B-2	7.208	0.792	8.000	0.188	0.113	0.002	2.054	0.048	2.763	0.004	5.182	0.103	1.772	0.363	2.238	0.047	0.082	0.129	1.871
LQD20A-2	7.829	0.171	8.000	0.150	0.044	0.001	1.650	0.011	3.175	0.000	5.031	0.027	1.862	0.117	2.006	0.001	0.107	0.108	1.892
LQD20A-4	7.110	0.890	8.000	0.198	0.117	0.000	2.104	0.043	2.752	0.005	5.219	0.121	1.749	0.402	2.272	0.052	0.117	0.169	1.831
LQD20A-5	7.225	0.775	8.000	0.186	0.099	0.011	1.981	0.045	3.007	0.002	5.331	0.108	1.633	0.340	2.081	0.050	0.096	0.146	1.854
LQD-21-2	7.020	0.980	8.000	0.156	0.141	0.006	2.225	0.043	2.635	0.000	5.206	0.140	1.808	0.369	2.317	0.082	0.067	0.149	1.851

Table 2 cont'd: Electron Microprobe Data – Amphibole

SAMPLE	Zone	Rock	SiO ₂	Al ₂ O ₃	TiO ₂	Cr ₂ O ₃	FeO	MnO	MgO	NiO	K ₂ O	CaO	Na ₂ O	Cl	F	TOTAL	TOT-O
36-1	Int. #2	LQD	48.07	5.20	0.99	0.00	19.24	0.39	11.38	0.00	0.50	9.88	1.10	0.16	0.16	97.07	96.97
36-2	Int. #2	LQD	52.94	2.36	0.07	0.03	15.75	0.29	13.97	0.01	0.09	10.64	0.45	0.13	0.12	96.85	96.77
89-2	Int. #2	QD>LQD	46.95	6.20	1.16	0.09	16.77	0.26	12.18	0.00	0.66	10.87	1.42	0.28	0.36	97.20	96.99
89-3	Int. #2	QD>LQD	47.64	6.03	1.00	0.06	16.68	0.25	12.08	0.00	0.65	10.95	1.38	0.31	0.20	97.23	97.08
27-2	Int. #3	LIQD/IQD	47.77	5.83	1.06	0.11	16.82	0.30	12.48	0.02	0.69	11.16	1.31	0.25	0.27	98.07	97.90
27-3	Int. #3	LIQD/IQD	49.66	4.61	0.50	0.01	16.36	0.32	12.83	0.01	0.45	11.39	0.94	0.20	0.22	97.50	97.36
27-5	Int. #3	LIQD/IQD	51.57	1.56	0.03	0.00	22.49	0.71	8.74	0.01	0.09	11.98	0.22	0.01	0.03	97.44	97.43
53-1	Int. #3	FBx/IQD?	48.03	5.68	1.20	0.03	15.38	0.27	13.20	0.02	0.57	11.09	1.31	0.24	0.21	97.23	97.09
QD-1	Distal	QD	44.88	6.94	1.55	0.06	18.76	0.20	10.47	0.00	0.91	10.76	1.48	0.36	0.21	96.58	96.41
QD-2	Distal	QD	55.33	0.97	0.01	0.01	15.79	0.33	13.10	0.00	0.03	11.70	0.19	0.03	0.06	97.55	97.52
QD-6	Distal	QD	46.02	6.94	1.62	0.04	18.86	0.24	10.76	0.00	0.95	10.50	1.48	0.33	0.14	97.88	97.75
77-1	Distal	QD	46.15	6.60	1.63	0.00	16.84	0.29	11.38	0.02	0.95	11.07	1.26	0.19	0.26	96.64	96.49
77-2	Distal	QD	50.48	4.31	0.78	0.01	16.19	0.29	12.70	0.00	0.58	11.36	0.74	0.10	0.19	97.73	97.63
77-3	Distal	QD	49.85	5.53	0.12	0.01	15.16	0.24	13.93	0.00	0.45	11.14	0.94	0.11	0.31	97.79	97.63
77-4	Distal	QD	46.33	6.66	1.39	0.00	17.48	0.25	11.56	0.00	0.85	10.99	1.28	0.23	0.31	97.33	97.15
91-1	Distal	QD	49.00	5.06	1.14	0.09	17.22	0.29	12.79	0.05	0.54	10.26	1.13	0.13	0.29	97.99	97.84
91-2	Distal	QD	55.24	0.77	0.00	0.02	13.39	0.24	15.59	0.03	0.01	12.00	0.07	0.03	0.17	97.56	97.48
91-4	Distal	QD	55.17	0.59	0.03	0.00	13.56	0.20	15.05	0.02	0.01	11.87	0.12	0.00	0.16	96.78	96.71

Table 2 cont'd: Electron Microprobe Data -- Amphibole

SAMPLE	Si	Al	SUBT	Al	Ti	Cr	Fe	Mn	Mg	Ni	SUBT	K	Ca	Na	SUBT	Cl	F	SUBT	OH calc.
36-1	7.265	0.735	8.000	0.192	0.112	0.000	2.431	0.050	2.563	0.000	5.348	0.096	1.600	0.322	2.018	0.041	0.078	0.119	1.881
36-2	7.789	0.211	8.000	0.198	0.008	0.003	1.937	0.036	3.063	0.001	5.246	0.017	1.677	0.130	1.824	0.032	0.054	0.086	1.914
89-2	7.079	0.921	8.000	0.181	0.131	0.011	2.115	0.033	2.736	0.000	5.207	0.128	1.755	0.416	2.299	0.072	0.171	0.243	1.757
89-3	7.153	0.847	8.000	0.221	0.113	0.007	2.094	0.032	2.703	0.000	5.170	0.124	1.762	0.401	2.287	0.079	0.094	0.173	1.827
27-2	7.126	0.874	8.000	0.152	0.119	0.013	2.098	0.038	2.775	0.003	5.198	0.131	1.784	0.378	2.293	0.064	0.126	0.190	1.810
27-3	7.382	0.618	8.000	0.189	0.056	0.002	2.034	0.040	2.843	0.002	5.166	0.086	1.813	0.270	2.169	0.050	0.103	0.153	1.847
27-5	7.829	0.171	8.000	0.109	0.003	0.000	2.856	0.091	1.978	0.001	5.038	0.017	1.948	0.065	2.030	0.003	0.012	0.015	1.985
53-1	7.162	0.838	8.000	0.160	0.134	0.003	1.918	0.035	2.934	0.003	5.187	0.109	1.771	0.378	2.258	0.060	0.097	0.157	1.843
QD-1	6.908	1.092	8.000	0.168	0.179	0.007	2.415	0.026	2.402	0.000	5.197	0.178	1.774	0.443	2.395	0.095	0.103	0.198	1.802
QD-2	8.046	0.000	8.046	0.166	0.002	0.001	1.920	0.041	2.840	0.000	4.970	0.006	1.823	0.052	1.881	0.006	0.029	0.035	1.965
QD-6	6.960	1.040	8.000	0.197	0.184	0.005	2.385	0.030	2.425	0.000	5.226	0.183	1.702	0.433	2.318	0.085	0.068	0.153	1.847
77-1	7.011	0.989	8.000	0.193	0.186	0.000	2.139	0.038	2.576	0.003	5.135	0.184	1.801	0.370	2.355	0.048	0.125	0.173	1.827
77-2	7.455	0.545	8.000	0.206	0.086	0.001	2.000	0.037	2.796	0.000	5.126	0.109	1.797	0.211	2.117	0.025	0.087	0.112	1.888
77-3	7.329	0.671	8.000	0.287	0.013	0.001	1.864	0.030	3.052	0.000	5.247	0.084	1.755	0.268	2.107	0.027	0.145	0.172	1.828
77-4	7.003	0.997	8.000	0.190	0.158	0.000	2.210	0.032	2.604	0.000	5.194	0.164	1.781	0.376	2.321	0.060	0.146	0.206	1.794
91-1	7.273	0.727	8.000	0.158	0.128	0.010	2.138	0.037	2.830	0.006	5.307	0.102	1.632	0.325	2.059	0.033	0.134	0.167	1.833
91-2	7.967	0.033	8.000	0.098	0.000	0.002	1.615	0.029	3.351	0.003	5.098	0.003	1.855	0.021	1.879	0.009	0.079	0.088	1.912
91-4	8.019	0.000	8.019	0.101	0.003	0.000	1.648	0.025	3.262	0.003	5.042	0.002	1.848	0.034	1.884	0.000	0.074	0.074	1.926

Table 3: Sample recalculations for amphibole using the average of 15eNK and 13eCNK

Sample 27 Analysis 27-2						Sample 27 Analysis 27-3					
Location: Int #3						Location: Int #3					
Oxygen: 23.0 OH: 0.0						Oxygen: 23.0 OH: 0.0					
	Fe ²⁺	15-NK	15-K	13-CNK	AV (2, 4)		Fe ²⁺	15-NK	15-K	13-CNK	AV (2, 4)
TSi	8.846	7.137	6.961	7.021	7.079	TSi	8.751	7.393	7.262	7.290	7.342
TAI	0.000	0.863	1.000	0.979	0.921	TAI	0.000	0.607	0.738	0.710	0.658
TFe ³⁺	0.000	0.000	0.039	0.000	0.000	TFe ³⁺	0.000	0.000	0.000	0.000	0.000
TTi	0.000	0.000	0.000	0.000	0.000	TTi	0.000	0.000	0.000	0.000	0.000
Sum T	8.846	8.000	8.000	8.000	8.000	Sum T	8.751	8.000	8.000	8.000	8.000
CAI	1.271	0.163	0.000	0.031	0.097	CAI	0.957	0.201	0.056	0.087	0.144
CCr	0.016	0.013	0.013	0.013	0.013	CCr	0.001	0.001	0.001	0.001	0.001
CFe ³⁺	0.000	0.000	1.036	0.683	0.342	CFe ³⁺	0.000	0.000	0.754	0.576	0.288
CTi	0.148	0.119	0.116	0.117	0.118	CTi	0.066	0.056	0.055	0.055	0.056
CMg	3.445	2.780	2.711	2.735	2.757	CMg	3.371	2.847	2.797	2.808	2.828
CFe ²⁺	0.119	1.926	0.975	1.384	1.655	CFe ²⁺	0.605	1.894	1.247	1.433	1.663
CMn	0.000	0.000	0.037	0.037	0.019	CMn	0.000	0.000	0.040	0.040	0.020
CCa	0.000	0.000	0.112	0.000	0.000	CCa	0.000	0.000	0.051	0.000	0.000
Sum C	5.000	5.000	5.000	5.000	5.000	Sum C	5.000	5.000	5.000	5.000	5.000
BMg	0.000	0.000	0.000	0.000	0.000	BMg	0.000	0.000	0.000	0.000	0.000
BFe ²⁺	2.485	0.176	0.000	0.000	0.880	BFe ²⁺	1.806	0.143	0.000	0.000	0.071
BMn	0.047	0.038	0.000	0.000	0.019	BMn	0.048	0.040	0.000	0.000	0.020
BCa	0.000	1.786	1.630	1.757	1.772	BCa	0.146	1.817	1.733	1.792	1.804
BNa	0.000	0.000	0.370	0.243	0.121	BNa	0.000	0.000	0.267	0.208	0.104
Sum B	2.532	2.000	2.000	2.000	2.000	Sum B	2.000	2.000	2.000	2.000	2.000
ANa	0.470	0.379	0.000	0.131	0.255	ANa	0.321	0.271	0.000	0.059	0.165
AK	0.163	0.132	0.128	0.129	0.130	AK	0.101	0.085	0.084	0.084	0.085
Sum A	2.848	0.511	0.128	0.260	0.386	Sum A	2.427	0.357	0.084	0.143	0.250
CCI	0.078	0.063	0.062	0.062	0.063	CCI	0.060	0.050	0.050	0.050	0.050
CF	0.158	0.128	0.124	0.126	0.127	CF	0.123	0.104	0.102	0.102	0.103
Sum cat	19.226	15.511	15.128	15.260	15.386	Sum cat	18.178	15.357	15.084	15.143	15.250
Sum oxy	28.547	23.031	23.000	23.000	23.015	Sum oxy	27.263	23.032	23.000	23.000	23.016

Sample 27	Location: Int #2				Oxygen: 23.0
Analysis 27-5					OH: 0.0
	Fe ²⁺	15-NK	15-K	13-CNK	AV (2, 4)
TSi	7.950	7.837	7.803	7.807	7.822
TAI	0.050	0.163	0.197	0.193	0.178
TFe ³⁺	0.000	0.000	0.000	0.000	0.000
TTi	0.000	0.000	0.000	0.000	0.000
Sum T	8.000	8.000	8.000	8.000	8.000
CAI	0.233	0.116	0.081	0.086	0.101
CCr	0.000	0.000	0.000	0.000	0.000
CFe ³⁺	0.000	0.000	0.156	0.132	0.066
CTi	0.003	0.003	0.003	0.003	0.003
CMg	2.009	1.980	1.972	1.973	1.976
CFe ²⁺	2.755	2.858	2.690	2.716	2.787
CMn	0.000	0.042	0.091	0.091	0.067
CCa	0.000	0.000	0.007	0.000	0.000
Sum C	5.000	5.000	5.000	5.000	5.000
BMg	0.000	0.000	0.000	0.000	0.000
BFe ²⁺	0.145	0.000	0.000	0.000	0.000
BMn	0.093	0.049	0.000	0.000	0.025
BCa	1.763	1.951	1.935	1.943	1.947
BNa	0.000	0.000	0.065	0.057	0.028
Sum B	2.000	2.000	2.000	2.000	2.000
ANa	0.066	0.065	0.000	0.008	0.036
AK	0.018	0.017	0.017	0.017	0.017
Sum A	0.300	0.082	0.017	0.025	0.054
CCI	0.003	0.003	0.003	0.003	0.003
CF	0.015	0.014	0.014	0.014	0.014
Sum cat	15.300	15.082	15.017	15.025	15.054
Sum oxy	23.353	23.021	23.000	23.000	23.011

Sample 36	Location: Int #2				Oxygen: 23.0
Analysis 36-1					OH: 0.0
	Fe ²⁺	15-NK	15-K	13-CNK	AV (2, 4)
TSi	8.267	7.290	7.136	7.075	7.183
TAI	0.000	0.710	0.864	0.901	0.806
TFe ³⁺	0.000	0.000	0.000	0.023	0.012
TTi	0.000	0.000	0.000	0.000	0.000
Sum T	8.267	8.000	8.000	8.000	8.000
CAI	1.053	0.219	0.045	0.000	0.109
CCr	0.000	0.000	0.000	0.000	0.000
CFe ³⁺	0.000	0.000	0.820	1.182	0.591
CTi	0.128	0.113	0.111	0.110	0.111
CMg	2.918	2.573	2.518	2.497	2.535
CFe ²⁺	0.901	2.096	1.506	1.163	1.629
CMn	0.000	0.000	0.000	0.049	0.024
CCa	0.000	0.000	0.000	0.000	0.000
Sum C	5.000	5.000	5.000	5.000	5.000
BMg	0.000	0.000	0.000	0.000	0.000
BFe ²⁺	1.866	0.345	0.063	0.000	0.172
BMn	0.057	0.050	0.049	0.000	0.025
BCa	0.077	1.605	1.571	1.558	1.582
BNa	0.000	0.000	0.317	0.314	0.157
Sum B	2.000	2.000	2.000	1.872	1.936
ANa	0.367	0.323	0.000	0.000	0.162
AK	0.110	0.097	0.095	0.094	0.095
Sum A	2.220	0.420	0.095	0.094	0.257
CCI	0.047	0.041	0.040	0.040	0.041
CF	0.087	0.077	0.075	0.074	0.076
Sum cat	17.488	15.420	15.095	14.966	15.193
Sum oxy	26.172	23.077	23.000	23.000	23.039

Table 4: Classification of amphibole

Method	Fe ²⁺	15-NK	15-K	13-CNK	AVE(15-NK & 13-CNK)	min-max-
Group	Fe-Mg-Mn	Calcic	Calcic	Calcic	Calcic	average
Sample		Minimum Fe ³⁺		Maximum Fe ³⁺		match?
LQD1-1	Cummingtonite	Edenite	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	n
LQD1-2	Cummingtonite	Actinolite	Actinolite	Actinolite	Actinolite	y
LQD12-1	Cummingtonite	Actinolitic-Hornblende	Magnesio-Hornblende	Actinolitic-Hornblende	Actinolitic-Hornblende	y
LQD12-3	Cummingtonite	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	y
LQD17-1	Cummingtonite	Actinolitic-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	Actinolitic-Hornblende	n
LQD17-2	Cummingtonite	Edenite	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	n
LQD17-3	Cummingtonite	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	y
LQD17-4	Cummingtonite	Actinolite	Actinolite	Actinolite	Actinolite	y
LQD17-5	Cummingtonite	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	y
LQD5A-1	Cummingtonite	Edenite	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	n
LQD5A-5	Cummingtonite	Silicic Edenite	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	n
LQD5B-1	Cummingtonite	Actinolitic-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	Actinolitic-Hornblende	n
LQD8-1	Cummingtonite	Edenite	Magnesio-Hornblende	Magnesio-Hornblende	Edenite	n
LQD8-2	Cummingtonite	Edenite	Magnesio-Hornblende	Magnesio-Hornblende	Edenite	n
LQD8-3	Cummingtonite	Edenite	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	n
LQD14-1	Cummingtonite	Edenite	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	n
LQD14-3	Cummingtonite	Edenite	Magnesio-Hornblende	Magnesio-Hornblende	Edenite	n
IQD17-1	Cummingtonite	Actinolite	Actinolitic-Hornblende	Actinolitic-Hornblende	Actinolite	n
IQD17-2	Cummingtonite	Actinolite	Actinolite	Actinolite	Actinolite	y
IQD4-1	Cummingtonite	Edenite	Magnesio-Hornblende	Magnesio-Hornblende	Edenite	n
LQD-15A-1	Cummingtonite	Edenite	Magnesio-Hornblende	Magnesio-Hornblende	Edenite	n
LQD-15A-2	Cummingtonite	Actinolitic-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	Actinolitic-Hornblende	n
LQD-15A-5	Cummingtonite	Edenite	Magnesio-Hornblende	Magnesio-Hornblende	Edenite	n
LQD15B-1	Cummingtonite Anthophyllite	Actinolitic-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	n
LQD18-1	Cummingtonite	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	y
LQD18-2	Cummingtonite	Ferro-Actinolite	Ferro-Actinolite	Ferro-Actinolite	Ferro-Actinolite	y
LQD18-5	Cummingtonite	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	y

Table 4 cont'd: Classification of amphibole

Method	Fe ²⁺	15-NK	15-K	13-CNK	AVE(15-NK & 13-CNK)	min-max-
Group	Fe-Mg-Mn	Calcic	Calcic	Calcic	Calcic	average
Sample		Minimum Fe ³⁺		Maximum Fe ³⁺		match?
LQD19-1	Cummingtonite	Actinolitic-Hornblende	Actinolitic-Hornblende	Magnesio-Hornblende	Actinolitic-Hornblende	n
LQD20A-2	Cummingtonite	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	y
LQD20A-4	Cummingtonite	Actinolite	Actinolite	Actinolite	Actinolite	y
LQD20A-5	Cummingtonite	Edenite	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	n
LQD20B-2	Cummingtonite	Actinolitic-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	n
LQD21-2	Cummingtonite	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	y
LQD22-1	Cummingtonite	Edenite	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	n
36-1	Cummingtonite	Actinolitic-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	n
36-2	Cummingtonite	Actinolite	Actinolite	Actinolite	Actinolite	y
89-2	Cummingtonite	Edenite	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	n
89-3	Cummingtonite	Edenite	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	n
27-2	Cummingtonite	Edenite	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	n
27-3	Cummingtonite	Actinolitic-Hornblende	Actinolitic-Hornblende	Actinolitic-Hornblende	Actinolitic-Hornblende	y
27-5	Ferro-Actinolite	Ferro-Actinolite	Ferro-Actinolite	Ferro-Actinolite	Ferro-Actinolite	y
53-1	Cummingtonite	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	y
QD-1	Cummingtonite	Ferro-Edenite	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	n
QD-2	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	y
QD-6	Cummingtonite	Edenite	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	n
77-1	Cummingtonite	Edenite	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	n
77-2	Cummingtonite	Actinolitic-Hornblende	Actinolitic-Hornblende	Actinolitic-Hornblende	Actinolitic-Hornblende	y
77-3	Cummingtonite	Actinolitic-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	Actinolitic-Hornblende	n
77-4	Cummingtonite	Edenite	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	n
91-1	Cummingtonite	Actinolitic-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	Magnesio-Hornblende	n
91-2	Magnesio-Hornblende	Actinolite	Actinolite	Actinolite	Actinolite	y
91-4	Actinolite	Actinolite	Actinolite	Actinolite	Actinolite	y

Amphibole data plotted on a) Fe# versus Cl# graph, b) NiO versus Cl, and c) Na+K versus Cl.

Figure 1: Back-scattered electron images of silicates. Locations of electron microprobe analyses are shown by arrows. a) Amphibole surrounded by partially altered plagioclase (saussuritized) and quartz, and locally overgrown by chlorite. b) Euhedral cross-section of amphibole, partially replaced by chlorite, surrounded by K-feldspar and quartz. c) Anhedral amphibole altering to chlorite. d) Ragged amphibole grain with chlorite alteration developed along cleavage planes. [Samples LQD-12 and LQD-17 from LQD Pod #1 in the Proximal Zone, Map 1.]

Figure 2: Back-scattered electron images of silicates. Locations of electron microprobe analyses are shown by arrows. a) Ragged amphibole surrounded by quartz and altered plagioclase, with minor chlorite alteration. b) Chlorite with K-feldspar inclusions, in a quartz and altered plagioclase groundmass. c) Chlorite and amphibole in quartz and altered plagioclase groundmass. d) Partially chloritized amphibole in quartz and altered plagioclase matrix. [Samples LQD-5A and LQD-5B from LQD Pod #2 in the Proximal Zone, Map 2.]

Figure 3: Back-scattered electron images of silicates. Locations of electron microprobe analyses are shown by arrows. a) and b) Euhedral amphiboles in quartz and altered plagioclase groundmass. c) Euhedral, homogeneous amphibole in quartz, near to a titanite-bearing chlorite grain. d) Relatively homogeneous amphibole in quartz, K-feldspar, and altered plagioclase groundmass. [Samples LQD-8 and LQD-14 from LQD Pod #3 in the Proximal Zone, Map 3.]

Figure 4: Back-scattered electron images of amphibole. Locations of electron microprobe analyses are shown by arrows. a) Irregular intergrowth of amphibole, biotite, chlorite and titanite in a quartz and altered plagioclase groundmass. b) Titanite-bearing chlorite inclusion in biotite grain. c) Amphibole, chlorite, apatite, quartz and altered plagioclase groundmass. d) Close-up view of amphibole in c), showing the mottled appearance of the grain. [Samples IQD-4 and IQD-17 from LQD Pod #3 area in the Proximal Zone, Map 3.]

Figure 5: Back-scattered electron images of silicates. Locations of electron microprobe analyses are shown by arrows. a) Homogeneous and mottled amphibole grains (1 and 2, respectively) with chlorite and K-feldspar in quartz and altered plagioclase groundmass. b) Subhedral, relatively homogeneous amphibole with partial chlorite alteration, and ilmenite inclusion. c) Amphibole grain surrounded by quartz, altered plagioclase, and K-feldspar. [Samples LQD-15A and LQD-15B are from the Proximal Zone, Map 5 area.]

Figure 6: Back-scattered electron images of silicates. Locations of electron microprobe analyses are shown by arrows. a) Chlorite overgrowing amphibole in a quartz and altered plagioclase groundmass; note the ferro-actinolitic patch where analysis LQD18-2 is. b) Relatively homogeneous, euhedral amphibole in quartz-plagioclase groundmass. c) A small remnant of amphibole remains in the centre of a large, ragged chlorite grain; the white patches in the chlorite grain are Ti-bearing, most likely titanite. [Samples LQD-18 and LQD-19 are from Intermediate Zone, Map 6 area.]

Figure 7: Back-scattered electron images of silicates. Locations of electron microprobe analyses are shown by arrows. a) Ragged amphibole and secondary chlorite in a quartz and altered plagioclase groundmass; note the cross-hatched pattern of titanite or rutile in the large chlorite grain. b) Amphibole, K-feldspar, and slightly altered plagioclase groundmass. c) Chlorite has overgrown most of the amphibole. [Samples LQD-20A and LQD-20B are from the Intermediate Zone, Map 7 area.]

Figure 8: Back-scattered electron images of silicates. Locations of electron microprobe analyses are shown by arrows. a) Chlorite overgrowing amphibole in a quartz, altered plagioclase, and K-feldspar groundmass. b) Chlorite overgrowing amphibole in a quartz and altered plagioclase groundmass. c) Ragged, slightly mottled amphibole with minor chlorite alteration, in a quartz and altered plagioclase groundmass. d) Biotite and amphibole in a quartz, K-feldspar, and altered plagioclase groundmass. [Samples LQD-21, LQD-22, 36 and 89 are from the Intermediate Zone, Map 7 area.]

Figure 9: Back-scattered electron images of silicates. Locations of electron microprobe analyses are shown by arrows. a) Chlorite overgrowing amphibole; note Ti-bearing mineral (white) in the chlorite. b) Actinolitic-hornblende with ferro-actinolitic zone at bottom, near chlorite alteration. c) Relatively homogeneous amphiboles in a quartz, K-feldspar, altered plagioclase groundmass; note the chlorite grain intergrown with a Ti-bearing mineral (likely titanite). [Samples 27 and 53 are from the Intermediate Zone, Map 8 area.]

Figure 10: Back-scattered electron images of silicates. Locations of electron microprobe analyses are shown by arrows. a) Slightly mottled amphibole inter-grown with K-feldspar, quartz and altered plagioclase, with secondary chlorite developing around oxides. b) False-colour image of a), where blue is amphibole and chlorite, green is K-feldspar, orange is quartz, and mottled areas are altered plagioclase. c) Very ragged and partially chloritized amphibole in quartz and altered plagioclase. d) False-colour image of c), where dark blue is amphibole, light blue is chlorite alteration, orange is quartz, yellow is K-feldspar, and mottled areas are altered plagioclase. [Sample QD is from the Distal Zone.]

Figure 11: Back-scattered electron images of silicates. Locations of electron microprobe analyses are shown by arrows. a) Mottled amphibole grain in quartz. b) Mottled amphibole grain, varying from magnesio-hornblende (1) to actinolitic hornblende (2 and 3). c) Chlorite overgrowing amphibole in a K-feldspar, quartz and altered plagioclase groundmass. d) Irregularly zoned amphibole, partially replaced by chlorite, in a quartz and altered plagioclase groundmass. [Samples 77 and 91 are from the Distal Zone.]

Table 5: Electron Microprobe Data -- Biotite

SAMPLE	Zone	SiO ₂	Al ₂ O ₃	TiO ₂	Cr ₂ O ₃	FeO	MgO	MnO	NiO	K ₂ O	CaO	Na ₂ O	BaO	F	CI TOTAL	TOT-O
IQD4-3	LQD Pod #3	37.60	13.94	2.37	0.04	21.53	10.54	0.20	0.00	9.67	0.01	0.03	0.03	0.47	0.18	96.61
IQD4-4	LQD Pod #3	37.97	13.61	2.60	0.03	21.68	10.75	0.25	0.05	9.66	0.01	0.02	0.06	0.47	0.18	97.34
IQD4-5	LQD Pod #3	37.35	13.91	2.47	0.01	21.29	10.53	0.23	0.01	9.57	0.12	0.04	0.07	0.45	0.17	96.22
89-1	Int. #2	37.74	13.90	2.78	0.01	20.59	10.90	0.22	0.00	9.17	0.17	0.00	0.14	0.45	0.38	96.45
																96.17

SAMPLE	Zone	Si	Al	Al	SUBT	Al	Ti	Cr	Fe	Mg	Mn	Ni	SUBT	K	Ca	Na	Ba	SUBT	F	CI	SUBT
IQD4-3	LQD Pod #3	5.762	2.238	8.000	0.279	0.273	0.004	2.759	2.408	0.026	0.000	5.749	1.891	0.002	0.002	0.008	0.002	1.903	0.230	0.048	0.278
IQD4-4	LQD Pod #3	5.777	2.223	8.000	0.218	0.297	0.004	2.760	2.439	0.032	0.006	5.756	1.876	0.002	0.002	0.006	0.004	1.888	0.225	0.046	0.271
IQD4-5	LQD Pod #3	5.745	2.255	8.000	0.267	0.286	0.001	2.739	2.414	0.029	0.002	5.738	1.878	0.019	0.019	0.012	0.004	1.913	0.218	0.044	0.262
89-1	Int. #2	5.766	2.234	8.000	0.268	0.319	0.002	2.632	2.482	0.028	0.000	5.731	1.788	0.028	0.028	0.001	0.008	1.825	0.219	0.097	0.316

Table 6: Electron Microprobe data – Chlorite

SAMPLE	Zone	Rock Type	SiO ₂	Al ₂ O ₃	TiO ₂	Cr ₂ O ₃	FeO	MnO	MgO	K ₂ O	CaO	NiO	Cl	F	TOTAL	TOT-O
LQD12-2	Prox #1	LQD	28.49	16.79	0.06	0.01	21.75	0.26	17.38	0.12	0.03	0.08	0.08	0.10	85.15	85.09
LQD12-4	Prox #1	LQD	26.75	19.45	0.05	0.22	25.70	0.36	15.36	0.02	0.43	0.02	0.04	0.04	88.44	88.41
LQD5A-2	Prox #2	LQD	26.73	18.75	0.07	0.05	25.30	0.38	15.82	0.03	0.09	0.03	0.01	0.10	87.36	87.32
LQD5A-3	Prox #2	LQD	28.98	16.13	0.10	0.00	26.08	0.23	15.96	0.03	0.05	0.03	0.05	0.10	87.74	87.69
LQD-5B-2	Prox #2	LQD	28.70	17.35	0.09	0.01	24.18	0.33	17.87	0.02	0.07	0.04	0.00	0.10	88.76	88.72
LQD-14-2	Prox #3	LQD	25.91	20.26	0.03	0.04	26.77	0.32	14.78	0.00	0.05	0.06	0.03	0.05	88.30	88.27
IQD4-2	Prox #3	IQD	27.40	18.75	0.39	0.14	26.98	0.39	14.06	1.00	0.11	0.00	0.05	0.06	89.33	89.29
IQD4-6	Prox #3	IQD	26.39	19.67	0.50	0.22	27.54	0.36	14.92	0.00	0.20	0.01	0.01	0.06	89.88	89.85
LQD-15A-3	Prox #5	LQD	26.01	20.09	0.03	0.04	27.33	0.38	14.46	0.00	0.02	0.03	0.00	0.07	88.46	88.43
LQD-15A-6	Prox #5	LQD	27.04	18.27	0.14	0.01	27.07	0.38	14.92	0.15	0.04	0.01	0.02	0.06	88.11	88.08
LQD-18-3	Int. #1	LQD	26.05	18.88	0.07	0.01	27.53	0.47	14.49	0.05	0.03	0.18	0.03	0.06	87.85	87.82
LQD-18-4	Int. #1	LQD	27.60	17.51	0.02	0.00	25.32	0.27	16.65	0.02	0.03	0.27	0.01	0.08	87.78	87.74
LQD-19-2	Int. #1	LIQD	26.55	18.88	0.09	0.06	26.46	0.31	15.23	0.07	0.03	0.09	0.02	0.03	87.82	87.80
LQD20A-1	Int. #1	LIQD	27.85	16.74	0.62	0.04	25.67	0.28	15.34	0.23	0.40	0.00	0.03	0.16	87.36	87.29
36-3	Int. #2	LQD	27.28	18.33	0.00	0.03	24.89	0.30	16.57	0.03	0.04	0.04	0.00	0.07	87.58	87.55
LQD-21-1	Int. #2	LIQD>LQD	27.04	18.48	0.39	0.07	25.89	0.35	15.21	0.09	0.31	0.12	0.03	0.08	88.06	88.02
LQD-21-3	Int. #2	LIQD>LQD	25.37	20.27	0.08	0.10	27.10	0.40	14.35	0.00	0.05	0.09	0.00	0.00	87.81	87.81
LQD-22-2	Int. #2	LQD	28.28	17.12	0.23	0.07	25.14	0.31	16.33	0.19	0.07	0.05	0.02	0.12	87.93	87.87
27-1	Int. #3	LIQD>IQD	28.25	16.84	0.10	0.02	25.39	0.29	16.24	0.12	0.03	0.05	0.01	0.14	87.48	87.42
27-4	Int. #3	LIQD>IQD	26.40	18.20	0.08	0.01	27.82	0.40	14.13	0.01	0.05	0.05	0.03	0.07	87.25	87.21
53-2	Int. #3	FwBx/IQD?	28.37	16.70	0.71	0.03	24.17	0.27	16.66	0.10	0.72	0.03	0.01	0.17	87.94	87.87
53-3	Int. #3	FwBx/IQD?	28.48	16.72	0.14	0.04	24.72	0.38	17.22	0.05	0.09	0.05	0.01	0.16	88.06	87.99
QD-3	Distal	QD	28.04	16.28	0.71	0.02	26.73	0.40	14.42	0.14	0.50	0.00	0.00	0.10	87.34	87.30
QD-5	Distal	QD	26.48	18.29	0.02	0.14	29.40	0.47	13.15	0.00	0.05	0.00	0.01	0.07	88.08	88.05
77-5	Distal	QD	26.47	18.84	0.07	0.02	28.19	0.38	14.03	0.20	0.02	0.06	0.01	0.09	88.38	88.34
91-3	Distal	QD	26.39	19.01	0.08	0.06	26.35	0.41	14.80	0.05	0.03	0.08	0.03	0.01	87.30	87.29

Table 6: Electron Microprobe data – Chlorite

SAMPLE	Si	Al	SUBT	Al	Ti	Cr	Fe	Mn	Mg	K	Ca	Ni	SUBT	Cl	F	SUBT
LQD12-2	6.078	1.922	8.000	2.298	0.009	0.002	3.880	0.047	5.528	0.032	0.008	0.014	11.818	0.028	0.065	0.093
LQD12-4	5.615	2.385	8.000	2.426	0.007	0.037	4.511	0.064	4.806	0.006	0.096	0.004	11.957	0.015	0.028	0.043
LQD5A-2	5.671	2.329	8.000	2.360	0.011	0.009	4.489	0.069	5.002	0.007	0.020	0.005	11.972	0.005	0.065	0.070
LQD5A-3	6.123	1.877	8.000	2.139	0.016	0.000	4.610	0.042	5.026	0.007	0.011	0.005	11.856	0.016	0.067	0.083
LQD-5B-2	5.932	2.068	8.000	2.158	0.014	0.002	4.180	0.058	5.505	0.005	0.015	0.007	11.944	0.002	0.063	0.065
LQD-14-2	5.475	2.525	8.000	2.520	0.005	0.006	4.731	0.057	4.655	0.000	0.010	0.010	11.994	0.009	0.031	0.040
IQD4-2	5.756	2.244	8.000	2.397	0.061	0.023	4.740	0.069	4.403	0.267	0.024	0.000	11.984	0.018	0.041	0.059
IQD4-6	5.500	2.500	8.000	2.331	0.078	0.036	4.800	0.064	4.635	0.000	0.044	0.002	11.990	0.005	0.040	0.045
LQD-15A-3	5.501	2.499	8.000	2.509	0.004	0.006	4.833	0.069	4.557	0.000	0.005	0.005	11.988	0.000	0.044	0.044
LQD-15A-6	5.738	2.262	8.000	2.307	0.022	0.001	4.805	0.069	4.721	0.041	0.008	0.002	11.976	0.009	0.043	0.052
LQD-18-3	5.576	2.424	8.000	2.338	0.011	0.002	4.928	0.085	4.621	0.013	0.008	0.031	12.037	0.013	0.040	0.053
LQD-18-4	5.824	2.176	8.000	2.180	0.004	0.000	4.468	0.049	5.238	0.005	0.007	0.047	11.998	0.003	0.053	0.056
LQD-19-2	5.635	2.365	8.000	2.357	0.014	0.011	4.696	0.056	4.817	0.020	0.008	0.015	11.994	0.007	0.018	0.025
LQD20A-1	5.933	2.067	8.000	2.137	0.099	0.006	4.574	0.050	4.872	0.064	0.092	0.000	11.894	0.012	0.110	0.122
36-3	5.749	2.251	8.000	2.303	0.000	0.004	4.387	0.053	5.206	0.008	0.009	0.007	11.977	0.002	0.043	0.045
LQD-21-1	5.712	2.288	8.000	2.313	0.061	0.012	4.575	0.062	4.791	0.025	0.071	0.020	11.930	0.010	0.053	0.063
LQD-21-3	5.409	2.591	8.000	2.503	0.013	0.017	4.832	0.073	4.559	0.001	0.011	0.015	12.024	0.000	0.000	0.000
LQD-22-2	5.948	2.052	8.000	2.192	0.037	0.011	4.422	0.055	5.118	0.052	0.016	0.009	11.912	0.007	0.077	0.084
27-1	5.980	2.020	8.000	2.180	0.017	0.003	4.495	0.053	5.122	0.032	0.007	0.009	11.918	0.005	0.092	0.097
27-4	5.691	2.309	8.000	2.314	0.013	0.002	5.016	0.073	4.541	0.002	0.012	0.010	11.983	0.011	0.049	0.060
53-2	5.952	2.048	8.000	2.079	0.112	0.005	4.240	0.047	5.208	0.026	0.161	0.006	11.884	0.002	0.109	0.111
53-3	5.968	2.032	8.000	2.099	0.022	0.007	4.333	0.067	5.379	0.015	0.020	0.008	11.950	0.004	0.103	0.107
QD-3	6.005	1.995	8.000	2.112	0.114	0.004	4.786	0.072	4.602	0.038	0.116	0.000	11.844	0.000	0.068	0.068
QD-5	5.697	2.303	8.000	2.334	0.004	0.024	5.290	0.086	4.219	0.000	0.011	0.000	11.968	0.002	0.044	0.046
77-5	5.641	2.359	8.000	2.373	0.011	0.004	5.024	0.069	4.458	0.054	0.004	0.010	12.007	0.003	0.059	0.062
91-3	5.634	2.366	8.000	2.418	0.013	0.010	4.706	0.075	4.709	0.013	0.006	0.014	11.964	0.009	0.009	0.018

Table 6: Electron Microprobe Data -- Apatite

[LQD12-2 and LQD12-4 are from the same spot]

SAMPLE	Zone	Rock Type	P ₂ O ₅	SiO ₂	As ₂ O ₅	SO ₃	CaO	Na ₂ O	FeO	MnO	SrO	BaO	Y ₂ O ₃	La ₂ O ₃	Ce ₂ O ₃	Pr ₂ O ₃	Nd ₂ O ₃	Sm ₂ O ₃	F	Cl	TOTAL	TOT-0
LQD12-1	Prox. #1	LQD	40.98	0.42	0.01	0.03	54.97	0.01	0.00	0.07	0.01	0.07	0.05	0.11	0.29	0.02	0.26	0.11	3.34	0.04	100.79	99.37
LQD12-2	Prox. #1	LQD	42.11	0.21	0.04	0.00	56.28	0.00	0.00	0.02	0.01	0.00	0.03	0.03	0.04	0.00	0.00	0.07	3.41	0.01	102.26	100.82
LQD12-3	Prox. #1	LQD	40.91	0.54	0.03	0.00	55.03	0.12	0.09	0.09	0.00	0.09	0.10	0.30	0.61	0.12	0.39	0.15	3.11	0.06	101.74	100.42
LQD12-4	Prox. #1	LQD	41.22	0.18	0.03	0.01	55.83	0.00	0.03	0.00	0.01	0.09	0.02	0.01	0.00	0.00	0.00	0.08	3.40	0.02	100.93	99.49
LQD15A-1	Prox. #5	LQD	40.00	0.33	0.00	0.00	55.02	0.06	0.05	0.03	0.05	0.00	0.11	0.17	0.39	0.07	0.30	0.14	2.94	0.05	99.71	98.46
LQD15A-2	Prox. #5	LQD	40.28	0.22	0.00	0.00	55.63	0.02	0.04	0.00	0.02	0.00	0.05	0.03	0.13	0.03	0.09	0.14	2.86	0.03	99.57	98.36
LQD15A-3	Prox. #5	LQD	40.48	0.31	0.00	0.02	55.24	0.09	0.10	0.00	0.05	0.05	0.05	0.28	0.49	0.03	0.18	0.00	2.64	0.08	100.09	98.96
LQD15A-4	Prox. #5	LQD	39.83	0.14	0.00	0.01	56.02	0.01	0.09	0.06	0.06	0.06	0.00	0.00	0.03	0.02	0.04	0.00	2.67	0.04	99.08	97.95
LQD17-1	Prox. #1	LQD	41.53	0.12	0.00	0.00	56.01	0.02	0.00	0.02	0.00	0.00	0.00	0.06	0.05	0.03	0.00	0.08	2.72	0.04	100.68	99.53
LQD17-2	Prox. #1	LQD	41.37	0.10	0.00	0.00	55.67	0.04	0.09	0.04	0.06	0.00	0.01	0.07	0.07	0.07	0.00	0.07	2.80	0.01	100.47	99.29
LQD17-3	Prox. #1	LQD	40.91	0.26	0.00	0.00	55.49	0.03	0.12	0.02	0.06	0.03	0.00	0.16	0.37	0.00	0.14	0.05	3.20	0.02	100.86	99.51
LQD17-4	Prox. #1	LQD	41.15	0.14	0.01	0.04	55.59	0.00	0.05	0.00	0.01	0.00	0.00	0.08	0.16	0.03	0.10	0.00	3.10	0.01	100.47	99.16
LQD17-5	Prox. #1	LQD	41.65	0.12	0.00	0.00	55.37	0.01	0.03	0.05	0.00	0.02	0.00	0.08	0.02	0.00	0.04	0.00	3.36	0.03	100.78	99.36
LQD5A-1	Prox. #2	LQD	41.43	0.20	0.04	0.00	55.61	0.01	0.06	0.00	0.03	0.03	0.03	0.08	0.03	0.01	0.10	0.08	2.99	0.04	100.77	99.50
LQD5A-2	Prox. #2	LQD	41.30	0.25	0.02	0.02	55.27	0.05	0.07	0.03	0.04	0.00	0.04	0.11	0.19	0.08	0.27	0.22	3.04	0.04	101.04	99.75
LQD5B-1	Prox. #2	LQD	41.24	0.10	0.03	0.00	54.42	0.03	0.00	0.05	0.05	0.00	0.05	0.01	0.09	0.00	0.09	0.00	3.00	0.04	99.20	97.93
LQD5B-2	Prox. #2	LQD	41.16	0.04	0.03	0.00	55.32	0.00	0.05	0.05	0.02	0.02	0.00	0.00	0.06	0.00	0.06	0.00	3.21	0.02	100.04	98.68
LQD14-1	Prox. #3	LQD	41.28	0.07	0.00	0.03	55.97	0.03	0.00	0.00	0.01	0.00	0.06	0.08	0.05	0.07	0.02	0.20	3.35	0.04	101.26	99.84
LQD14-2	Prox. #3	LQD	40.78	0.17	0.00	0.00	55.72	0.09	0.25	0.05	0.03	0.02	0.03	0.18	0.38	0.04	0.14	0.00	3.56	0.05	101.49	99.98
LQD14-3	Prox. #3	LQD	39.82	0.17	0.00	0.00	55.14	0.03	0.04	0.00	0.05	0.05	0.02	0.05	0.27	0.00	0.08	0.02	3.50	0.02	99.26	97.78
LQD18-1	Int. #1	LQD	42.06	0.33	0.00	0.03	54.38	0.07	0.12	0.08	0.05	0.00	0.06	0.24	0.52	0.06	0.07	0.01	2.96	0.05	101.09	99.83
LQD18-2	Int. #1	LQD	41.28	0.25	0.02	0.01	54.81	0.00	0.02	0.04	0.01	0.00	0.10	0.07	0.22	0.03	0.24	0.16	3.27	0.03	100.56	99.18
LQD18-3	Int. #1	LQD	41.39	0.37	0.00	0.01	54.58	0.02	0.28	0.03	0.04	0.00	0.04	0.00	0.04	0.14	0.00	0.39	3.10	0.01	100.44	99.13
LQD18-4	Int. #1	LQD	41.62	0.46	0.00	0.00	54.93	0.03	0.14	0.00	0.06	0.07	0.14	0.16	0.33	0.01	0.29	0.04	2.98	0.01	101.27	100.01
LQD20A-1	Int. #1	LQD	38.65	0.29	0.00	0.00	55.01	0.09	0.06	0.02	0.04	0.00	0.10	0.09	0.41	0.00	0.27	0.25	3.23	0.03	98.54	97.17
LQD20A-1b	Int. #1	LQD	41.84	0.33	0.01	0.03	55.63	0.08	0.16	0.00	0.04	0.00	0.05	0.16	0.43	0.16	0.21	0.06	3.24	0.03	102.46	101.09
LQD20A-2	Int. #1	LQD	41.61	0.20	0.00	0.00	54.40	0.04	0.05	0.00	0.00	0.00	0.08	0.14	0.29	0.01	0.16	0.14	3.24	0.03	100.39	99.02
LQD20A-3	Int. #1	LQD	41.07	0.37	0.00	0.04	53.73	0.04	0.05	0.02	0.02	0.09	0.06	0.12	0.35	0.08	0.19	0.15	3.39	0.03	99.80	98.37
LQD20A-4	Int. #1	LQD	41.34	0.26	0.00	0.00	54.20	0.02	0.04	0.02	0.02	0.00	0.08	0.04	0.07	0.01	0.05	0.01	3.67	0.01	100.04	98.49
LQD-21-1	Int. #2	LQD	41.73	0.23	0.00	0.00	55.40	0.03	0.00	0.00	0.05	0.01	0.08	0.06	0.18	0.12	0.18	0.00	3.51	0.01	101.39	99.91
LQD-21-2	Int. #2	LQD	42.32	0.18	0.00	0.02	55.57	0.00	0.01	0.01	0.06	0.00	0.06	0.06	0.13	0.02	0.09	0.03	3.62	0.00	102.18	100.66
LQD-21-3	Int. #2	LQD	42.37	0.10	0.00	0.03	54.42	0.00	0.08	0.00	0.05	0.00	0.02	0.03	0.06	0.01	0.06	0.00	3.00	0.03	100.26	98.99
LQD-21-4	Int. #2	LQD	41.25	0.24	0.00	0.01	54.53	0.05	0.09	0.01	0.02	0.05	0.04	0.15	0.32	0.07	0.08	0.00	2.94	0.03	99.88	98.64

Table 6: Electron Microprobe Data – Apatite

P	Si	As	S	SUBT	Ca	Na	Fe	Mn	Sr	Ba	Y	La	Ce	Pr	Nd	Sm	SUBT	F	Cl	SUBT
5.896	0.072	0.001	0.004	5.973	10.008	0.003	0.000	0.010	0.001	0.005	0.004	0.007	0.018	0.001	0.016	0.006	10.079	1.794	0.010	1.804
5.941	0.035	0.004	0.000	5.980	10.049	0.000	0.000	0.003	0.001	0.000	0.002	0.002	0.002	0.000	0.000	0.004	10.063	1.798	0.004	1.802
5.854	0.091	0.003	0.000	5.948	9.966	0.038	0.013	0.013	0.000	0.006	0.009	0.019	0.038	0.008	0.024	0.009	10.143	1.665	0.016	1.681
5.910	0.030	0.002	0.001	5.943	10.132	0.000	0.005	0.001	0.001	0.006	0.002	0.001	0.000	0.000	0.000	0.005	10.153	1.819	0.007	1.826
5.834	0.058	0.000	0.001	5.893	10.156	0.021	0.008	0.005	0.005	0.000	0.010	0.011	0.025	0.004	0.019	0.008	10.272	1.602	0.014	1.616
5.854	0.037	0.000	0.000	5.891	10.233	0.007	0.006	0.000	0.002	0.000	0.005	0.002	0.008	0.002	0.006	0.008	10.279	1.552	0.008	1.560
5.856	0.052	0.000	0.002	5.910	10.112	0.028	0.015	0.000	0.005	0.003	0.005	0.018	0.030	0.002	0.011	0.000	10.229	1.426	0.023	1.449
5.819	0.024	0.000	0.002	5.845	10.357	0.004	0.012	0.009	0.006	0.004	0.000	0.004	0.002	0.001	0.003	0.000	10.398	1.458	0.011	1.469
5.927	0.021	0.000	0.000	5.948	10.114	0.008	0.000	0.002	0.000	0.000	0.000	0.004	0.003	0.002	0.000	0.005	10.138	1.449	0.012	1.461
5.926	0.017	0.000	0.000	5.943	10.093	0.013	0.013	0.005	0.006	0.000	0.001	0.004	0.005	0.004	0.000	0.004	10.148	1.498	0.002	1.500
5.885	0.044	0.000	0.000	5.929	10.101	0.009	0.017	0.003	0.006	0.002	0.000	0.010	0.023	0.000	0.008	0.003	10.182	1.722	0.005	1.727
5.913	0.023	0.001	0.005	5.942	10.111	0.000	0.007	0.000	0.001	0.000	0.000	0.005	0.010	0.002	0.006	0.000	10.142	1.662	0.004	1.666
5.961	0.020	0.000	0.000	5.981	10.028	0.004	0.005	0.008	0.000	0.001	0.000	0.005	0.001	0.000	0.002	0.000	10.054	1.796	0.008	1.804
5.925	0.034	0.003	0.000	5.962	10.066	0.003	0.008	0.000	0.003	0.002	0.003	0.005	0.002	0.001	0.006	0.005	10.104	1.599	0.011	1.610
5.913	0.042	0.002	0.002	5.959	10.016	0.015	0.010	0.004	0.004	0.000	0.004	0.007	0.011	0.005	0.016	0.013	10.105	1.626	0.012	1.638
5.975	0.018	0.002	0.000	5.995	9.979	0.010	0.000	0.007	0.005	0.000	0.004	0.001	0.006	0.000	0.005	0.000	10.017	1.626	0.012	1.638
5.940	0.007	0.002	0.000	5.949	10.103	0.000	0.007	0.006	0.002	0.001	0.000	0.000	0.004	0.000	0.003	0.000	10.126	1.731	0.005	1.736
5.910	0.011	0.000	0.003	5.924	10.141	0.009	0.000	0.000	0.001	0.000	0.005	0.005	0.003	0.005	0.001	0.012	10.182	1.791	0.011	1.802
5.865	0.030	0.000	0.001	5.896	10.140	0.031	0.035	0.007	0.003	0.001	0.003	0.011	0.024	0.003	0.009	0.000	10.267	1.911	0.014	1.925
5.850	0.029	0.000	0.001	5.880	10.253	0.009	0.006	0.000	0.005	0.003	0.002	0.003	0.017	0.000	0.005	0.001	10.304	1.922	0.007	1.929
5.982	0.056	0.000	0.003	6.041	9.788	0.022	0.016	0.012	0.004	0.000	0.005	0.015	0.032	0.004	0.004	0.000	9.902	1.571	0.014	1.585
5.937	0.042	0.002	0.002	5.983	9.975	0.000	0.003	0.006	0.001	0.000	0.009	0.005	0.013	0.002	0.015	0.009	10.038	1.756	0.007	1.763
5.940	0.063	0.000	0.001	6.004	9.913	0.006	0.040	0.005	0.004	0.000	0.004	0.000	0.002	0.009	0.000	0.023	10.006	1.660	0.002	1.662
5.927	0.077	0.000	0.001	6.005	9.900	0.008	0.019	0.000	0.006	0.005	0.004	0.010	0.020	0.000	0.017	0.002	9.999	1.587	0.004	1.591
5.756	0.050	0.000	0.000	5.806	10.367	0.029	0.009	0.003	0.004	0.000	0.009	0.006	0.027	0.000	0.017	0.015	10.486	1.799	0.010	1.809
5.915	0.055	0.001	0.003	5.974	9.953	0.026	0.022	0.000	0.004	0.000	0.004	0.010	0.026	0.010	0.013	0.004	10.072	1.712	0.009	1.721
5.979	0.033	0.000	0.000	6.012	9.894	0.012	0.007	0.000	0.000	0.000	0.007	0.009	0.018	0.001	0.010	0.008	9.966	1.738	0.007	1.745
5.954	0.063	0.000	0.005	6.022	9.859	0.015	0.006	0.003	0.002	0.006	0.005	0.008	0.022	0.005	0.011	0.009	9.951	1.837	0.009	1.846
5.970	0.044	0.000	0.000	6.014	9.944	0.006	0.006	0.003	0.002	0.000	0.007	0.002	0.005	0.000	0.003	0.000	9.978	1.980	0.003	1.983
5.953	0.039	0.000	0.000	5.992	9.967	0.009	0.001	0.000	0.005	0.000	0.007	0.004	0.011	0.007	0.011	0.000	10.022	1.870	0.002	1.872
5.979	0.030	0.000	0.003	6.012	9.937	0.000	0.002	0.001	0.006	0.000	0.006	0.004	0.008	0.001	0.006	0.002	9.973	1.912	0.001	1.913
6.042	0.016	0.000	0.003	6.061	9.821	0.000	0.011	0.000	0.005	0.000	0.002	0.002	0.004	0.001	0.004	0.000	9.850	1.598	0.008	1.606
5.948	0.041	0.000	0.001	5.990	9.951	0.018	0.013	0.001	0.002	0.003	0.004	0.010	0.020	0.004	0.005	0.000	10.031	1.586	0.010	1.596

Table 6: Electron Microprobe Data – Apatite

SAMPLE	Zone	Rock Type	P ₂ O ₅	SiO ₂	As ₂ O ₅	SO ₃	CaO	Na ₂ O	FeO	MnO	SrO	BaO	Y ₂ O ₃	La ₂ O ₃	Ce ₂ O ₃	Pr ₂ O ₃	Nd ₂ O ₃	Sm ₂ O ₃	F	Cl	TOTAL	TOT-O
36-1	Int. #2	LQD	40.72	0.42	0.00	0.01	55.22	0.08	0.18	0.08	0.01	0.00	0.07	0.37	0.59	0.05	0.24	0.00	2.98	0.08	101.10	99.83
36-2	Int. #2	LQD	41.20	0.22	0.00	0.01	55.92	0.00	0.09	0.01	0.01	0.04	0.03	0.12	0.14	0.00	0.04	0.04	3.42	0.02	101.31	99.87
36-3	Int. #2	LQD	40.13	0.38	0.00	0.00	54.85	0.05	0.13	0.08	0.00	0.00	0.06	0.36	0.61	0.00	0.17	0.06	3.17	0.08	100.13	98.78
36-4	Int. #2	LQD	41.58	0.09	0.00	0.00	56.37	0.00	0.09	0.01	0.01	0.00	0.02	0.13	0.06	0.00	0.04	0.00	3.42	0.03	101.85	100.40
45-1	Int. #3	IQD	41.83	0.19	0.00	0.00	56.36	0.00	0.07	0.00	0.08	0.07	0.03	0.03	0.09	0.07	0.11	0.00	3.09	0.02	102.04	100.73
45-2	Int. #3	IQD	41.99	0.16	0.00	0.00	56.53	0.02	0.14	0.00	0.06	0.02	0.01	0.00	0.02	0.03	0.10	0.00	3.14	0.02	102.24	100.91
45-3	Int. #3	IQD	41.01	0.11	0.00	0.00	55.57	0.02	0.06	0.04	0.07	0.00	0.02	0.03	0.12	0.08	0.06	0.07	3.33	0.05	100.64	99.23
89-1	Int. #2	QD	40.43	0.33	0.00	0.00	54.42	0.13	0.12	0.01	0.00	0.00	0.06	0.35	0.62	0.07	0.34	0.00	2.89	0.29	100.06	98.78
53-1	Int. #3	FwBx	41.11	0.29	0.00	0.00	53.75	0.01	0.00	0.00	0.04	0.03	0.04	0.14	0.24	0.00	0.12	0.00	3.12	0.03	98.92	97.60
53-2	Int. #3	FwBx	41.02	0.29	0.00	0.00	54.47	0.04	0.09	0.06	0.03	0.00	0.07	0.08	0.27	0.16	0.19	0.15	3.48	0.03	100.43	98.96
53-3	Int. #3	FwBx	40.47	0.38	0.00	0.01	53.10	0.15	0.11	0.08	0.06	0.12	0.11	0.37	0.77	0.14	0.36	0.04	3.16	0.06	99.49	98.15
QD1-1	Distal	QD	39.60	0.52	0.00	0.03	54.59	0.01	0.30	0.00	0.00	0.01	0.13	0.07	0.10	0.02	0.17	0.00	3.30	0.00	98.85	97.46
QD1-2	Distal	QD	40.51	0.66	0.00	0.03	54.15	0.01	0.04	0.07	0.03	0.01	0.11	0.29	0.71	0.00	0.17	0.07	3.32	0.10	100.28	98.86
QD1-3	Distal	QD	41.46	0.29	0.01	0.00	54.70	0.03	0.03	0.09	0.00	0.01	0.12	0.05	0.16	0.05	0.14	0.00	3.62	0.03	100.79	99.26
QD1-4	Distal	QD	41.38	0.52	0.00	0.00	53.83	0.08	0.05	0.06	0.05	0.01	0.10	0.24	0.54	0.04	0.08	0.03	3.17	0.00	100.18	98.85
82-1	Distal	QD	41.51	0.26	0.00	0.01	55.36	0.03	0.01	0.10	0.07	0.00	0.05	0.09	0.09	0.00	0.09	0.10	3.30	0.00	101.07	99.68
82-2	Distal	QD	41.74	0.10	0.04	0.00	56.05	0.00	0.02	0.05	0.07	0.03	0.00	0.03	0.00	0.00	0.00	0.12	3.05	0.02	101.32	100.03
82-3	Distal	QD	41.42	0.13	0.04	0.00	55.88	0.00	0.04	0.05	0.07	0.00	0.00	0.01	0.00	0.00	0.00	0.00	3.25	0.01	100.90	99.53
82-5	Distal	QD	40.81	0.43	0.00	0.00	55.17	0.07	0.17	0.04	0.07	0.03	0.05	0.16	0.41	0.01	0.20	0.10	2.91	0.02	100.65	99.42
82-6	Distal	QD	40.65	0.23	0.00	0.00	54.37	0.12	0.11	0.06	0.05	0.00	0.06	0.26	0.51	0.01	0.23	0.05	2.78	0.04	99.53	98.35
82-7	Distal	QD	39.73	0.57	0.01	0.02	53.63	0.13	0.21	0.09	0.05	0.10	0.12	0.37	0.86	0.08	0.41	0.22	2.73	0.06	99.39	98.23
78-1	Distal	QD	40.31	0.26	0.01	0.00	54.11	0.15	0.22	0.06	0.06	0.00	0.07	0.27	0.64	0.04	0.29	0.04	2.95	0.05	99.53	98.28
78-2	Distal	QD	39.73	0.50	0.03	0.02	53.68	0.13	0.19	0.13	0.06	0.06	0.14	0.45	0.83	0.04	0.39	0.17	2.80	0.05	99.40	98.21
78-3	Distal	QD	39.19	0.31	0.04	0.00	54.36	0.12	0.12	0.10	0.07	0.04	0.08	0.32	0.58	0.02	0.20	0.14	3.07	0.04	98.80	97.50
78-4	Distal	QD	40.08	0.09	0.03	0.02	55.76	0.03	0.06	0.03	0.03	0.04	0.04	0.03	0.05	0.00	0.09	0.08	3.17	0.00	99.63	98.30
78-5	Distal	QD	39.76	0.50	0.00	0.01	53.67	0.11	0.23	0.11	0.09	0.00	0.04	0.26	0.47	0.00	0.23	0.08	2.99	0.04	98.59	97.32
78-6	Distal	QD	40.33	0.22	0.00	0.01	55.27	0.03	0.03	0.06	0.05	0.00	0.01	0.01	0.02	0.00	0.08	0.12	3.60	0.01	99.85	98.33
78-7	Distal	QD	40.29	0.50	0.03	0.01	54.81	0.07	0.08	0.04	0.06	0.06	0.04	0.17	0.37	0.00	0.17	0.13	3.06	0.02	99.91	98.62
92-1	Distal	QD	42.93	0.29	0.00	0.04	54.66	0.07	0.17	0.00	0.01	0.01	0.07	0.23	0.48	0.04	0.21	0.18	2.88	0.06	102.33	101.10
92-2	Distal	QD	42.56	0.39	0.00	0.00	55.52	0.00	0.47	0.00	0.00	0.00	0.02	0.00	0.05	0.02	0.02	0.16	3.18	0.00	102.39	101.05
92-3	Distal	QD	42.19	0.41	0.00	0.04	54.13	0.08	0.17	0.04	0.01	0.00	0.09	0.30	0.63	0.11	0.37	0.07	2.73	0.10	101.47	100.30
92-4	Distal	QD	42.49	0.38	0.01	0.01	53.98	0.07	0.15	0.09	0.01	0.01	0.11	0.29	0.58	0.14	0.23	0.06	2.89	0.16	101.66	100.41
92-5	Distal	QD	42.75	0.13	0.00	0.00	54.30	0.00	0.04	0.00	0.03	0.01	0.05	0.00	0.10	0.01	0.11	0.05	3.09	0.02	100.69	99.38

Table 6: Electron Microprobe Data - Apatite

P	Si	As	S	SUBT	Ca	Na	Fe	Mn	Sr	Ba	Y	La	Ce	Pr	Nd	Sm	SUBT	F	Cl	SUBT
5.853	0.071	0.000	0.001	5.925	10.045	0.027	0.026	0.011	0.001	0.000	0.006	0.023	0.037	0.003	0.015	0.000	10.194	1.600	0.023	1.623
5.895	0.038	0.000	0.002	5.935	10.128	0.000	0.012	0.002	0.001	0.003	0.002	0.007	0.008	0.000	0.002	0.003	10.168	1.826	0.007	1.833
5.842	0.065	0.000	0.000	5.907	10.106	0.015	0.019	0.012	0.000	0.000	0.005	0.023	0.039	0.000	0.011	0.004	10.234	1.722	0.022	1.744
5.914	0.015	0.000	0.001	5.930	10.145	0.000	0.013	0.001	0.001	0.000	0.002	0.008	0.004	0.000	0.002	0.000	10.176	1.814	0.009	1.823
5.918	0.031	0.000	0.000	5.949	10.091	0.000	0.009	0.001	0.008	0.004	0.002	0.002	0.006	0.004	0.006	0.000	10.133	1.633	0.005	1.638
5.923	0.027	0.000	0.000	5.950	10.092	0.006	0.020	0.000	0.006	0.001	0.001	0.000	0.001	0.002	0.006	0.000	10.135	1.657	0.006	1.663
5.908	0.018	0.000	0.000	5.926	10.132	0.007	0.008	0.005	0.007	0.000	0.002	0.002	0.008	0.005	0.004	0.004	10.184	1.790	0.015	1.805
5.878	0.056	0.000	0.000	5.934	10.014	0.043	0.018	0.002	0.000	0.000	0.006	0.022	0.039	0.004	0.021	0.000	10.169	1.570	0.084	1.654
5.978	0.050	0.000	0.001	6.029	9.894	0.002	0.000	0.000	0.004	0.002	0.004	0.009	0.015	0.000	0.007	0.000	9.937	1.697	0.007	1.704
5.928	0.049	0.000	0.000	5.977	9.962	0.012	0.013	0.009	0.003	0.000	0.006	0.005	0.017	0.010	0.011	0.009	10.057	1.879	0.010	1.889
5.918	0.066	0.000	0.002	5.986	9.827	0.050	0.016	0.012	0.006	0.008	0.010	0.024	0.049	0.009	0.022	0.002	10.035	1.726	0.018	1.744
5.821	0.090	0.000	0.004	5.915	10.158	0.002	0.044	0.000	0.000	0.001	0.012	0.005	0.006	0.001	0.011	0.000	10.240	1.812	0.000	1.812
5.871	0.113	0.000	0.003	5.987	9.932	0.004	0.006	0.010	0.003	0.000	0.010	0.019	0.045	0.000	0.010	0.004	10.043	1.798	0.028	1.826
5.953	0.049	0.001	0.000	6.003	9.941	0.009	0.004	0.013	0.000	0.001	0.011	0.003	0.010	0.003	0.009	0.000	10.004	1.939	0.008	1.947
5.954	0.089	0.000	0.000	6.043	9.802	0.026	0.008	0.009	0.005	0.001	0.009	0.015	0.034	0.002	0.005	0.002	9.918	1.704	0.001	1.705
5.931	0.044	0.000	0.002	5.977	10.010	0.011	0.002	0.014	0.007	0.000	0.004	0.006	0.005	0.000	0.005	0.006	10.070	1.761	0.001	1.762
5.934	0.018	0.003	0.001	5.956	10.085	0.001	0.003	0.008	0.007	0.002	0.000	0.002	0.000	0.000	0.000	0.007	10.115	1.619	0.005	1.624
5.925	0.021	0.003	0.000	5.949	10.116	0.002	0.006	0.007	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	10.138	1.736	0.003	1.739
5.869	0.073	0.000	0.000	5.942	10.041	0.024	0.025	0.005	0.007	0.002	0.005	0.010	0.026	0.001	0.012	0.006	10.164	1.566	0.006	1.572
5.907	0.039	0.000	0.000	5.946	9.998	0.038	0.016	0.008	0.005	0.000	0.005	0.016	0.032	0.000	0.014	0.003	10.135	1.509	0.011	1.520
5.825	0.098	0.001	0.003	5.927	9.952	0.044	0.030	0.013	0.005	0.007	0.011	0.024	0.054	0.005	0.025	0.013	10.183	1.498	0.016	1.514
5.884	0.045	0.001	0.000	5.930	9.995	0.050	0.032	0.009	0.006	0.000	0.007	0.017	0.040	0.003	0.018	0.002	10.179	1.607	0.015	1.622
5.828	0.087	0.003	0.003	5.921	9.966	0.043	0.028	0.020	0.006	0.004	0.013	0.029	0.053	0.003	0.024	0.010	10.199	1.536	0.014	1.550
5.801	0.055	0.004	0.000	5.860	10.185	0.042	0.018	0.015	0.007	0.003	0.008	0.021	0.037	0.001	0.012	0.008	10.357	1.699	0.011	1.710
5.844	0.016	0.003	0.003	5.866	10.290	0.011	0.009	0.005	0.003	0.003	0.004	0.002	0.003	0.000	0.005	0.005	10.340	1.727	0.001	1.728
5.856	0.086	0.000	0.001	5.943	10.003	0.038	0.033	0.016	0.009	0.000	0.004	0.017	0.030	0.000	0.015	0.005	10.170	1.648	0.013	1.661
5.874	0.038	0.000	0.001	5.913	10.189	0.010	0.004	0.008	0.005	0.000	0.001	0.001	0.001	0.000	0.005	0.007	10.231	1.958	0.003	1.961
5.850	0.085	0.002	0.002	5.939	10.071	0.025	0.011	0.006	0.006	0.004	0.004	0.011	0.023	0.000	0.010	0.007	10.178	1.657	0.005	1.662
8.018	0.048	0.000	0.005	6.071	9.697	0.022	0.023	0.001	0.001	0.001	0.006	0.014	0.029	0.003	0.012	0.010	9.819	1.506	0.017	1.523
5.970	0.065	0.000	0.000	6.035	9.856	0.000	0.066	0.000	0.000	0.000	0.002	0.000	0.003	0.001	0.001	0.009	9.938	1.668	0.001	1.669
5.979	0.068	0.000	0.005	6.052	9.710	0.026	0.023	0.006	0.001	0.000	0.008	0.018	0.038	0.007	0.022	0.004	9.863	1.447	0.029	1.476
6.009	0.064	0.001	0.002	6.076	9.663	0.023	0.021	0.013	0.001	0.001	0.010	0.018	0.036	0.009	0.014	0.004	9.813	1.527	0.045	1.572
6.066	0.021	0.000	0.000	6.087	9.752	0.000	0.005	0.000	0.003	0.001	0.005	0.000	0.006	0.000	0.007	0.003	9.782	1.640	0.006	1.646

Figure 12: Back-scattered electron images of apatite. Locations of electron microprobe analyses are shown by arrows. a) Relatively homogeneous apatite with an axial melt inclusion. b) Long-sections and cross-sections of apatite in quartz and feldspar. c) Apatite near the bottom-middle in b), with minor mottling due to variable REE content. [a), b), and c), are from sample LQD-17, from LQD Pod #1, Proximal Zone, Map 1.] d) Relatively homogeneous apatite in quartz-feldspar intergrowth (Sample LQD-5B from LQD Pod #2, Proximal Zone, Map 2).

Figure 13: Back-scattered electron images of apatite. Locations of electron microprobe analyses are shown by arrows. a) Apatite grain in quartz-feldspar granophyric intergrowth; slight mottling due to variable REE content (LQD-14 from LQD Pod #3, Proximal Zone, Map 3). b) Apatite grain in quartz-feldspar intergrowth. c) Apatite in quartz surrounded by saussuritized feldspar. d) Close-up of c) showing mottled appearance due to variation in REE content throughout the grain. [B), c) and d) are from LQD-15A from the Proximal Zone, Map 5 area.]

Figure 14: Back-scattered electron images of apatite. Locations of electron microprobe analyses are shown by arrows. a) Apatite grain in quartz-feldspar granophyric intergrowth; b) close-up of same grain, with slight REE-mottling. c) Apatite with axial melt inclusion in quartz-feldspar granophyric intergrowth; d) close-up of the same grain. [All images are from LQD-18 from Intermediate Zone, Map 6 area.]

Figure 15: Back-scattered electron images of apatite. Locations of electron microprobe analyses are shown by arrows. a) Apatite grains in quartz-feldspar granophyric intergrowth. b) *En echelon* apatite grains in quartz-feldspar granophyric intergrowth. [a) and b) are from LQD-20A from the Intermediate Zone, Map 6 area.] c) and d) Homogeneous apatite grains in quartz and saussuritized feldspar (Sample LQD-21 is from the Intermediate Zone, Map 7 area).

Figure 16: Back-scattered electron images of apatite. Locations of electron microprobe analyses are shown by arrows. a) Large apatite grain in quartz-feldspar granophyric intergrowth, b) false-colour image of a), where bright yellow-orange is K-feldspar, pale yellow is chlorite, purple is altered plagioclase feldspar, and black is quartz. c) Close-up of a) revealing a generally homogeneous grain. Sample 89 from Intermediate Zone, Map 7 area.

Figure 17: Back-scattered electron images of apatite. Locations of electron microprobe analyses are shown by arrows. a) and b) Apatite grains in quartz-feldspar granophyric intergrowth (Sample 53 from Intermediate Zone, Map 8 area).

Figure 18: Back-scattered electron images of apatite. Locations of electron microprobe analyses are shown by arrows. a) Apatite grain in quartz and saussuritized feldspar adjacent to partly chloritized amphibole. b) Close-up view of a) reveals mottled appearance (due to variable concentration of REE). c) Apatite grain in quartz-feldspar granophyric intergrowth. d) Close-up view of c) shows mottled grain. Sample QD-1 from the Distal Zone.

Figure 19: Back-scattered electron images of apatite. Locations of electron microprobe analyses are shown by arrows. a) Apatite cluster in granophyre and altered plagioclase, with locations of analyses in b) and c), respectively. Note the elongate epidote inclusion in the apatite grain right of the b) box. b) Axial zonations due to REE content. c) Both axial and mottled zonation patterns occur in this section of the grain. d) False-colour image highlighting areas of greater REE content (bright yellow) versus areas of lower REE content (orangish-yellow). Also note the axial melt inclusion (quartz in this case), and the mottled REE zoning. All images from sample 78, Distal Zone.

Figure 20: Back-scattered electron images of apatite. Locations of electron microprobe analyses are shown by arrows. a) Relatively homogeneous apatite in granophyre. b) Homogeneous apatite in quartz, feldspar and altered plagioclase. c) Moderately zoned apatite in granophyre and altered plagioclase. d) Close-up, false-colour image of axial zonation in c), where dark blue = greater REE and light blue = lesser REE. All images from sample 82, Distal Zone.

Figure 21: Back-scattered electron images of apatite. Locations of electron microprobe analyses are shown by arrows. a) Cluster of apatite in quartz, feldspar and altered plagioclase, with box showing the location of analyses shown in b). b) False-colour image showing the relative abundance of REE (light orange = greater REE, dark orange = less REE). c) Slightly mottled apatite grain in quartz. d) False-colour image showing relative abundances of REE (bright yellow = greater REE, orange = less REE). All images from sample 92, Distal Zone.

Table 7: Whole-Rock Geochemistry

Lab No.	GSC No.	Sample No.	Zone	Rock Type	Mapped As	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃ T	Fe ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O
1	03AV-01	03AV-01	Prox #5	PPD	PPD	48.40	1.56	12.60	17.10	4.65	11.2	0.24	5.21	8.93	2.30
2	03AV-02	03AV-02	Prox #3	PPD	PPD	48.40	1.35	13.80	15.00	5.44	8.6	0.20	5.74	9.99	2.20
3	03AV-03	03AV-03	Prox #3	PPD	PPD	48.00	1.30	14.40	14.40	3.51	9.8	0.21	6.53	9.37	2.10
4	03AV-04	03AV-04	Proximal	PPD	PPD	48.30	1.40	13.70	16.40	4.62	10.6	0.20	5.07	8.15	2.70
5	03AV-05	03AV-05	Proximal	PPD	PPD	47.90	1.46	14.00	15.40	3.84	10.4	0.20	5.52	9.73	2.70
6	03AV-06	03AV-06	Proximal	PPD	PPD	53.40	1.05	14.10	11.80	2.13	8.7	0.17	5.68	7.37	2.90
7	03AV-07	03AV-07	Proximal	PPD	PPD	49.40	1.34	15.50	15.00	4.44	9.5	0.20	4.57	9.55	2.70
8	03AV-08	03AV-08	Proximal	PPD	PPD	50.10	1.08	13.90	13.50	3.05	9.4	0.17	5.86	7.32	2.80
9	03AV-09	03AV-09	Proximal	PPD	PPD	53.00	1.04	14.60	11.80	2.24	8.6	0.17	5.37	7.64	2.80
10	03AV-10	03AV-10	Proximal	PPD	PPD	49.50	1.26	14.10	15.20	5.53	8.7	0.19	4.96	9.31	2.30
14	03AV-15	03AV-15	Prox #1	PPD	PPD	49.70	1.24	13.60	15.30	4.85	9.4	0.20	5.25	8.39	1.80
17	03AV-18	03AV-18	Prox #1	PPD	PPD	50.70	1.18	13.80	14.60	4.82	8.8	0.20	5.45	8.95	2.20
18	03AV-19	03AV-19	Prox #1	PPD	PPD	48.70	1.00	14.70	14.30	5.19	8.2	0.17	6.10	10.46	2.50
19	03AV-20	03AV-20	Prox #1	PPD	PPD	49.00	1.34	14.20	15.50	5.94	8.6	0.22	5.27	9.75	2.30
20 dup	03AV-21 (lab #74)	03AV-21	Prox #1	PPD	PPD	49.00	1.19	14.40	13.10	3.76	8.4	0.18	6.39	10.48	2.40
21	03AV-22	03AV-22	Prox #1	PPD	PPD	48.20	1.03	13.30	16.10	-999.00	-999.00	0.21	5.55	9.40	1.90
23	03AV-25	03AV-25	Prox #2	PPD	PPD	46.10	1.29	14.40	14.60	5.26	8.4	0.18	6.99	10.12	1.30
24	03AV-26	03AV-26	Int. #2	PPD	PPD	49.30	1.33	14.10	15.30	3.52	10.6	0.20	5.81	9.69	2.50
25	03AV-27	03AV-27	Int. #2	PPD	PPD	49.00	1.32	14.50	13.50	3.72	8.8	0.20	6.19	8.44	3.10
27	03AV-29	03AV-29	Distal	PPD	PPD	48.30	1.33	14.30	14.40	4.06	9.3	0.21	5.75	9.09	2.10
11	03AV-11	03AV-11	Prox #1	PPD ?	PPD ?	48.00	1.63	12.40	17.80	6.69	10.0	0.18	6.44	7.54	2.60
13	03AV-14	03AV-14	Prox #1	NPD	PPD	51.60	1.84	13.90	13.60	6.38	6.5	0.18	4.76	7.54	3.20
28	03AV-30	03AV-30	Distal	PPD ?	PPD ?	47.70	1.98	12.90	16.40	3.62	11.5	0.24	6.56	7.08	1.60
15	03AV-16	03AV-16	Prox #1	QD	QD	49.30	1.66	15.10	11.70	3.03	7.8	0.20	6.25	9.30	2.90
33	03AV-44	28	Int. #2	QD	QD	61.50	0.66	14.20	8.80	0.91	7.1	0.12	3.47	4.38	3.30
39	03AV-50	51	Int. #3	QD-QD	QD	61.90	0.74	13.70	8.10	-888.00	8.1	0.11	3.41	3.32	4.20
45	03AV-56	78	Distal	QD	QD	55.00	1.12	14.30	11.00	1.00	9.0	0.14	4.33	5.46	3.00
46	03AV-57	82	Distal	QD	QD	61.30	0.71	14.40	8.10	0.21	7.1	0.12	3.30	3.74	3.50
49	03AV-60	89	Int. #2	QD>LQD	QD	60.90	0.73	14.10	8.20	0.20	7.2	0.12	3.33	4.19	3.40
50	03AV-61	90	Distal	QD	QD	61.90	0.76	14.40	7.50	-888.00	7.2	0.07	3.58	1.69	3.60
51	03AV-62	91	Distal	QD	QD	60.20	0.88	14.80	8.30	0.74	6.8	0.10	3.30	4.16	5.00
69	03AV-80	LQD-23	Int. #2	QD>QD	QD	61.40	0.77	14.20	7.00	0.78	5.6	0.10	3.34	4.50	4.10
26	03AV-28	03AV-28	Int. #2	LQD	LQD	61.00	0.80	14.00	7.40	1.51	5.3	0.11	3.94	4.62	3.70
22	03AV-24	03AV-24	Prox #2	LQD	LQD	60.00	0.74	13.80	8.30	2.08	5.6	0.15	4.59	5.13	3.30
16	03AV-17	03AV-17	Prox #1	LQD	LQD	57.80	0.98	14.00	8.80	2.13	6.0	0.15	4.47	5.83	3.40
12	03AV-13	03AV-13	Prox #1	LQD	LQD	59.00	0.80	13.90	7.30	2.63	4.2	0.13	4.15	7.06	5.70
34	03AV-45	35	Int. #2	LQD	LQD	61.90	0.73	13.90	9.40	-888.00	9.7	0.06	3.37	1.31	2.90
35	03AV-46	36	Int. #2	LQD	LQD	60.50	0.70	15.00	7.20	-888.00	6.6	0.10	3.39	4.22	4.40
61	03AV-72	LQD-4	Prox #2	LQD	LQD	59.50	0.65	14.10	9.60	-888.00	9.9	0.08	3.49	2.78	3.00

Table 7 cont'd: Whole-Rock Geochemistry

Lab No.	GSC No.	Sample No.	Zone	Rock Type	Mapped As	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃ T	Fe ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O
62	03AV-73	LQD-5	Prox #2	LQD	LQD	60.50	0.95	14.70	7.90	1.34	5.9	0.10	2.75	4.44	4.40
63	03AV-74	LQD-11	Prox #2	LQD	LQD	58.90	0.86	17.20	6.10	0.21	5.3	0.06	1.96	3.93	5.50
64	03AV-75	LQD-14	Prox #3	LQD	LQD	60.70	0.73	14.50	8.20	1.31	6.2	0.11	3.63	4.48	3.30
65	03AV-76	LQD-18	Int. #1	LQD/QD	LQD	60.30	0.74	14.20	9.00	1.11	7.1	0.11	3.16	3.88	3.40
66	03AV-77	LQD-19	Int. #1	LIQD	LQD	58.60	0.78	13.90	9.90	0.23	8.7	0.11	4.32	3.33	3.10
67	03AV-78	LQD-20	Int. #1	LIQD	IQD-FwBx cont	60.70	0.73	14.30	8.00	-888.00	7.4	0.10	3.45	4.05	4.20
68	03AV-79	LQD-21	Int. #2	LIQD>LQD	LQD	59.90	0.77	14.40	8.60	0.60	7.2	0.11	3.71	4.75	3.50
36	03AV-47	44	Int. #3	IQD	IQD	58.90	0.93	13.70	9.00	0.89	7.3	0.10	3.42	6.74	4.10
44	03AV-55	77	Distal	IQD	IQD	55.20	1.13	14.40	10.20	0.64	8.6	0.14	4.08	6.18	2.80
70	03AV-81	IQD-7	Prox #2	IQD to QD	IQD	56.80	0.88	15.10	10.60	1.04	8.6	0.15	4.18	6.19	3.20
71	03AV-82	IQD-14	Prox #3	IQD (to FwBx)	IQD	54.80	1.05	16.90	8.60	0.60	7.2	0.11	4.20	3.08	6.00
72	03AV-83	IQD-15	Prox #3	IQD	IQD	50.50	1.07	13.40	14.50	0.72	12.4	0.18	5.64	7.23	2.40
73	03AV-84	IQD-17	Prox #3	IQD	IQD	54.00	1.01	14.40	13.30	0.63	11.4	0.16	4.29	5.86	3.00
57	03AV-68	FB-14	Prox #2	IQD to FwBx	IQD	57.00	0.82	15.80	9.00	0.22	7.9	0.12	3.51	5.18	3.80
30	03AV-41	19	Int. #1	FwBx	FwBx	58.60	0.72	16.20	7.40	-888.00	7.4	0.08	2.48	3.52	4.40
31	03AV-42	23	Int. #2	FwBx	FwBx	62.30	0.62	14.90	7.20	-888.00	6.5	0.08	2.36	3.94	4.60
32	03AV-43	25	Int. #2	FwBx	FwBx	62.20	0.71	14.70	6.40	-888.00	6.2	0.07	2.42	3.61	5.30
37	03AV-48	47	Int. #3	FwBx	IQD ?	63.30	0.75	13.90	6.90	-888.00	7.2	0.08	2.48	3.10	5.00
38	03AV-49	50	Int. #3	FwBx	IQD	60.50	0.72	14.80	7.80	-888.00	7.9	0.10	3.23	3.11	4.60
40 dup	03AV-51 (lab #75)	52	Int. #3	FwBx	FwBx	63.00	0.59	14.70	6.60	-888.00	6.2	0.08	2.60	3.24	4.30
41	03AV-52	60	Int. #1	FwBx	FwBx	64.80	0.48	14.00	5.20	-888.00	4.7	0.06	1.91	2.53	4.10
43	03AV-54	63	Int. #1	FwBx	FwBx	56.00	0.72	17.20	7.70	-888.00	7.2	0.09	2.64	4.26	4.40
47	03AV-58	85	Distal	FwBx	FwBx	64.10	0.68	13.90	6.00	-888.00	5.5	0.07	2.08	3.54	3.50
48	03AV-59	87	Distal	FwBx	FwBx	61.90	0.63	16.00	5.70	-888.00	5.7	0.06	1.70	3.08	4.40
56	03AV-67	FB-13	Prox #2	FwBx	FwBx	59.80	0.77	14.70	7.90	1.12	6.1	0.10	3.50	4.31	4.10
58	03AV-69	FB-15	Prox #2	FwBx	FwBx	61.20	0.70	15.10	6.90	0.79	5.5	0.09	2.66	4.14	4.20
59	03AV-70	FB-23	Prox #3	FwBx	FwBx	55.30	0.76	17.00	8.60	0.15	7.6	0.11	3.49	5.54	4.60
60 dup	03AV-71 (lab #76)	FB-26	Prox #3	FwBx	FwBx	56.30	0.96	15.70	9.60	0.26	8.4	0.11	3.68	5.47	3.90
42	03AV-53	62	Int. #1	Granite	Granite	70.30	0.38	13.20	3.40	-888.00	4.1	0.02	0.65	0.70	3.40
52	03AV-63	G-5	Int. #1	Granite	Granite	68.00	0.35	15.50	2.80	-888.00	2.8	0.02	0.70	0.77	4.20
54	03AV-65	Qtz Monzodiorite	Prox #3	White Granite	White Granite	56.50	0.65	17.50	6.40	0.40	5.4	0.10	3.68	6.02	4.80
55	03AV-66	Int. Gn.	Prox #2	Int. Gn.	Int. Gn.	66.40	0.58	14.50	6.40	3.62	2.5	0.08	1.57	3.40	4.40
29	03AV-40	15	Int. #1	Gabbro	Gabbro	47.00	0.99	12.50	17.40	-999.00	-999.0	0.23	5.74	9.40	2.80
53	03AV-64	OL DIA	Int. #1	OL DIA	OL DIA	45.90	3.68	15.70	16.20	5.31	9.8	0.20	4.29	7.35	3.70
74 dup	03-024-74 (lab #20)	03AV-21	Prox #1	PPD	PPD	49.10	1.15	14.30	13.20	3.98	8.3	0.19	6.37	10.46	2.40
75 dup	03-024-75 (lab #40)	52	Int. #3	FwBx	FwBx	62.50	0.68	14.60	6.30	-888.00	6.2	0.07	2.51	3.23	4.30
76 dup	03-024-76 (lab #60)	FB-26	Prox #3	FwBx	FwBx	56.40	0.95	15.80	9.70	0.03	8.7	0.12	3.74	5.44	3.90

Table 7 cont'd: Whole-Rock Geochemistry

Lab No.	K ₂ O	H ₂ O _T	CO ₂ I	P ₂ O ₅	ST	ST IC	Ag	Ba	Be	Bi	Cd	Cl	Co	Cr	Cs	Cu	F	Ga	Hf	In
1	0.93	2.2	0.3	0.17	0.14	1256	1.1	399	0.6	-0.2	0.2	998	71	78	0.63	151	368	19.00	2.90	0.09
2	1.56	1.8	0.2	0.12	0.11	895	0.5	295	0.5	-0.2	-0.2	372	56	182	1.80	98	364	18.00	2.80	0.08
3	1.44	2.8	0.1	0.13	0.13	1164	0.4	379	0.5	-0.2	-0.2	237	63	157	0.67	169	303	17.00	2.60	0.08
4	1.56	2.3	0.2	0.28	0.47	4732	0.5	484	0.7	-0.2	0.2	695	77	80	1.20	246	622	19.00	3.20	0.07
5	1.32	1.6	0.2	0.13	0.16	1385	0.3	467	0.6	-0.2	0.4	773	62	105	1.40	74	466	18.00	2.40	0.08
6	1.62	2.1	0.2	0.26	0.39	3443	0.4	409	0.9	0.2	0.7	719	56	206	1.30	387	754	18.00	4.40	0.06
7	1.09	1.3	0.1	0.14	0.12	968	0.3	336	0.5	-0.2	-0.2	500	59	79	1.10	119	315	19.00	2.40	-0.05
8	1.51	2.3	0.2	0.32	0.97	9385	0.7	490	1.1	0.5	0.3	589	74	182	1.20	515	853	18.00	4.00	0.09
9	1.90	2.0	0.1	0.23	0.26	2136	0.4	481	0.9	-0.2	0.4	494	57	184	1.30	249	517	18.00	3.30	0.06
10	1.55	1.7	0.1	0.14	0.11	893	0.4	333	0.6	-0.2	0.4	510	59	75	1.40	126	418	18.00	2.70	0.14
14	1.96	2.6	0.1	0.14	0.11	1013	0.2	549	0.6	-0.2	0.3	302	62	77	0.24	175	420	18.00	3.20	0.07
17	1.23	1.9	0.1	0.12	0.11	984	0.2	354	0.6	-0.2	-0.2	234	62	72	1.30	151	387	18.00	2.60	0.06
18	1.18	1.8	0.1	0.13	0.12	1055	0.2	429	0.5	0.3	0.2	287	61	116	1.30	102	503	18.00	1.80	0.16
19	1.27	1.8	0.1	0.14	0.11	986	0.3	330	0.6	-0.2	-0.2	340	58	1030	1.20	182	405	18.00	3.10	0.08
20 dup	1.19	1.7	0.1	0.10	0.13	1116	0.3	223	0.6	-0.2	-0.2	323	59	177	1.40	175	351	17.00	2.40	0.08
21	0.86	-999.0	0.1	0.12	1.39	-10000	4.7	287	0.5	0.4	0.3	266	114	77	0.52	10100	331	17.00	2.50	0.17
23	1.93	3.1	0.1	0.13	0.08	845	0.2	260	0.7	-0.2	-0.2	290	55	204	1.80	185	457	18.00	1.60	0.08
24	0.92	1.9	0.1	0.12	0.12	1080	0.2	232	0.6	-0.2	-0.2	483	60	168	1.30	190	388	18.00	2.70	0.08
25	0.93	2.9	0.4	0.13	0.22	1873	0.1	381	1.4	-0.2	-0.2	151	62	206	0.22	112	724	18.00	3.10	0.16
27	0.56	3.2	0.3	0.12	0.04	418	0.2	248	1.5	-0.2	0.2	124	30	182	0.31	602	784	20.00	2.80	0.19
11	0.59	2.8	0.2	0.14	0.20	1870	0.4	244	1.1	-0.2	-0.2	201	60	69	0.36	153	736	18.00	4.10	0.09
13	0.75	2.2	0.2	0.35	0.14	1258	0.2	360	1.4	-0.2	-0.2	153	45	108	0.72	74	903	19.00	4.60	0.09
28	1.79	3.5	0.9	0.28	0.24	2070	0.7	162	1.4	0.6	0.3	337	62	84	2.50	2280	1615	19.00	5.10	0.10
15	2.35	1.6	0.1	0.34	0.12	1084	0.2	378	0.8	-0.2	-0.2	396	47	232	3.10	43	1403	18.00	3.70	0.06
33	2.46	1.9	0.2	0.15	0.09	741	0.2	697	1.5	-0.2	0.3	560	27	158	0.72	66	607	17.00	4.30	0.17
39	1.87	1.9	0.2	0.13	0.04	466	0.1	780	1.5	-0.2	-0.2	532	25	153	0.23	44	616	15.00	3.50	0.07
45	1.98	2.4	0.2	0.25	0.27	2399	2.8	660	1.4	2.2	0.4	416	35	155	0.30	2720	870	19.00	4.40	0.16
46	2.91	1.9	0.2	0.15	0.04	411	0.6	993	1.4	0.7	0.2	471	21	153	0.31	636	576	18.00	4.10	0.09
49	2.28	1.9	0.2	0.14	0.06	1115	0.2	766	1.5	0.3	0.3	445	30	147	0.36	105	593	18.00	3.80	0.33
50	2.34	2.8	1.1	0.16	0.01	244	0.2	749	1.9	-0.2	-0.2	256	22	147	0.44	365	725	18.00	4.10	0.06
51	0.50	2.5	1.2	0.22	0.00	103	0.1	137	0.8	0.3	0.4	336	21	138	0.19	75	492	19.00	3.70	0.09
69	2.02	1.7	0.2	0.14	0.02	234	0.2	701	1.2	-0.2	0.4	436	21	150	0.16	50	542	18.00	3.90	0.08
26	1.67	2.1	0.2	0.15	0.04	496	-0.1	700	1.4	-0.2	-0.2	532	29	176	0.25	67	578	18.00	5.50	-0.05
22	2.13	2.1	0.1	0.20	0.04	398	0.2	722	1.3	-0.2	-0.2	508	30	191	0.20	446	701	18.00	5.90	0.07
16	1.70	2.1	0.1	0.27	0.14	1135	0.2	641	1.3	0.2	0.3	588	27	155	0.21	190	866	18.00	6.50	0.05
12	0.60	1.2	0.1	0.19	0.00	120	0.2	169	1.1	-0.2	-0.2	815	24	187	0.07	43	795	18.00	5.40	0.09
34	2.78	2.8	1.0	0.14	0.06	540	0.2	813	1.4	-0.2	-0.2	254	25	177	0.56	61	545	17.00	4.30	0.08
35	1.88	1.8	0.3	0.15	0.08	671	-0.1	619	1.5	0.3	-0.2	433	23	144	0.25	60	530	18.00	1.90	-0.05
61	3.14	2.4	1.5	0.13	0.04	413	0.1	937	1.6	-0.2	0.2	470	23	185	1.00	741	759	18.00	4.10	0.06

Table 7 cont'd: Whole-Rock Geochemistry

Lab No.	K ₂ O	H ₂ O _T	Co ₂ I	P ₂ O ₅	ST	ST IC	Ag	Ba	Be	Bi	Cd	Cl	Co	Cr	Cs	Cu	F	Ga	Hf	In
62	1.14	1.8	0.2	0.21	0.06	448	-0.1	567	1.4	-0.2	-0.2	361	20	64	0.22	82	448	19.00	3.10	0.07
63	1.97	1.7	0.2	0.31	0.17	1501	0.3	952	1.4	-0.2	-0.2	481	19	46	0.21	1420	605	21.00	2.80	0.09
64	2.73	2.0	0.2	0.16	0.04	395	0.2	922	1.4	0.3	0.4	423	25	143	0.29	38	508	18.00	3.70	0.38
65	1.99	2.2	0.2	0.12	0.91	9407	0.2	764	1.6	0.7	-0.2	485	85	147	0.26	550	645	17.00	4.10	0.08
66	2.31	2.8	0.3	0.16	0.13	1476	-0.1	712	1.5	-0.2	-0.2	397	26	221	0.38	89	745	20.00	3.80	0.06
67	2.22	1.8	0.2	0.14	0.04	350	-0.1	776	1.5	-0.2	-0.2	367	20	166	0.24	86	602	18.00	4.20	0.08
68	2.17	2.0	0.2	0.13	0.13	1164	0.1	873	1.6	-0.2	-0.2	446	31	157	0.33	132	686	19.00	3.60	0.09
36	1.14	1.5	0.3	0.20	0.13	1164	0.2	247	1.4	-0.2	-0.2	343	24	203	0.08	30	949	19.00	3.80	0.12
44	2.96	2.1	0.2	0.28	0.04	338	0.4	1150	1.4	0.3	0.4	353	31	150	0.28	551	777	19.00	4.50	0.11
70	2.13	2.8	0.2	0.20	0.07	616	0.2	733	1.3	0.3	0.3	360	30	172	0.80	145	824	20.00	4.10	0.29
71	2.24	2.6	0.2	0.35	0.08	630	0.2	802	0.7	-0.2	-0.2	223	38	144	0.12	89	520	19.00	4.00	0.05
72	2.23	2.6	0.2	0.22	0.73	7546	0.3	783	1.1	0.2	0.2	465	79	177	0.57	342	775	18.00	3.20	0.13
73	2.16	2.1	0.3	0.28	0.36	3868	0.2	906	1.4	-0.2	-0.2	503	53	192	1.10	266	970	20.00	3.40	0.10
57	2.07	2.1	0.3	0.31	0.18	1648	0.3	930	1.4	0.5	0.4	296	30	163	0.47	131	672	20.00	4.90	0.40
30	3.88	1.7	0.2	0.27	0.02	249	0.1	1930	1.5	-0.2	-0.2	432	16	104	0.22	76	646	20.00	5.20	-0.05
31	2.53	1.4	0.2	0.20	0.09	831	0.1	1080	1.6	-0.2	-0.2	313	18	109	0.35	69	613	19.00	3.70	-0.05
32	2.04	1.3	0.2	0.18	0.06	570	0.1	654	1.5	-0.2	-0.2	507	17	94	0.18	59	668	18.00	3.70	0.07
37	2.64	1.1	0.4	0.20	0.13	1102	0.2	494	0.8	-0.2	-0.2	444	20	126	0.11	34	731	13.00	4.10	0.06
38	2.18	2.0	0.3	0.17	0.10	1083	0.2	1030	1.5	-0.2	-0.2	351	24	131	0.31	163	624	17.00	2.90	0.08
40 dup	3.10	1.6	0.3	0.18	0.08	775	0.2	1020	1.5	-0.2	-0.2	311	18	97	0.19	43	573	18.00	4.90	0.07
41	3.59	1.2	0.2	0.20	0.47	4920	3.6	1020	1.5	23.0	0.2	410	12	98	0.45	4900	683	17.00	3.80	0.19
43	4.05	1.7	0.2	0.38	0.07	710	-0.1	1810	2.0	-0.2	-0.2	237	15	59	0.30	33	709	22.00	3.80	0.06
47	3.65	1.4	0.1	0.18	0.02	234	0.3	1280	1.3	0.3	0.4	385	13	72	0.23	176	626	17.00	4.10	0.15
48	3.88	1.5	0.2	0.18	0.00	89	0.1	1470	1.7	-0.2	-0.2	358	10	71	0.33	111	468	19.00	5.10	0.09
56	2.17	2.2	0.2	0.23	0.12	1478	0.2	791	1.5	-0.2	-0.2	407	25	139	0.35	85	652	19.00	4.10	0.07
58	3.02	1.7	0.2	0.26	0.12	931	0.1	1210	1.3	-0.2	-0.2	450	24	97	0.23	70	654	19.00	5.00	0.06
59	2.46	1.8	0.3	0.39	0.16	1357	-0.1	905	2.1	-0.2	-0.2	188	24	151	0.33	112	718	22.00	2.90	0.07
60 dup	2.06	1.7	0.2	0.26	0.16	1491	0.1	755	1.1	-0.2	-0.2	428	34	142	1.40	113	922	21.00	3.70	0.07
42	5.73	0.6	0.2	0.06	0.24	2359	0.6	1590	0.8	0.5	-0.2	467	5	35	0.29	2450	223	14.00	4.00	0.10
52	6.30	0.9	0.3	0.16	0.03	308	0.1	1670	1.0	-0.2	-0.2	619	8	24	0.41	28	294	18.00	2.90	-0.05
54	2.14	1.3	0.2	0.16	0.01	198	0.1	797	1.8	-0.2	-0.2	156	18	231	0.61	23	703	21.00	2.90	0.08
55	2.08	1.1	0.2	0.11	0.07	743	0.2	743	1.3	-0.2	-0.2	400	12	73	0.44	109	612	17.00	3.70	-0.05
29	0.64	-999.0	0.3	0.07	1.83	-10000	0.1	172	1.1	0.9	-0.2	703	128	153	0.10	949	934	17.00	2.00	0.11
53	1.52	1.5	0.2	0.53	0.08	762	0.1	724	1.4	-0.2	-0.2	243	62	57	1.10	66	778	23.00	4.80	0.11
74 dup	1.23	1.8	0.1	0.11	0.13	1144	0.2	229	0.6	0.3	-0.2	385	60	179	1.50	181	383	17.00	2.50	0.10
75 dup	2.92	1.7	0.3	0.20	0.08	744	0.3	1020	1.5	-0.2	-0.2	234	17	96	0.18	44	522	19.00	5.00	0.10
76 dup	2.10	1.7	0.2	0.28	0.16	1296	0.2	790	1.1	-0.2	-0.2	436	35	141	1.30	109	835	23.00	3.60	0.07

Table 7 cont'd: Whole-Rock Geochemistry

Lab No.	Mo	Nb	Ni	Pb	Rb	Sb	Sc	Sn	Sr	Ta	Te	Th	Ti	U	V	Zn	Zr	Ce	Dy	Er
1	0.9	5.20	85	8	31.00	0.4	41.0	0.9	273	0.30	-0.2	2.00	0.25	0.44	411	152	101.0	31.0	5.30	3.10
2	0.7	6.50	84	8	69.00	0.3	40.0	1.7	261	0.39	-0.2	1.60	0.60	0.39	313	117	108.0	25.0	5.20	3.10
3	0.6	5.70	110	5	44.00	-0.2	37.0	0.8	380	0.34	-0.2	1.50	0.33	0.35	326	143	109.0	22.0	4.50	2.90
4	0.8	5.70	519	19	46.00	-0.2	34.0	1.1	453	0.30	-0.2	2.40	0.41	0.48	355	138	127.0	44.0	4.80	2.80
5	0.7	5.20	74	15	35.00	0.3	41.0	0.8	299	0.31	-0.2	1.20	0.31	0.29	368	144	95.0	27.0	5.10	3.10
6	0.9	7.10	523	35	45.00	0.3	27.0	1.3	437	0.37	-0.2	3.90	0.34	0.76	241	166	176.0	60.0	4.10	2.30
7	0.7	4.60	76	8	30.00	-0.2	32.0	0.6	313	0.26	-0.2	1.50	0.24	0.34	356	124	98.0	28.0	4.10	2.40
8	0.6	6.90	1290	21	47.00	0.3	27.0	2.3	492	0.35	-0.2	3.40	0.52	0.63	246	125	171.0	71.0	4.20	2.20
9	0.8	5.90	273	27	55.00	-0.2	28.0	1.2	438	0.34	-0.2	3.60	0.42	0.67	258	146	142.0	53.0	3.90	2.20
10	0.7	4.50	78	10	49.00	-0.2	35.0	1.0	337	0.26	-0.2	1.90	0.41	0.41	336	135	106.0	30.0	4.50	2.70
14	0.7	4.80	110	7	47.00	0.3	36.0	0.8	315	0.30	-0.2	2.70	0.23	0.55	338	145	125.0	32.0	4.70	2.90
17	0.6	5.00	101	8	45.00	0.3	36.0	0.9	259	0.28	-0.2	2.20	0.37	0.38	340	127	103.0	31.0	4.00	2.40
18	0.6	2.80	108	10	39.00	-0.2	37.0	0.7	404	0.14	-0.2	0.67	0.31	0.13	310	117	71.0	27.0	3.70	2.30
19	0.6	7.40	84	14	44.00	-0.2	39.0	1.1	248	0.45	-0.2	1.80	0.37	0.43	323	134	121.0	30.0	5.40	3.40
20 dup	0.6	5.80	95	11	47.00	-0.2	38.0	1.0	236	0.35	-0.2	1.70	0.44	0.41	289	121	95.0	24.0	4.30	2.70
21	0.8	4.20	473	12	28.00	0.3	36.0	1.2	311	0.23	0.5	1.70	0.22	0.31	313	149	108.0	28.0	3.80	2.30
23	0.4	3.80	223	7	96.00	0.4	41.0	0.8	401	0.22	-0.2	1.00	0.83	0.23	334	134	57.0	24.0	4.30	2.60
24	0.8	6.90	69	4	26.00	0.3	41.0	1.4	174	0.42	-0.2	1.80	0.24	0.42	311	136	103.0	26.0	5.20	3.20
25	0.7	7.00	112	5	31.00	-0.2	39.0	0.9	487	0.41	-0.2	2.30	0.23	0.56	315	156	133.0	32.0	4.90	3.00
27	0.7	6.70	216	27	20.00	0.5	41.0	1.9	735	0.40	-0.2	1.90	0.13	0.44	316	194	143.0	30.0	5.00	3.10
11	0.9	9.00	109	5	18.00	0.4	40.0	1.7	501	0.59	-0.2	3.50	0.13	0.91	391	190	167.0	42.0	7.10	4.30
13	0.7	9.00	72	7	31.00	0.3	34.0	2.1	719	0.54	-0.2	3.60	0.25	0.60	286	157	226.0	68.0	6.20	3.60
28	0.7	9.60	105	13	116.00	0.7	41.0	1.8	663	0.62	-0.2	4.00	1.00	0.89	425	234	211.0	44.0	8.20	4.90
15	1.2	9.40	146	7	85.00	-0.2	23.0	1.1	411	0.51	-0.2	0.95	0.67	0.30	225	137	165.0	48.0	4.60	2.50
33	26.0	8.50	203	7	61.00	0.3	16.0	1.6	445	0.58	-0.2	8.20	0.33	1.70	125	99	157.0	68.0	3.40	1.80
39	32.0	8.20	195	6	33.00	0.4	15.0	1.9	383	0.53	-0.2	7.50	0.16	1.40	114	88	147.0	60.0	3.00	1.60
45	27.0	8.80	350	58	35.00	0.6	23.0	2.6	469	0.53	0.7	6.10	0.21	1.20	188	126	185.0	82.0	4.60	2.30
46	21.0	8.40	316	40	62.00	0.5	15.0	4.2	441	0.53	0.3	8.20	0.31	1.80	118	83	167.0	73.0	3.40	1.70
49	25.0	8.40	221	7	44.00	0.4	15.0	2.3	455	0.55	-0.2	7.90	0.22	1.60	120	83	167.0	69.0	3.40	1.70
50	16.0	8.20	143	6	53.00	0.4	16.0	1.6	310	0.52	-0.2	8.50	0.26	1.70	121	80	165.0	68.0	2.90	1.40
51	14.0	7.40	1340	23	11.00	0.6	17.0	2.5	448	0.42	-0.2	6.00	0.08	0.90	140	110	158.0	72.0	3.60	1.80
69	18.0	8.40	104	8	38.00	0.3	16.0	1.6	412	0.53	-0.2	8.50	0.18	1.70	123	92	161.0	70.0	3.30	1.80
26	1.3	9.90	54	11	23.00	0.3	18.0	1.7	298	0.60	-0.2	10.00	0.10	2.00	140	123	222.0	74.0	3.70	2.10
22	0.8	9.70	81	7	40.00	-0.2	19.0	1.6	414	0.62	-0.2	11.00	0.20	2.30	149	108	234.0	83.0	4.20	2.30
16	1.3	8.90	222	16	20.00	-0.2	21.0	1.7	372	0.50	-0.2	7.60	0.12	1.40	167	118	247.0	86.0	4.40	2.40
12	0.4	9.60	103	7	8.30	-0.2	17.0	2.5	568	0.61	-0.2	10.00	0.05	1.90	142	76	223.0	92.0	4.20	2.30
34	48.0	8.30	228	6	62.00	0.5	16.0	1.8	224	0.58	-0.2	7.70	0.31	1.90	125	102	157.0	58.0	3.00	1.50
35	22.0	8.90	124	7	38.00	-0.2	14.0	1.8	414	0.76	-0.2	2.10	0.20	0.62	116	95	77.0	50.0	2.50	1.30
61	51.0	8.60	287	7	91.00	0.4	17.0	1.9	358	0.55	-0.2	9.20	0.51	2.10	133	85	173.0	77.0	3.60	1.70

Table 7 cont'd: Whole-Rock Geochemistry

Lab No.	Mo	Nb	Ni	Pb	Rb	Sb	Sc	Sn	Sr	Ta	Te	Th	Ti	U	V	Zn	Zr	Ce	Dy	Er
62	24.0	5.30	129	6	32.00	0.3	14.0	1.5	611	0.23	-0.2	3.40	0.19	0.34	136	70	170.0	77.0	2.50	1.20
63	25.0	4.70	234	10	37.00	0.6	6.9	1.7	612	0.20	-0.2	4.10	0.18	0.43	103	53	120.0	83.0	2.10	0.85
64	16.0	8.40	129	9	62.00	0.3	17.0	1.5	414	0.51	-0.2	7.10	0.29	1.60	137	70	163.0	69.0	3.50	1.80
65	26.0	8.50	937	8	48.00	0.4	14.0	1.9	543	0.56	-0.2	8.00	0.26	2.00	117	75	157.0	68.0	3.30	1.70
66	32.0	7.60	295	5	48.00	0.4	17.0	1.5	365	0.47	-0.2	6.70	0.25	1.30	134	95	144.0	58.0	3.00	1.50
67	37.0	8.30	183	27	40.00	0.4	15.0	1.9	432	0.49	-0.2	7.10	0.20	1.40	124	74	177.0	68.0	3.30	1.60
68	30.0	8.30	204	10	45.00	0.4	19.0	1.6	454	0.53	-0.2	6.50	0.22	1.50	129	105	139.0	70.0	3.80	1.90
36	33.0	8.30	238	4	16.00	0.3	22.0	2.1	899	0.45	-0.2	5.10	0.08	1.10	144	90	204.0	72.0	3.90	1.90
44	29.0	8.70	227	41	52.00	0.7	22.0	2.1	521	0.47	-0.2	5.50	0.31	0.97	189	110	189.0	89.0	4.50	2.20
70	34.0	8.00	208	13	51.00	0.3	19.0	1.7	557	0.44	-0.2	6.00	0.33	1.00	159	107	172.0	79.0	4.00	2.00
71	18.0	6.40	294	4	45.00	-0.2	17.0	1.5	320	0.25	-0.2	4.60	0.31	0.38	167	75	180.0	82.0	3.50	1.50
72	45.0	5.60	777	9	56.00	1.0	31.0	1.9	513	0.30	-0.2	3.00	0.35	0.62	253	131	123.0	57.0	4.40	2.20
73	62.0	8.00	643	11	54.00	0.6	21.0	2.1	534	0.37	-0.2	5.10	0.38	0.71	181	104	143.0	82.0	4.00	1.90
57	39.0	6.90	305	11	45.00	0.5	15.0	1.7	596	0.32	-0.2	4.90	0.30	0.77	126	88	216.0	85.0	3.10	1.40
30	41.0	5.60	194	8	59.00	-0.2	12.0	1.4	505	0.15	-0.2	2.10	0.34	0.31	88	73	230.0	84.0	2.80	1.30
31	42.0	5.00	201	9	45.00	0.2	12.0	1.6	569	0.17	-0.2	2.70	0.26	0.31	91	74	183.0	63.0	2.20	1.10
32	35.0	4.80	202	5	34.00	0.2	11.0	1.3	491	0.19	-0.2	3.70	0.17	0.42	89	71	178.0	68.0	2.10	0.94
37	37.0	6.10	256	4	35.00	0.3	15.0	1.4	347	0.28	-0.2	5.00	0.18	0.59	93	71	174.0	63.0	2.70	1.30
38	33.0	4.70	206	8	38.00	-0.2	15.0	1.4	417	0.24	-0.2	3.30	0.20	0.52	119	118	133.0	52.0	2.60	1.30
40 dup	28.0	5.40	156	6	47.00	0.4	12.0	1.5	534	0.21	-0.2	3.20	0.26	0.45	94	65	207.0	60.0	2.70	1.30
41	19.0	4.00	795	360	71.00	0.6	7.2	6.9	534	0.15	4.0	4.80	0.48	0.65	64	61	161.0	61.0	1.70	0.74
43	29.0	5.80	124	10	65.00	-0.2	11.0	2.4	857	0.19	-0.2	1.20	0.38	0.30	105	64	224.0	88.0	3.70	1.50
47	21.0	4.80	170	101	65.00	0.3	11.0	4.7	524	0.16	-0.2	5.10	0.38	0.39	94	56	189.0	83.0	2.60	1.10
48	22.0	6.70	154	15	78.00	0.2	8.0	1.5	660	0.19	-0.2	3.20	0.45	0.44	74	59	208.0	96.0	2.60	1.20
56	19.0	6.60	277	10	31.00	0.3	15.0	1.5	510	0.33	-0.2	5.10	0.18	0.70	125	83	193.0	80.0	3.10	1.40
58	22.0	6.60	204	9	42.00	0.3	12.0	1.6	547	0.29	-0.2	7.60	0.23	0.76	105	72	212.0	97.0	3.00	1.30
59	39.0	10.00	218	13	63.00	0.4	16.0	1.9	694	0.51	-0.2	5.10	0.36	0.52	116	82	160.0	124.0	4.90	2.00
60 dup	26.0	5.30	202	19	63.00	0.3	20.0	1.1	587	0.25	-0.2	4.60	0.48	0.41	172	103	167.0	79.0	3.30	1.50
42	29.0	1.30	358	9	107.00	0.4	1.1	2.2	272	-0.05	0.7	1.00	0.60	0.56	27	19	140.0	17.0	0.45	0.22
52	19.0	3.40	115	10	119.00	0.4	2.1	0.9	337	0.11	-0.2	8.00	0.73	0.27	24	18	114.0	67.0	1.10	0.40
54	24.0	4.00	170	12	55.00	0.3	14.0	0.8	931	0.15	-0.2	0.74	0.32	0.16	53	81	174.0	63.0	3.30	1.40
55	36.0	6.20	147	11	38.00	0.2	8.3	1.7	434	0.30	-0.2	2.30	0.23	0.46	68	51	154.0	41.0	1.60	0.75
29	48.0	4.10	258	6	12.00	0.6	37.0	1.9	411	0.25	0.3	1.00	0.08	0.23	251	125	76.0	26.0	4.20	2.60
53	7.2	19.00	66	5	41.00	-0.2	26.0	1.7	469	1.10	-0.2	1.60	0.33	0.39	268	136	203.0	58.0	6.10	3.10
74 dup	0.8	5.80	93	12	48.00	0.4	39.0	1.3	242	0.36	-0.2	1.80	0.44	0.44	298	113	96.0	24.0	4.40	2.60
75 dup	26.0	5.30	142	5	48.00	0.7	11.0	1.6	511	0.20	-0.2	3.10	0.27	0.47	93	65	205.0	59.0	2.50	1.30
76 dup	26.0	5.50	209	18	64.00	0.3	19.0	1.3	554	0.23	-0.2	4.50	0.50	0.40	169	105	168.0	79.0	3.20	1.50

Table 7 cont'd: Whole-Rock Geochemistry

Lab No.	Eu	Gd	Ho	La	Lu	Nd	Pr	Sm	Tb	Tm	Y	Yb	TOTAL	LOI
1	1.40	5.00	1.10	15.0	0.49	17.0	4.00	4.50	0.84	0.47	31.00	3.00	99.0	1.1
2	1.30	4.60	1.10	12.0	0.48	14.0	3.20	3.90	0.79	0.49	31.00	3.00	99.7	0.5
3	1.10	4.20	1.00	10.0	0.44	13.0	2.90	3.60	0.73	0.43	29.00	2.80	100.0	1.6
4	1.50	5.00	1.00	21.0	0.41	23.0	5.40	5.10	0.78	0.40	28.00	2.60	99.8	1.3
5	1.20	4.60	1.10	13.0	0.48	15.0	3.40	4.00	0.80	0.46	31.00	3.10	99.4	0.6
6	1.50	4.90	0.83	30.0	0.33	28.0	7.10	5.80	0.71	0.33	24.00	2.10	100.4	1.3
7	1.20	3.70	0.85	13.0	0.38	14.0	3.40	3.50	0.64	0.37	25.00	2.40	100.1	0.3
8	1.70	5.60	0.84	33.0	0.31	35.0	8.70	7.10	0.77	0.31	24.00	2.00	99.4	1.5
9	1.40	4.50	0.82	26.0	0.33	26.0	6.30	5.30	0.69	0.32	23.00	2.10	100.2	1.2
10	1.30	4.20	0.96	15.0	0.43	16.0	3.80	3.90	0.71	0.41	28.00	2.70	99.6	0.6
14	1.20	4.40	1.00	16.0	0.45	16.0	3.90	4.10	0.75	0.43	29.00	2.80	99.6	1.5
17	1.10	3.80	0.84	15.0	0.37	16.0	3.80	3.60	0.64	0.36	24.00	2.30	99.7	0.8
18	1.10	3.70	0.81	12.0	0.34	15.0	3.30	3.60	0.63	0.33	23.00	2.20	100.5	0.6
19	1.30	4.90	1.20	14.0	0.54	17.0	3.80	4.30	0.84	0.50	34.00	3.30	100.3	0.7
20 dup	1.10	3.80	0.93	11.0	0.40	13.0	3.00	3.30	0.66	0.39	27.00	2.60	99.6	0.6
21	1.00	3.70	0.80	13.0	0.36	14.0	3.40	3.30	0.61	0.34	24.00	2.20	99.4	1.0
23	1.20	4.00	0.92	11.0	0.40	13.0	3.10	3.50	0.69	0.38	27.00	2.50	99.6	1.8
24	1.20	4.60	1.10	12.0	0.50	15.0	3.40	3.90	0.81	0.48	32.00	3.20	100.4	0.7
25	1.10	4.60	1.00	15.0	0.47	17.0	4.00	4.10	0.78	0.45	31.00	3.00	100.1	2.0
27	1.30	4.60	1.10	14.0	0.49	16.0	3.70	4.00	0.78	0.46	32.00	3.10	99.0	2.2
11	1.40	6.40	1.50	21.0	0.65	23.0	5.30	5.80	1.10	0.63	43.00	4.10	99.6	1.6
13	1.90	6.50	1.30	33.0	0.56	32.0	7.90	6.80	1.00	0.54	37.00	3.40	99.8	1.3
28	1.80	7.40	1.70	21.0	0.77	24.0	5.60	6.30	1.30	0.73	50.00	4.80	100.4	2.7
15	1.70	5.50	0.93	20.0	0.34	28.0	6.40	6.10	0.79	0.34	26.00	2.20	100.3	0.4
33	1.30	4.20	0.69	33.0	0.28	27.0	7.50	5.00	0.60	0.28	20.00	1.80	100.7	1.0
39	1.10	3.60	0.62	29.0	0.25	25.0	6.90	4.50	0.54	0.25	18.00	1.60	99.8	1.0
45	1.70	5.60	0.89	40.0	0.34	38.0	10.00	6.80	0.80	0.35	26.00	2.20	99.0	1.3
46	1.30	4.10	0.65	36.0	0.27	31.0	8.50	5.30	0.59	0.27	20.00	1.70	99.9	1.1
49	1.20	4.00	0.66	35.0	0.26	29.0	8.00	5.00	0.59	0.27	20.00	1.70	99.0	1.1
50	0.98	3.60	0.54	34.0	0.22	28.0	7.80	4.50	0.50	0.22	17.00	1.50	100.2	3.0
51	1.60	4.60	0.69	35.0	0.25	33.0	8.70	5.60	0.64	0.27	21.00	1.70	100.7	2.8
69	1.30	4.10	0.69	35.0	0.28	29.0	7.90	5.20	0.59	0.28	20.00	1.80	99.1	1.1
26	1.20	4.40	0.74	36.0	0.33	30.0	8.20	5.60	0.64	0.30	23.00	2.00	99.4	1.6
22	1.20	5.00	0.83	41.0	0.35	35.0	9.30	6.30	0.74	0.32	25.00	2.20	100.2	1.6
16	1.50	6.00	0.88	41.0	0.35	39.0	10.00	7.60	0.82	0.35	26.00	2.20	99.3	1.5
12	1.70	5.00	0.82	49.0	0.33	37.0	10.00	6.50	0.72	0.33	24.00	2.10	99.8	0.6
34	1.10	3.60	0.61	29.0	0.24	25.0	6.60	4.40	0.52	0.24	17.00	1.60	100.6	2.3
35	1.20	3.00	0.49	23.0	0.19	21.0	5.80	3.60	0.43	0.20	15.00	1.30	99.9	1.2
61	1.60	4.60	0.67	39.0	0.26	32.0	8.80	5.70	0.63	0.27	20.00	1.70	100.7	2.5

Table 7 cont'd: Whole-Rock Geochemistry

Lab No.	Eu	Gd	Ho	La	Lu	Nd	Pr	Sm	Tb	Tm	Y	Yb	TOTAL	LOI
62	1.50	3.60	0.49	39.0	0.17	32.0	8.90	5.10	0.48	0.17	14.00	1.00	98.7	1.0
63	1.50	3.70	0.37	42.0	0.11	34.0	9.30	5.40	0.44	0.12	11.00	0.69	98.7	0.9
64	1.40	4.30	0.70	34.0	0.28	31.0	8.20	5.30	0.61	0.28	21.00	1.80	100.3	1.3
65	1.20	3.90	0.66	34.0	0.27	28.0	7.60	4.90	0.57	0.27	19.00	1.80	99.8	1.6
66	1.10	3.60	0.59	30.0	0.24	25.0	6.80	4.50	0.51	0.25	17.00	1.60	99.0	1.8
67	1.20	3.90	0.63	33.0	0.25	29.0	7.90	4.90	0.55	0.25	19.00	1.60	100.2	0.9
68	1.40	4.80	0.75	34.0	0.28	32.0	8.30	6.10	0.68	0.29	21.00	1.80	99.8	1.0
36	1.40	5.00	0.74	33.0	0.29	34.0	8.90	6.20	0.70	0.30	22.00	1.90	99.6	0.6
44	1.80	5.80	0.86	43.0	0.31	41.0	11.00	7.40	0.80	0.32	25.00	2.10	99.1	1.0
70	1.70	5.10	0.77	39.0	0.31	35.0	9.50	6.40	0.71	0.29	23.00	1.90	101.8	0.7
71	1.70	5.00	0.63	40.0	0.20	36.0	9.60	6.60	0.64	0.22	18.00	1.30	99.7	1.8
72	1.70	5.10	0.86	27.0	0.35	29.0	7.30	5.80	0.77	0.35	26.00	2.10	99.9	1.2
73	1.80	5.70	0.75	39.0	0.27	39.0	10.00	7.30	0.73	0.28	22.00	1.70	100.3	0.5
57	1.90	4.60	0.57	43.0	0.19	37.0	9.80	6.20	0.61	0.20	17.00	1.30	99.6	0.9
30	1.60	4.40	0.50	43.0	0.17	35.0	9.40	6.20	0.57	0.17	15.00	1.10	99.8	0.7
31	1.30	3.60	0.40	31.0	0.15	29.0	7.60	5.30	0.45	0.15	12.00	0.91	100.7	0.4
32	1.30	3.40	0.38	34.0	0.14	29.0	7.80	4.70	0.41	0.14	11.00	0.88	99.4	0.5
37	1.10	3.60	0.50	29.0	0.19	27.0	7.30	4.80	0.50	0.20	14.00	1.20	100.2	0.6
38	1.20	3.30	0.50	25.0	0.19	23.0	6.10	4.20	0.47	0.20	14.00	1.20	99.9	1.2
40 dup	1.30	3.70	0.49	30.0	0.20	27.0	7.10	4.70	0.49	0.19	14.00	1.20	100.6	0.9
41	1.30	2.90	0.32	31.0	0.12	25.0	6.80	4.40	0.36	0.11	8.90	0.71	99.6	0.7
43	2.30	6.20	0.64	38.0	0.19	46.0	12.00	8.70	0.77	0.21	19.00	1.30	99.8	0.9
47	1.50	3.80	0.47	43.0	0.16	34.0	9.40	5.30	0.48	0.17	14.00	0.99	99.5	0.7
48	1.60	3.90	0.47	50.0	0.18	38.0	11.00	5.80	0.50	0.17	14.00	1.10	99.6	0.8
56	1.50	4.40	0.57	40.0	0.19	35.0	9.60	6.10	0.59	0.21	17.00	1.30	99.7	1.3
58	1.70	4.70	0.55	51.0	0.19	42.0	11.00	6.70	0.59	0.20	16.00	1.20	100.0	0.9
59	2.20	7.70	0.88	57.0	0.28	59.0	15.00	11.00	0.97	0.30	26.00	1.90	100.0	0.7
60 dup	1.90	4.60	0.60	41.0	0.23	35.0	9.20	6.00	0.62	0.23	18.00	1.50	99.4	0.6
42	0.82	0.80	0.08	9.9	0.04	6.4	1.80	1.10	0.10	0.03	2.50	0.21	99.4	0.1
52	1.10	2.20	0.18	35.0	0.05	25.0	7.40	3.50	0.25	0.05	5.70	0.29	100.3	0.6
54	2.30	4.40	0.58	34.0	0.20	31.0	7.90	5.90	0.61	0.22	17.00	1.40	99.1	0.5
55	0.83	2.00	0.30	21.0	0.12	17.0	4.60	2.70	0.29	0.13	9.00	0.77	100.8	0.2
29	1.00	3.80	0.89	12.0	0.41	14.0	3.30	3.30	0.63	0.38	27.00	2.60	99.2	1.5
53	2.50	6.90	1.20	25.0	0.46	34.0	7.90	7.20	1.00	0.47	34.00	2.90	100.0	0.4
74 dup	1.10	3.90	0.94	11.0	0.40	13.0	3.10	3.30	0.67	0.40	27.00	2.50	99.8	0.6
75 dup	1.30	3.50	0.48	29.0	0.21	27.0	7.00	4.60	0.50	0.21	15.00	1.30	99.6	0.9
76 dup	1.80	4.50	0.59	40.0	0.24	35.0	9.30	5.90	0.63	0.24	18.00	1.50	99.8	0.6

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**Whistle Offset
MAP #1
Proximal Zone
Proximal #1 Area
UTM NAD 27, Zone 17
W.M. Carter, 2005**

Notes:

The LQD pods of the Whistle Offset occur at the margin of the offset structure, and are interpreted as the primary-most pulse of magma into the offset structure. IQD occurs inboard from the LQD and is interpreted to represent the second pulse of magma into the offset structure.

The Footwall Breccia is an *in situ* impact breccia occurring irregularly throughout the offset structure. It is heterogeneous and clast-rich, and was intruded by the LQD and IQD.

The sulphide mineralization in the Proximal Zone is typically disseminated. Epidote veining is prevalent, and generally trends north like the offset structure.

Geology	
Post-Sudbury Event Rocks	Sudbury Olivine Diabase Dyke
	Epidote Veining

10 15 20 25

metres

1.85 Ga

Pre-Sudbury Event
Archean Rocks

Leucocratic Quartz Diorite
Footwall Breccia (more felsic)
Footwall Breccia
Sudbury Breccia
Matachewan Diabase
Quartz Monzodiorite
Granite
Gabbro
Leucosome / Pegmatite
Mafic Gneiss
Intermediate Gneiss

Contacts

Observed
Inferred
Interpreted

Faults

Fault
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Symbols

Sample
FNX Grid Point
Drill Hole

10

15

20

25

metres

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**Whistle Offset
MAP #2
Proximal Zone
Proximal #2 Area
UTM NAD 27, Zone 17
W.M. Carter, 2005**

Notes:

The LQD pod abuts the footwall rocks and represents the first pulse of magma into the offset structure. The IQD occurs inboard of the LQD and represents the second pulse of magma into the offset structure.

Epidote veining is well developed here, with the general north-northeast trend characteristic of the offset structure.

N

0

5

10

15

metres

Post-Sudbu
Rock

Sudbu
Rock
1.8

Pre-Sudbu
Archean

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metres

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Whistle Offset

MAP #3

Proximal Zone

Proximal #3 Area

UTM NAD 27, Zone 17

W.M. Carter, 2005

Notes:

The LQD pod occurs along the eastern margin of the offset structure in the Proximal Zone. Footwall Breccia and IQD occur inboard from the LQD pod. As the contact of the Footwall Breccia is considered to be very irregular, it is likely that the IQD was/is in contact with the LQD at some level other than the present erosional level.

The Footwall Breccia was subdivided here based on clast composition and overall colour of the matrix material.

Notes.

The LQD pod occurs along the eastern margin of the offset structure in the Proximal Zone. Footwall Breccia and IQD occur inboard from the LQD pod. As the contact of the Footwall Breccia is considered to be very irregular, it is likely that the IQD was/is in contact with the LQD at some level other than the present erosional level.

The Footwall Breccia was subdivided here based on clast composition and overall colour of the matrix material.

5

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20

25

metres

metres

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Whistle Offset

MAP #4

Proximal Zone

Proximal #4 Area

UTM NAD 27, Zone 17

W.M. Carter, 2005

Notes:

Footwall Breccia is a very heterogeneous rock type, and subdivision can be difficult. The "more felsic" Footwall Breccia occurs adjacent to granite and grades into "typical" Footwall Breccia over a distance of about 5 metres. The distinction was based on colour and clast composition.

The IQD is intrusive into the Footwall Breccia, and the contact is envisioned as a very irregular and undulose zone (like an egg carton), with the present erosional surface exposing pits full of IQD.

Notes:

Footwall Breccia is a very heterogeneous rock type, and subdivision can be difficult. The "more felsic" Footwall Breccia occurs adjacent to granite and grades into "typical" Footwall Breccia over a distance of about 5 metres. The distinction was based on colour and clast composition.

The IQD is intrusive into the Footwall Breccia, and the contact is envisioned as a very irregular and undulose zone (like an egg carton), with the present erosional surface exposing pits full of IQD.

0

5

5

10

15

20

25

metres

Whistle Offset MAP #5 Proximal Zone Proximal #5 Area UTM NAD 27, Zone 17 W.M. Carter, 2005

Notes:

Inclusion/clastic material in the IQD is all
This gives the impression that the QD po
IQD, which then ejected the clastic mater

0

m

clastic material in the IQD is aligned with long dimensions parallel to the QD pods.
es the impression that the QD pods represent convective cells developed within the
ch then ejected the clastic material to areas with a lower degree of convective action.

5

metres

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Whistle Offset
MAP #6
Intermediate Zone
Intermediate #1 Area
UTM NAD 27, Zone 17
W.M. Carter, 2005

Notes:

Very little LQD occurs in this map area. Hematitic alteration is prevalent here, and it can make field identification of LQD and QD suspect.

A narrow body of IQD occurs near the margin of the offset structure, with the map area being dominated by Footwall Breccia. A late Sudbury Olivine Diabase dyke cuts across the northern section of the map area.

Small-scale sulphide veining is characteristic of the Intermediate Zone. The veins generally contain chalcopyrite, pyrite, and millerite, and are typically surrounded by an epidote alteration rim. In some cases the vein follow contact zones, or they occur in fractures within clastic material. The veins generally trend north, approximately the same direction as the offset structure.

Post-Sudbury Event
Rocks

Geology

Sudbury Olivine Diabase Dyke

ase Dyke

Post-Sudbury Event
Rocks

Geology

Sudbury Olivine Diabase Dyke

Epidote Veining

Sulphide Veins

Quartz Diorite

Inclusion Quartz Diorite

Leucocratic Quartz Diorite

Footwall Breccia (more felsic)

Footwall Breccia

Sudbury Breccia

Sudbury Event
Rocks
1.85 Ga

Matachewan Diabase

Quartz Monzodiorite

Granite

Gabbro

Leucosome / Pegmatite

Mafic Gneiss

Intermediate Gneiss

Pre-Sudbury Event
Archean Rocks

Contacts

Observed

Inferred

Interpreted

Faults

Fault

Symbols

Sample

FNX Grid Point

base Dyke

rite

Diorite

ore felsic)

e

ntite

15

20

25

Sudbury Event
Rocks
1.85 Ga

Quartz Diorite
Inclusion Quartz Diorite
Leucocratic Quartz Diorite
Footwall Breccia (more felsic)
Footwall Breccia
Sudbury Breccia

Pre-Sudbury Event
Archean Rocks

Matachewan Diabase
Quartz Monzodiorite
Granite
Gabbro
Leucosome / Pegmatite
Mafic Gneiss
Intermediate Gneiss

Contacts

————— Observed
— — — — — Inferred
- . - . - . - Interpreted

Faults

- + - + - Fault

Symbols

× Sample
□ FNX Grid Point
⊙ Drill Hole

rite
Diorite
ore felsic)

e

tite

60
x
252/88

x 59

15

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25

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Whistle Offset

MAP #7

Intermediate Zone

Intermediate #2 Area

UTM NAD 27, Zone 17

W.M. Carter, 2005

Notes:

LQD pods are significantly smaller in the Intermediate Zone compared to the Proximal Zone. This may be due to the present erosional surface, or it could represent the terminal extent of the LQD intrusion.

QD pods occur in the Footwall Breccia, and it is interpreted that they developed within IQD, most of which appears to have been eroded here.

© FNX-4100

24
x

Pre-Sudbury Event
Archean Rocks

Matachewan Diabase
Quartz Monzodiorite
Granite
Gabbro
Leucosome / Pegmatite
Mafic Gneiss
Intermediate Gneiss

Contacts

Observed
Inferred
Interpreted

Faults

Fault
---	-------

Symbols

Sample
FNX Grid Point
Drill Hole

0

5

10

15

metres

15

20

25

metres

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Whistle Offset

MAP #8

Intermediate Zone

Intermediate #3 Area

UTM NAD 27, Zone 17

W.M. Carter, 2005

Notes:

IQD occurs irregularly between the contact of the Footwall Breccia and the unbrecciated footwall rocks. This contact zone may have presented an easy pathway for the IQD magma to intrude along.

Small irregular pods of QD occur in the IQD. These may be the products of small convective cells which developed in the IQD and ejected or assimilated clastic material, producing inclusion-free areas of QD within the IQD.

Geology	
Post-Sudbury Event Rocks	Sudbury Olivine Diabase Dyke
	Epidote Veining
	Sulphide Veins
	Quartz Diorite
	Inclusion Quartz Diorite
	Leucocratic Quartz Diorite
	Footwall Breccia (more felsic)
	Footwall Breccia
Sudbury Event Rocks 1.85 Ga

IQD occurs irregularly between the contact of the Footwall Breccia and the unbrecciated footwall rocks. This contact zone may have presented an easy pathway for the IQD magma to intrude along.

Small irregular pods of QD occur in the IQD. These may be the products of small convective cells which developed in the IQD and ejected or assimilated clastic material, producing inclusion-free areas of QD within the IQD.

5

10

15

20

25

metres

10

15

20

25

metres

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Whistle Offset
MAP #9
Distal Zone
UTM NAD 27, Zone 17
W.M. Carter, 2005

⑥ FNX 4113

⑥ FNX 4112

Notes:

The absence of LQD in the Intermediate Zone may indicate an offset structure.

The IQD intrudes the F

The small irregular pool indicates the composition of the

The sulphide veins are irregular in size, varying in thickness and containing inclusions (clastic material)

es:

absence of LQD in this map area and the relatively small LQD pod size in the
mediate Zone may suggest that the LQD did not intrude to this distance within the
structure.

IQD intrudes the Footwall Breccia, and the contact is very irregular.

small irregular pods of QD in IQD are interpreted as preserved convection cells, as
composition of the QD and the matrix of the IQD is essentially identical.

sulphide veins are Cu-PGE-rich with chloritic alteration halos. The veins are
ular in size, varying from mm- to m-scale, following contact zones, bending around
sions (clastic material), and widening in areas that appear tensional in some cases.

irregular in size, varying
inclusions (clastic material)

Post-Sudbury Event
Rocks

Sudbury Event
Rocks
1.85 Ga

Pre-Sudbury Event
Archean Rocks

83
x

Pre-Sudbury Ev
Archean Rock

0

5

10

re-Sudbury Event
Archean Rocks

Sudbury Breccia
Matachewan Diabase
Quartz Monzodiorite
Granite
Gabbro
Leucosome / Pegmatite
Mafic Gneiss
Intermediate Gneiss

Contacts

Observed
Inferred
Interpreted

Faults

Fault
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Symbols

Sample
FNX Grid Point
Drill Hole

10

15

20

25

metres