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**Geology, Structure and Gold Mineralization within the Porcupine-Destor
Deformation Zone, Harker-Holloway Gold Camp, Southwestern Abitibi
Greenstone Belt, Canada**

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**GEOLOGY, STRUCTURE AND GOLD MINERALIZATION WITHIN THE
PORCUPINE-DESTOR DEFORMATION ZONE, HARKER-HOLLOWAY GOLD
CAMP, SOUTHWESTERN ABITIBI GREENSTONE BELT, CANADA**

By

Brian Richard Luinstra

A thesis submitted to the School of Graduate
Studies in partial fulfillment of the requirements for the degree of
Ph. D. in Earth Sciences

OTTAWA-CARLETON GEOSCIENCE CENTRE
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ABSTRACT

The Harker-Holloway gold camp is located along the Porcupine-Destor Deformation Zone in the northern portions of Harker and Holloway Townships, Ontario. The gold camp is host to two operating gold mines, the Holloway and Holt-McDermott mines as well as several minor gold showings.

The Holloway and Holt-McDermott deposits are located entirely within splays of the Porcupine-Destor Deformation Zones within meta-volcanic rocks of the Kidd-Munro and Kinojevis lithotectonic assemblages, respectively, and are separated by a narrow band of Timiskaming meta-sedimentary rocks. The rocks of the area form a steeply south dipping package within which rocks have been deformed associated with development of the Porcupine-Destor Deformation Zone. Within the Holloway mine, a polyolithic breccia folded into the volcanic stratigraphy was dated at 2686.6 ± 1.8 Ma.

Meta-volcanic rocks which host the two deposits belong to a tholeiitic suite of rocks and can be separated into four distinct groups based on litho-geochemistry. Tholeiites all have flat lying REE profiles and can be grouped into Types I, II and III based on increasing normalized REE values and are interpreted to represent a fractional crystallization trend from a tholeiitic source magma. An additional trachytic meta-volcanic unit was identified in the Holt-McDermott mine and is characterized by an enriched LREE profile and is interpreted to have formed via fractional crystallization from tholeiitic magma.

Several episodes of gold mineralization have been identified in the area. The first and most economically important gold mineralizing event (Au1) is associated with albite alteration (Ab) and pyrite mineralization (Py1). Primary gold mineralization (Au1) predates D₁ deformation, and is confined to specific stratigraphic units bounded by zones of intense S₁ foliation development. A second, volumetrically less important, gold mineralization (Au2) is located within haloes of subhorizontal quartz-carbonate veins which cross cut the S₁ foliation. Secondary mineralization is associated with a sericite+carbonate alteration (Sr) and a second generation of pyrite mineralization (Py2) and is interpreted to be a remobilization of primary gold mineralization. A third, volumetrically minor, gold mineralization event (Au3) is associated with N to NNE striking quartz veins which cross cut all other structures.

All rocks in the study area have been affected by 5 generations of structures associated with the development of the Porcupine-Destor Deformation Zone. D₁ structures include rootless isoclinal folds, a well-developed east striking and steeply south dipping S₁ foliation and a locally developed, steeply south dipping L₁ extension lineation. Deflection of marker lithological contacts, asymmetrical folding of veins and apophyses of dykes as well as pyrite pressure shadows indicate a predominantly south over north, reverse sense of shear about D₁ structures. Rootless isoclinal folds, intrafolial folding and the parallel orientations of S₀ and S₁ in the area suggest that the stratigraphy has been transposed parallel to the S₁ foliation. D₂ structures include open folds with subhorizontal axes and a S₂ crenulation cleavage developed within the hinge zones of such folds. Open F₃ folds with steeply dipping axes fold

all stratigraphy, S_1 foliation and F_2 fold axes. East striking, steeply south dipping D_4 faults are cross cut by a series of N to NNE striking, subvertical faults with consistent east side down sense of displacements.

A S_1 foliated intermineral dyke which cross cuts the primary gold mineralization (Au1) and albite alteration (Ab) was dated establishing an upper limit for primary gold mineralization in the Holloway mine of 2671.5 ± 1.9 Ma. Hematite alteration (Hm), albite alteration (Ab), primary pyrite and gold mineralization (Py1 and Au1) all predate intrusion of the intermineral dyke while sericite+carbonate alteration (Sr) as well as D_1 deformation are synchronous with or post date intrusion of the dyke. The incorporation of both hematized and albitized clasts within S_1 foliated Timiskaming assemblage conglomerates suggest that primary gold mineralization (Au1) predates deposition of Timiskaming rocks.

The Porcupine-Destor Deformation Zone is defined as an anastomosing zone of heterogeneous deformation, composed of lithons of competent rocks bounded by discrete zones of intense shear. The orientation and style of structures within the Porcupine-Destor Deformation Zone are consistent with its development on the limb of the Blake River synclinorium during a single north-south oriented compressional event.

SOMMAIRE

Le camp d'Or Harker-Holloway est situé le long de la Zone de Déformation Porcupine-Destor dans la partie nord des rangs Harker et Holloway, Ontario. Le camp d'Or abrite 2 mines d'or opérationnelles, les mines Holloway et Holt-McDermott, ainsi que quelques mines de plus petites importance.

Les dépôts Holloway et Holt-McDermott sont situés exclusivement dans des zones de déformation Porcupine-Destor respectivement à l'intérieur de roches méta-volcaniques de l'assemblage lithotectonique Kidd-Munro et Kinojévis, qui sont séparés par une bande mince de roches méta-sédimentaires Timiskaming. Des roches de cette zone correspondant à un ensemble à pendage vers le sud, à l'intérieur duquel les roches ont été déformées en association avec le développement de la Zone de Déformation Porcupine-Destor. À l'intérieur de la mine Holloway, une brèche polyolithique plissée dans la stratigraphie volcanique, a été datée à 2686.6 ± 1.8 Ma.

Les roches méta-volcaniques qui contiennent les deux dépôts, appartiennent à une suite de roches tholéiitiques, et peuvent être séparés en 4 groupes distincts, basés sur la lithogéochimie. Toutes les tholéiites qui montrent un profil plat de REE, peuvent être regroupées dans le type I, II et III, en se basant sur l'augmentation des valeurs normalisées REE, ce qui est interprété comme la représentation de la tendance de cristallisation fractionnée, à partir du magma tholéiitique source. Une unité additionnelle méta-volcanique trachytique a été identifiée dans la mine Holt-McDermott, et est caractérisée par un profil LREE enrichi. Sa formation est interprétée par cristallisation fractionnée à partir d'un magma tholéiitique.

Plusieurs épisodes de minéralisation aurifère ont été identifiés dans cette zone. Le premier, qui est le plus important économiquement (Au1), est associé à une alteration de l'albite (Ab) est une minéralisation pyritique (Py1). La minéralisation aurifère primaire (Au1) est antérieure à la déformation D_1 , sa localisation correspond à des unités stratigraphiques spécifiques boudinées par les zones de développement intense de foliation S_1 . Une seconde épisode de minéralisation aurifère (Au2), qui est volumétriquement moins important, est situé à l'intérieur de veines quartzo-carbonatées, subhorizontales, qui recourent la foliation S_1 . La minéralisation secondaire est associée à une alteration sericite+carbonate (Sr), ainsi qu'une seconde génération de minéralisation de pyrite (Py2), et est interprétée comme étant le résultat de la remobilisation de la minéralisation aurifère primaire. Un troisième épisode de minéralisation aurifère (Au3), volumétriquement mineur, est associé à des veines de quartz à plongement N-NNE, veines qui recourent toutes les autres structures.

Toutes les roches de la zone étudiée ont été affectées par 5 générations de structures, associées au développement de la Zone de Déformation Porcupine-Destor. Les structures D_1 comprennent les plis isoclinaux, une foliation bien développée de direction Est et à pendage fort vers le Sud, ainsi que localement développée une linéation d'extension L_1 , plongeante

vers le Sud. Le déflexion des marqueurs, les contacts lithologiques, les veines plissées asymétriquement, les apophyses de dykes, ainsi que les ombres de pression autour des pyrites, indiquent un sens inverse de cisaillement prédominant Sud vers Nord des structures D_1 . Les plis isolcinaux, le plissement à l'intérieur de la foliation et les orientations parallèles de S_0 et S_1 dans cette zone, suggèrent que la stratigraphie a été transposée parallèlement à la foliation S_1 .

Les structures D_2 comprennent des plis ouverts avec des axes subhorizontaux, et un clivage de crénulation S_2 développé dans le charnière de ces plis. Les plis ouverts F_3 , avec axes de plis plongeant fortement plissent toute la stratigraphie, la foliation et les axes de plis F_2 . Les failles D_4 plongeant fortement vers le Sud, de direction Est, sont coupées par une série de failles subverticales, direction N-NNE, avec sens de déplacement consistant, de la partie Est vers le bas.

Un filon folié S_1 , qui coupe la minéralisation aurifère primaire ($Au1$) et l'alteration albitique (Ab), est daté à 2671.5 ± 1.9 Ma établissant une limite supérieure pour la minéralisation primaire dans la mine Holloway. L'alteration Hematitique (Hm), l'alteration albitique (Ab), la minéralisations primaire aurifère et de pyrite ($Py1$ et $Au1$), toutes sont antérieures à l'intrusion du filon, alors que l'alteration sericite+carbonate (Sr) ainsi que la déformation D_1 sont synchrones ou postérieures à l'intrusion du filon. L'incorporation de clasts hématisés et albitisés dans l'assemblage de conglomérats Timiskaming montrant une foliation S_1 , suggère que la minéralisation primaire aurifère ($Au1$) est antérieure au dépôt de roches Timiskaming.

La Zone de Déformation Porcupine-Destor est définie comme une zone anastomosée de déformations hétérogènes, composés de litons de roches compétentes boudinés par de zones discrets d'intense cisaillement. L'orientation et le style de structures dans la Zone de Déformation Porcupine-Destor sont consistants avec son développement sur le flanc du synclinorium Blake River, pendant un événement unique, compressif, orienté nord-sud.

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For Wayne

Forever my Big Brother

CHAPTER ONE: INTRODUCTION

1.1 Introductory statement

Gold deposits have been known to be associated with major regional shear zones in the Abitibi region for half a century (Satterly, 1953; Ayer et al., 1999). In particular, many of the large deposits of the Timmins and Val D'Or gold camps are spatially related to major shear zones. Since 1981, exploration along the Porcupine-Destor Deformation Zone (PDDZ) east of Timmins, one such regional shear zone, has led to the opening of two new mines, thereby sparking renewed interest in this area.

During the course of the study, the Holloway Mine was 87.5% owned and operated by Battle Mountain Canada Ltd. (BMC), a subsidiary of Battle Mountain Gold Ltd., now a subsidiary of Nemwont Gold Inc., and the Holt-McDermott Mine, owned and operated by American Barrick Gold Corporation (BGC) are both located near to the PDDZ. These two mines were selected for this study to determine the relationships of sometimes unpredictable and discontinuous zones of mineralization with the PDDZ and associated structures. Additionally, location of these two mines within deformed rocks adjacent to the PDDZ provides an unique opportunity to study the geology within underground workings in an area with very little surface exposure.

The project was a part of a collaborative research program involving BMC, BGC, the Ontario Geological Survey (OGS) and the University of Ottawa (UO), and was undertaken

concurrently with lithogeochemical investigations of the area by Nattress (1999), Ropchan (2000) and Jones (2001). BMC and the OGS provided funding and logistical support, including field assistants provided by the OGS. BMC and BGC provided full access to both underground workings and drill core, allowing for an extensive and detailed analysis of the geology and the structure of the two properties.

1.2 Location and access

The Holloway and Holt-McDermott mines are located 500 meters north and 500 meters south, respectively, of Ontario highway 101, 60 kilometers east of Matheson and 15 kilometers west of the Ontario-Quebec border (Fig. 1). Access to the mine sites are from a gravel road that runs between them and crosses Highway 101. Several additional roads provide access to the mine properties, including the “Ontario Provincial Police Tower Road” (local name) which runs from Highway 101 north for 2 km, near the Holloway-Harker Townships boundary. As well, an old tractor road that runs to the historic Seagar’s Hill claims, west of the Holloway mine, curves around the north edge of the mine property. Several roads extend south from the Holt-McDermott mine to the tailings pile. Additional roads on the mine sites provide access to outcrops and trenches.

Underground investigation was restricted to areas of recent or active development due to safety considerations. During the summer of 1997, the western portion of the Holloway

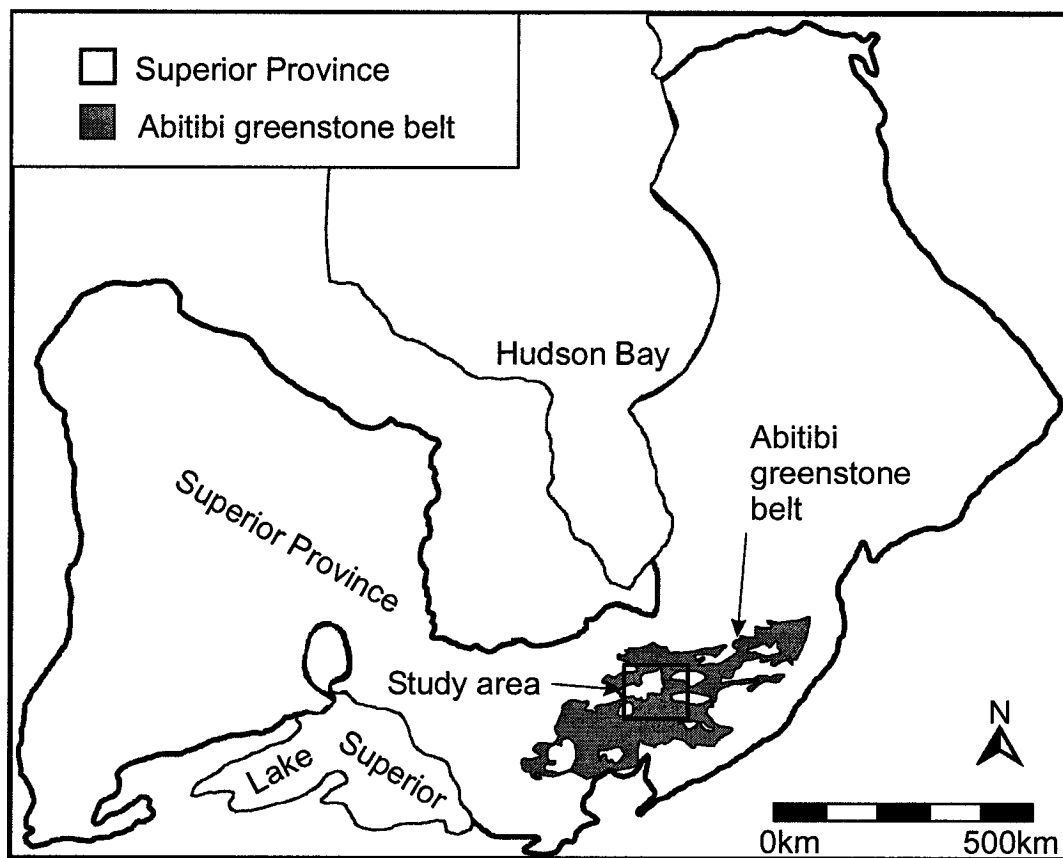


Figure 1. Location of the Abitibi greenstone belt within the Superior Province. Study area shown.

deposit between the 415 and 520-meter levels was actively being mined, and most mapping was confined to that area. The eastern portion of the Holloway deposit was available for study between the 505 and 650-meter levels during the summer of 1998. At the Holt-McDermott deposit, main accesses between the 550 and 1160-meter levels were mapped during the summer of 1999, as well as active sublevels between the 680 and 730-meter levels.

1.3 Outline of thesis

This thesis will begin by introducing the goals of the study including the specific problems outlined upon commencement of the study (Chapter 2). A brief overview of the tectonic setting in which the mines are located will be provided as background for discussing these problems (Chapter 3). Subsequently, I will discuss the methods used to resolve these problems and how the data are presented (Chapter 4). Each mine will be dealt with in turn, beginning with the Holloway mine (Chapter 5), in which most mapping was conducted. Analysis of the Holloway Mine provides a detailed overview of the lithologies, alteration, mineralization and structural geology of the area. The background provided by that investigation will be built upon in a description of the Holt-McDermott mine (Chapter 6). The data will then be analyzed by comparing the two mines with the available data from the literature, and synthesized into a model for gold mineralization.

CHAPTER TWO: GOALS OF THE WORK

2.1 Tectonic interpretation of the PDDZ

The PDDZ is an integral element in the understanding of the tectonic history of the Abitibi greenstone belt. Surprisingly little detailed work has been done on the PDDZ, especially from a structural point of view, compared to gold deposits in the Timmins area (cf. Hodgson, 1983) and the Duparquet area (Mueller et al., 1994). The Holloway and Holt-McDermott mines provide a unique opportunity for three-dimensional access to the PDDZ in this area of poor outcrop exposure. A detailed and systematic investigation of the structures and kinematics associated with the PDDZ can contribute to tests of several of the tectonic models for the Abitibi greenstone belt. This study undertakes to delineate the extent of deformation associated with the PDDZ, describing the structures associated with it and thereby helping to define its makeup. This effort should allow a refinement of our understanding of the role of the PDDZ in the tectonic evolution of the Abitibi region given that the PDDZ occupies a critical place in most regional tectonic models.

2.2 Structural controls on gold mineralization

Structural controls on gold mineralization have been recognized across the Abitibi region (Robert, 1997). However, the exact nature of the structural control is poorly understood for many individual deposits. This study defines the major structures that control, in part, the

location, distribution and geometry of ore zones in the study area. In addition, the different alteration and mineralization styles are identified. Determining the relative timing of alteration and mineralization with respect to each other and to the major structures helps to define and understand the controls on the geometry, location and distribution of mineralized zones. This information should contribute to a predictive model for gold mineralization in the area, which would be useful for further exploration along the PDDZ.

2.3 Timing of gold introduction and deposit formation

A significant debate over the timing of gold introduction and deposit formation in the Abitibi greenstone belt is ongoing. The concentration of gold deposits along major regional shear zones (i.e. the PDDZ) and the similarities in the gold mineralization styles in many camps led to a model of a single, subprovince-wide gold mineralization event (cf. Corfu 1993 and references therein). Subsequently, further examinations of individual gold deposits have recognized different phases of gold mineralization within the Abitibi (Wyman et al., 1999 and references therein). Based on the timing relationships of alteration, mineralization and deformation events and geochronological analysis, the present research will establish an absolute age bracket for the mineralizing events in the Holloway and Holt-McDermott mines, thereby contributing to the database pertinent to the origin of gold deposits in the Abitibi as a whole.

CHAPTER THREE: TECTONIC SETTING, GEOLOGY AND MINERALIZATION

3.1 Geology of the Abitibi

The Abitibi greenstone belt is situated within the southeastern portion of the Archean Superior Province of Canada's Precambrian Shield (Fig. 1). The low metamorphic grades (outside of the contact aureoles of granitoid plutons and batholiths), the good preservation of the (predominantly) volcanic rocks, and the abundant mineral resources of the region have attracted worldwide interest, especially amongst volcanologists and economic geologists. This section is intended to provide the reader with a brief overview of the present state of knowledge on the Abitibi. This includes a specific look at the place of the PDDZ within the models of formation of the Abitibi. The metamorphism in the belt and the debate surrounding gold mineralization are also discussed. The usage of the prefix "meta" for all rocks will not be employed with the understanding that all rocks have undergone metamorphism.

Until the early 1980s, the geology of the Abitibi greenstone belt is most often described as a stratigraphic sequence of volcanic events. Early workers noted a number of (concomitant) volcanic cycles progressing from komatiitic and tholeiitic volcanic rocks to more fractionated calc-alkalic and alkalic volcanic rocks (Goodwin, 1977; Dimroth et al., 1982, 1983a; Jensen and Langford, 1985). This sequence of volcanic rocks is thought to have been folded in a regional deformation event and subsequently intruded by calc-alkalic intrusions. The rocks

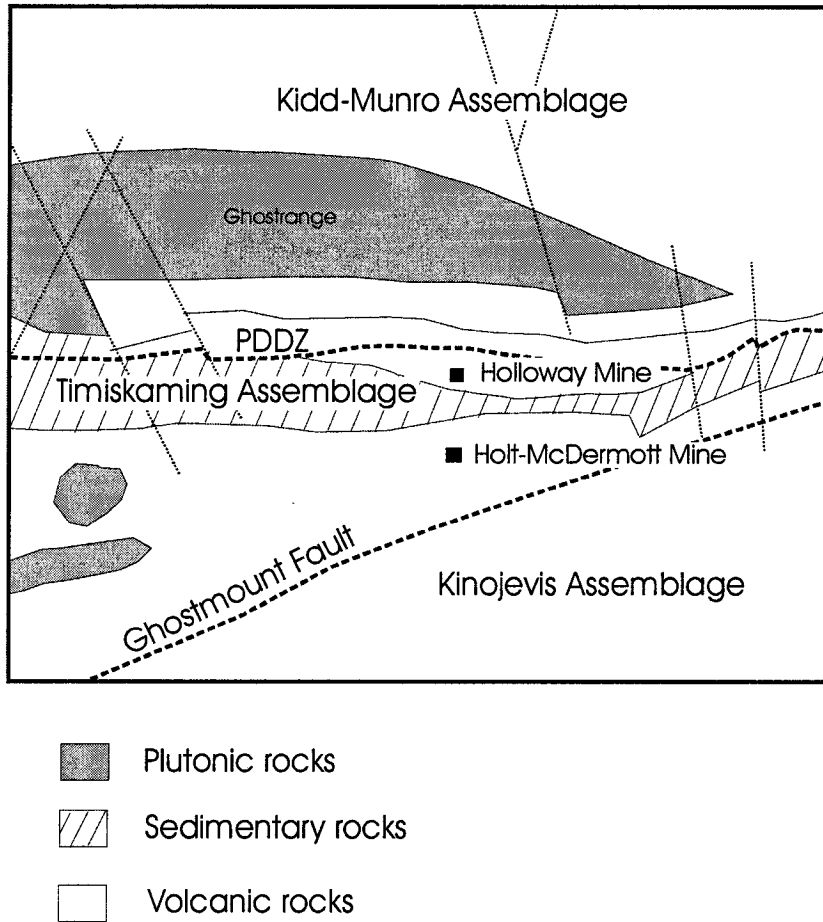


Figure 2. Simplified geology map of the Abitibi greenstone belt in the study area showing major lithotectonic assemblages and structures in the area, after Ayer et al. (1999).

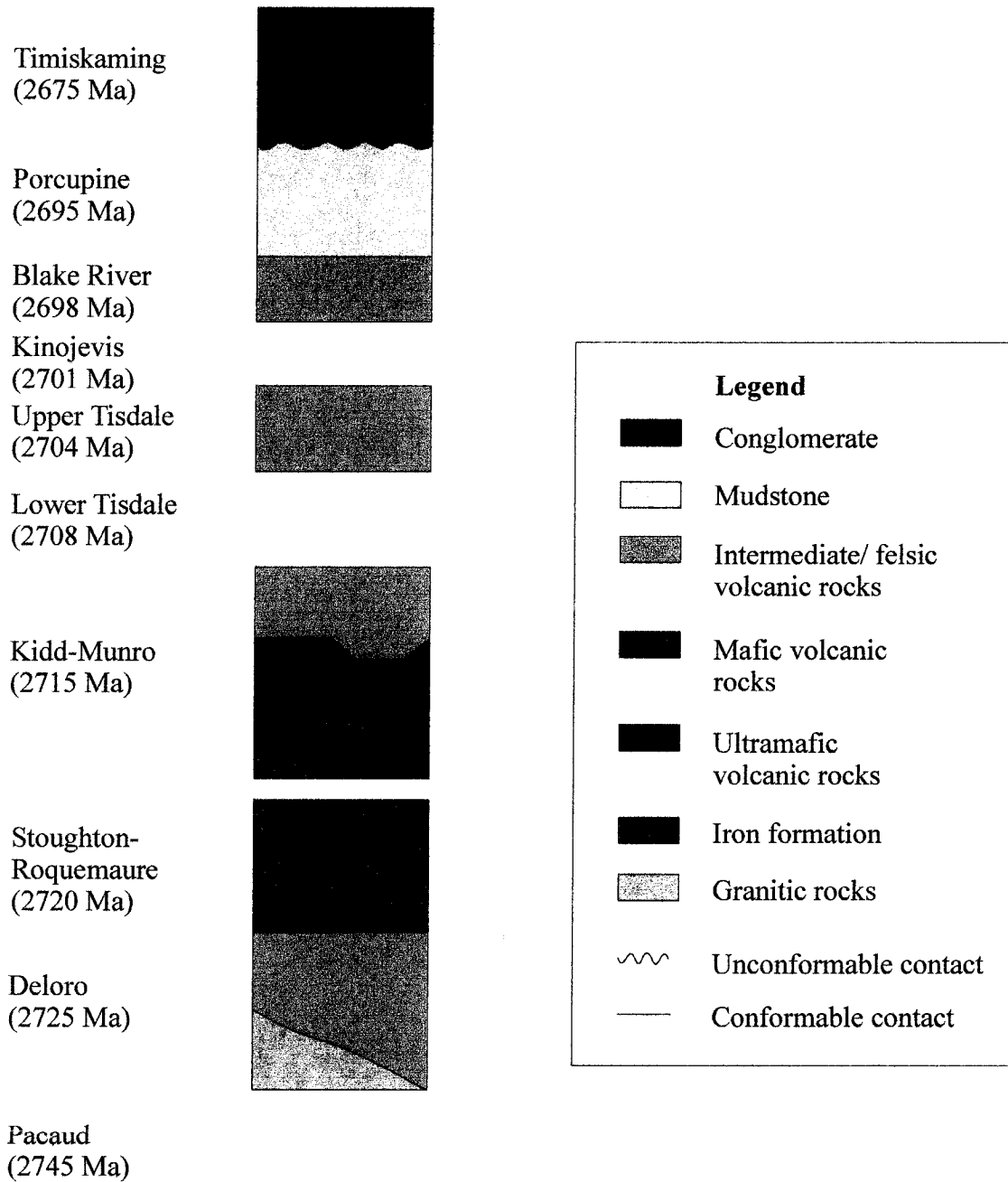


Figure 3. Generalized Stratigraphy of the North Section of the Ontario Portion of the Abitibi greenstone belt from Ayer et al. (1999).

are unconformably overlain by a sequence of sedimentary rocks (Thurston and Chivers, 1990). Contacts between different volcanic suites were poorly understood, with some appearing to be depositional in nature and others appearing to be tectonic. In order to simplify this debate, the concept of lithotectonic assemblages was developed.

Lithotectonic assemblages are groups of rocks deposited in similar tectonic environments and separated from each other either by major faults or by unconformities (Jackson et al., 1994). Utilizing this approach, major assemblages were separated and analyzed within the context of a single stratigraphy, defined with the help of geochronological data without invoking a particular model for the formation of the Abitibi (Jackson et al., 1994). These lithotectonic assemblages will be briefly introduced for the reader in geochronological sequence, from the oldest to youngest, in order to provide a background to discuss the major models for formation of the Abitibi. Due to the large number of researchers working in the Abitibi and the apparent lack of consensus among them, different names have been applied to rocks of the same assemblage. For further discussion of the lithotectonic assemblages of the Abitibi, readers are directed to Ayer et al. (1999). Figure 1 is a simplified regional geology map showing the location of the study area within the Abitibi. Figure 2 shows a more detailed map of the geology of the study area as well as the location of the Holloway and Holt-McDermott mines. . Important lithotectonic assemblages in the immediate vicinity of the study area are discussed in the following sections. Figure 3 provides a generalized stratigraphy of the Abitibi that shows stratigraphic positions and contact relationships of these lithotectonic assemblages within the regional stratigraphy.

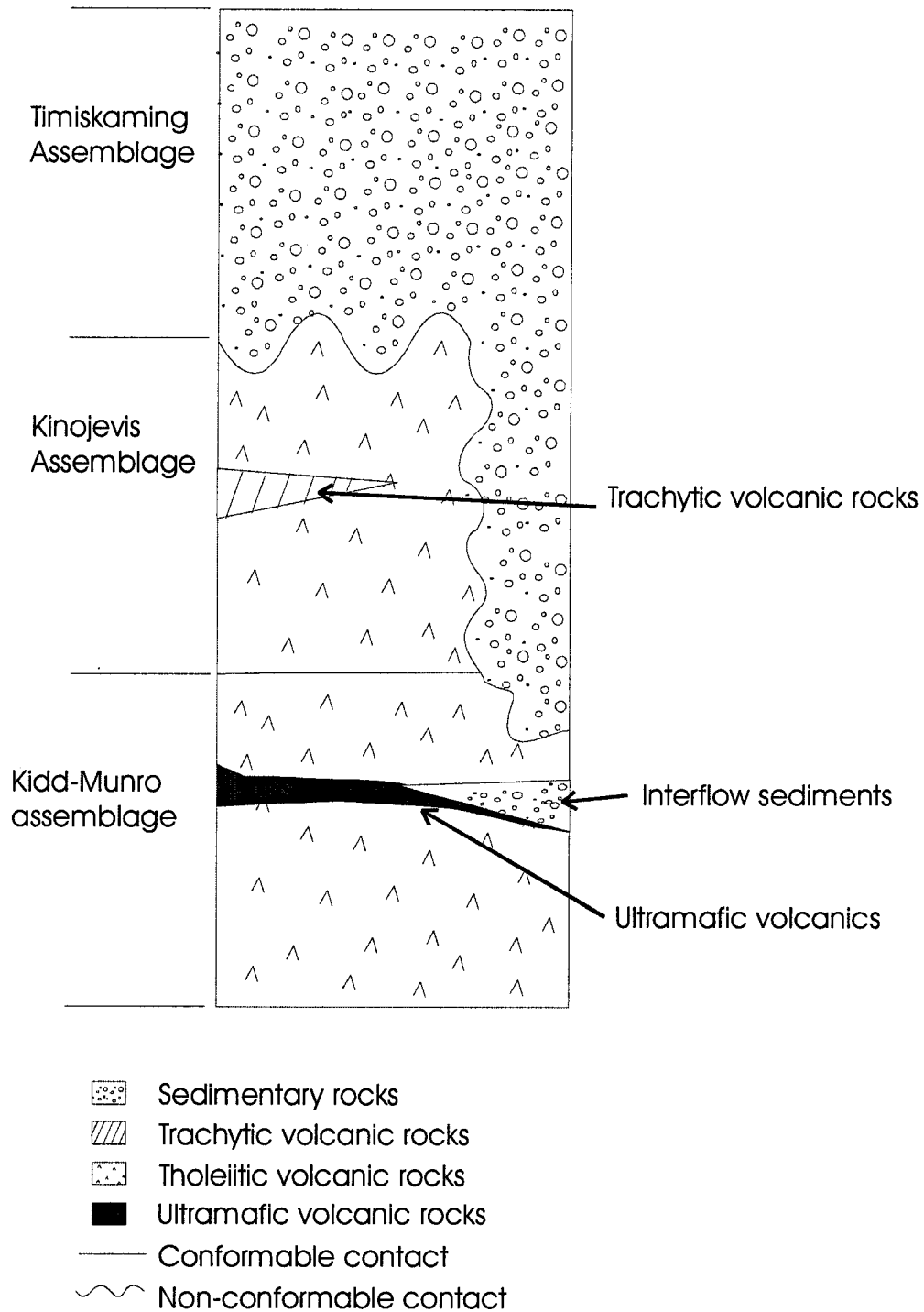


Figure 4. Composite stratigraphic column of the study area.

3.1.1. Kidd-Munro assemblage

The oldest assemblage in the area is the Kidd-Munro Assemblage. In the Ontario portion of the Abitibi greenstone belt, rocks of the Kidd-Munro assemblage were previously identified as the Hunter Mine Assemblage (Corfu, 1993; Ayer et al., 1999). Hunter Mine group rocks were originally suggested to host the Holloway deposit (Guy, 1996). This part of the Kidd-Munro assemblage is composed of a sequence of calc-alkalic volcanic rocks and volcanoclastic tuffs capped by a distinct banded iron formation (Figure 3; Ayer et al., 1999).

To the west the Kidd-Munro Assemblage is composed of komatiitic and tholeiitic volcanic rocks with minor intercalations of felsic pyroclastic tuffs as well as rhyolitic volcanic rocks (Figure 3; Ayer et al., 1999). Kidd-Munro rocks have been dated between 2719 and 2712 Ma (Corfu, 1993; Bleeker and Parrish, 1996; Ayer et al., 1999). Originally thought to be restricted to a small area between Kidd and Munro townships (Jackson and Fyon, 1991), the assemblage has been extended from the Swayze greenstone belt in the west (Heather et al., 1996) to the Quebec border in the east (Berger and Amelin, 1998). One unit of particular interest is a variolitic, pillowed tholeiite that serves as a marker unit and can be traced from east of Timmins to the Quebec border (Berger and Amelin, 1998). Similar rocks that have poorly defined contacts with the Kidd-Munro assemblage and that share similar tectonic settings include the underlying Stoughton-Roquemaure assemblage composed of mafic

tholeiites and ultramafic komatiites interpreted to be the result of mantle plume activity (Dostal and Mueller, 1997).

3.1.2 Kinojevis assemblage

The Kinojevis assemblage is comprised of a monotonous succession of pillowed, massive and brecciated tholeiitic rocks. These units have been folded as part of the Blake River synclinorium to a steeply south dipping and east-west striking orientation in the study area. The rocks likely form a continuous succession with the overlying calc-alkaline Blake River assemblage, recording a transition from deep marine to arc-related volcanism. The Kinojevis assemblage has been dated at 2701 ± 1 Ma (Berger and Amelin, 1998).

3.1.3 Porcupine assemblage

The Porcupine assemblage is comprised of intercalated greywackes and shales. The rocks have been interpreted to represent a continental shelf environment, dominated by turbidite derived sedimentary rocks (Born, 1995). They are conformable with the underlying Blake River assemblage and have been dated ca. 2695 Ma (Ayer et al., 1999). Born (1995) interpreted them to be a deep-water portion of the Timiskaming group; however, an angular unconformity, which has been identified in the Timmins area (Brisbin, 1997), between the two assemblages require that they were formed in temporally discrete events (Brisbin, 1997; Ayer et al., 1999). Greywackes and shales identified in this study (Section 5.5.4, 6.4.2 and

6.4.3), formerly considered to be Porcupine assemblage rocks (Guy, 1996), are now correlated with younger Timiskaming assemblage rocks based on clast composition and new geochronological data from Ayer et al. (1999).

3.1.4 Timiskaming assemblage

The Timiskaming assemblage is composed of polymictic conglomerates, sandstones and turbiditic greywackes that conformably overly volcanic rocks of the Kinojevis and Blake River assemblages and sedimentary rocks of the Porcupine assemblage. The Timiskaming assemblage crops out within restricted regions that are interpreted as former depositional basins spatially related to regional shear zones (Thurston and Chivers, 1990; Mueller et al., 1994). Red jasper and alkali feldspar clasts are considered to be diagnostic features of Timiskaming assemblage sedimentary rocks (Hyde, 1980). This assemblage has been interpreted, based on primary structures such as intercalated sand and gravel dominated layers, to be alluvial-fluvial sediments deposited in fault bounded pull-apart basins in association with alkalic intrusive and extrusive igneous rocks. (Hyde, 1980; Thurston and Chivers, 1990; Mueller et al., 1994; Ayer et al., 1999). Detrital zircons from Timiskaming assemblage rocks give apparent maximum depositional ages from 2687 to 2675 Ma (Corfu, 1993; Ayer et al., 1999).

3.2 Metamorphism

The metamorphic grade throughout the Abitibi is greenschist to sub-greenschist grade, with amphibolite grade rocks encountered only in proximity to large plutons (Jolly, 1978; Powell et al., 1993). In the southern Abitibi, Powell et al. (1993) found peak regional metamorphic conditions between 250 to 270 ° C and 2- 2.5 kbar, corresponding to a depth of 7 to 8 kilometers and occurred ca. 2660 – 2640 Ma. It is important to recognize that this conflicts with the interpreted stratigraphy of the Abitibi, which requires volcanic piles of ~ 35-40 kilometers in thickness (Dimroth et al., 1982; Heather et al., 1996; Ayer et al., 1999). Powell et al. (1993) also suggested that regional metamorphic isograds are subhorizontal and cross-cut stratigraphy. Therefore, peak metamorphism would post-date tilting of the stratigraphy. Peak hydrothermal metamorphism has been dated by Wong et al. (1991) to be 2684 ± 7 Ma based on U-Pb analysis of the metamorphic mineral monazite from haloes around syntectonic carbonate veins which cross-cut tholeiitic rocks. This is consistent with observations made by Powell et al. (1993) that peak metamorphism largely postdates deposition of the major volcanic units which comprise the Abitibi (between 2750 and 2700 Ma) and maximum depositional ages acquired from detrital zircons from Timiskaming assemblage sedimentary rocks. Subhorizontal regional isograds may have been displaced by vertical components of displacement on regional shear zones such as the Cadillac-Larder Lake Deformation Zone (CLLDZ) and the PDDZ. However, Powell et al. (1993) found a maximum of 1 kilometer of post-regional metamorphic reverse, south side up movement was plausible given metamorphic gradients across the CLLDZ in the southern Abitibi. Powell et al. (1993) also

suggest that any movement within major regional shear zones would have been penecontemporaneous with peak metamorphic conditions, based on pressure solution cleavages and carbonate minerals found within the deformation zones.

3.3 Tectonic models for the development of the Abitibi

Early workers in Archean cratons disputed the existence of plate tectonic processes as they exist on modern Earth (Kroner, 1981; Anhaeusser, 1981). They suggested that the high Archean heat flow in the mantle would have led to decreased density of mantle plumes which would not produce the asthenospheric 'conveyor belt' system thought to be operating today. The lack of the asthenospheric conveyor belt accompanied by the lack of density contrasts between modern oceanic plates thought to be necessary to drive plate tectonics, was used to rule out the viability of modern style plate tectonic processes for the formation of Archean greenstone belts (Goodwin, 1977; Kroner, 1981; Anhaeusser, 1981).

Goodwin (1977) proposed a layered crust model for Archean cratons in which the crust is divided into supracrustal rocks deposited lying on top of middle crustal 'ensimatic' tonalities, in turn overlying migmatitic lower crust. Goodwin (1977) postulated that supracrustal greenstone belts such as the Abitibi were deposited within rift basins in tonalitic crust. This model failed to explain the fractionation trend of rocks within the Abitibi, which requires some anatexis of pre-existing rocks, and requires a thick volcanic pile, which contradicts observations made by Powell et al. (1993) that regional metamorphic isograds cross cut

stratigraphic contacts. Additionally, geochronological investigations of the Abitibi by Corfu (1993) noted a lack of inherited zircons in supracrustal rocks suggesting that they were not extruded through underlying ensimatic crust. However, new ages produced by Heather et al. (1996) and Ayer et al. (1999) show that there are significant amounts of inherited zircons in supracrustal rocks which supports the layered crust model proposed by Goodwin (1977).

Several models involving 'vertical tectonics' were developed in order to explain the progressive fractionation of volcanic rocks in the Abitibi. Goodwin (1981) invoked a model of 'sagduction', in which volcanic edifices were built upon ensimatic crust and sank due to the higher density of volcanic rocks overlying less dense, ensimatic crust which may have been anomalously hot due to a modified Archean mantle heat flow. As the edifices sank, they were progressively recycled and more fractionated rocks were extruded, and diapirs first of Na-rich and subsequently K-rich granitoids were emplaced in the upper crust (Goodwin, 1981; Anhaeusser, 1981). Kroner (1981) suggested that Archean crust was formed by vertical accretion of volcanic rocks between closely spaced mantle plumes.

The 'vertical tectonic' models are largely conjectural and cannot be tested by comparison to modern analogues, as these mechanisms are not known on modern earth. However, large volcanic piles with stratigraphic thickness of 30 kilometers required by these models should exhibit higher metamorphic grades at their base than is observed in the greenschist to sub-greenschist facies Abitibi greenstone belt (Powell et al., 1993; Ayer et al., 1999).

Metamorphism in the Abitibi post-dates volcanic accumulation and deformation (Powell et al., 1993).

Windley (1981) first proposed a plate tectonic model for the Abitibi. He suggested that a fast-moving plate tectonic system would result in rapid production and destruction of oceanic lithosphere, in the form of numerous small plates. These small plates would collide in numerous small subduction zones, accreting oceanic lithosphere in rifted marginal basins as proto-ophiolites.

Dimroth et al. (1982; 1983 a,b) were the first workers to apply the plate tectonic paradigm to the Abitibi subprovince based on extensive fieldwork. They proposed that the Abitibi greenstone belt was formed when a magmatic arc was built from subducted tholeiitic and komatiitic oceanic lithosphere within a south-dipping subduction zone. The island arc was subsequently shortened in a north-south compressional event that led to production of granitic material derived from partial melting of subducting oceanic lithosphere. Termination of subduction was temporally associated with the rise of the late tectonic batholiths. This model adequately explains the general younging to the south of plutonic rocks in the Abitibi and the low metamorphic grades observed. However, the lack of a recognized accretionary wedge and the apparent presence of conformable contacts between major lithotectonic assemblages suggest that the rocks of the Abitibi were deposited in a normal stratigraphic sequence (Heather et al., 1996; Ayer et al., 1999).

Jensen and Langford (1985) invoked a stratigraphic or 'fixist' model for formation of the Abitibi. In this model, large synclinoria, such as the Blake River synclinorium, formed by subsidence of large volcanic piles. Thus, the stratigraphy of the Abitibi would consist of a relatively continuous sequence of volcanic rocks. The CLLDZ and the PDDZ were considered to be syn-volcanic normal faults on the limbs of these large synclinoria. (i.e Blake River syncline). Later reactivation of the faults accommodated a relatively minor north-south compressional event associated with the 'Kenoran' orogeny. Jensen and Langford (1985) suggested that progressive anatexis of underlying rocks due to 'sagduction' would produce volcanic sequences of the thickness observed in the Abitibi. This model requires that rocks be folded as they subside into the sagging edifice during extrusion of the volcanic pile, contrary to field observations (Powell et al., 1993) that indicate that metamorphism associated with folding and deformation in the area post date deposition of volcanic rocks.

Ludden et al. (1986) divided the Abitibi greenstone belt into an emergent Northern Volcanic Zone (NVZ) and a submergent Southern Volcanic Zone (SVZ). The NVZ was interpreted as a volcanic arc, which formed above a south dipping subduction zone. The SVZ was defined as a series of komatiitic and tholeiitic oceanic plateaus and bimodal volcanic centers deposited within rifted basins on the NVZ. The authors inferred a south dipping subduction zone, as proposed by Dimroth et al. (1983b). This model attempted to explain the apparent 30 kilometer thick sequence of volcanic rocks by envisaging deposition within a number of rift basins, thereby restricting SVZ volcanic piles to 5 to 8 km. However, this model fails to adequately explain the conformable stratigraphy and observations by Heather et al. (1996)

and Ayer et al. (1999) that demonstrates the importance of inherited zircons in rocks of the Abitibi.

Thurston and Chivers (1990) interpreted greenstone belts of the Superior Province to represent komatiitic and tholeiitic oceanic crust upon which calc-alkalic arc sequences were extruded from central volcanic edifices. Arcs were subsequently accreted through multiple plate collisions and denudated by pull-apart basins formed along dextral-oblique strike-slip faults within the arcs.

Williams (1990) suggested that greenstone belts of the Superior Province were formed by accretion of arcs and fore-arc basins, based on the repetition of sedimentary and volcanic belts. Corfu (1993) recognized older-over-younger sequences, which were interpreted to be the result of overthrusting during accretion of numerous allochthonous terranes.

Chown et al. (1992) and Mueller et al. (1994; 1997) proposed a terrane docking (accretionary) model for the Abitibi, based largely on the stratigraphy proposed by Dimroth et al. (1982; 1983a) and the facies associations of the Duparquet and Kirkland Lake sedimentary basins. These authors developed a four-stage model for development of the Abitibi. *Ca.* 2730-2720 Ma massive volcanism accompanied arc formation was followed by collision of northern (NVZ) and southern arcs (SVZ, c.f Ludden et al., 1986) around 2697-2690 Ma. This would correspond to the 'docking' of the Zones NVZ and SVZ along the PDDZ. The arcs would have been subsequently fragmented by transcurrent shear zones

which coincided with Timiskaming assemblage sedimentation between 2689 and 2680 Ma. The final stage of this model involves uplift and extension between 2660 and 2640 Ma.

Kimura et al. (1993) also proposed a plate tectonic model for the Abitibi. They suggested that the Abitibi represents the accretion of oceanic crust and the resultant step-back of north dipping subduction. As subduction migrated southward, recycling and partial melting of oceanic crust led to calc-alkalic magmatism through overriding komatiitic and tholeiitic crust, as interpreted in the Malartic block in Quebec (Desrochers et al., 1993). Subduction of a spreading center led to the onset of transpression through the belt. Desrochers et al. (1993) suggested that calc-alkalic volcanism was triggered by extension related to termination of subduction due to ridge collision. Models proposed by Ludden et al., (1986), Chown et al. (1992), Kimura et al., (1993), Desrochers et al. (1993) and Mueller et al. (1994; 1997) fail if extended into Ontario where assemblages can be correlated across the PDDZ (Jensen and Langford, 1985; Brisbin, 1997; Ayer et al., 1999). In addition, the lack of an identifiable accretionary wedge anywhere in the Abitibi is problematic.

Interpretations of deep-crustal seismic-reflection data obtained through the LITHOPROBE project were also proposed in support of accretionary plate tectonic models for the Abitibi (Jackson et al., 1994). Jackson et al. (1994) interpreted shallow north dipping reflectors as paleo-subduction zones. They suggested that the Abitibi formed as a number of small microplates above numerous subduction zones that were amalgamated once modern style tectonic processes commenced. Jackson and Cruden (1995) suggested that these oceanic

terrane were accreted coincident with arc-trench migration to the south and mid-crustal magmatism.

Dostal and Mueller (1996) adopted a plate tectonic model by introducing evidence for plume related volcanism during subduction. The authors suggested that plume-associated komatiitic and tholeiitic rocks of the Stoughton-Roquemaure Group overly folded calc-alkalic rocks. They interpreted this as a plume underlying an arc sequence during accretion of the NVZ and SVZ, with the PDDZ representing a terrane boundary. This model can be disputed based on the lack of a well-defined accretionary wedge and the apparent conformable contacts between major lithotectonic assemblages determined from both field and geochronological evidence (Ayer et al., 1999).

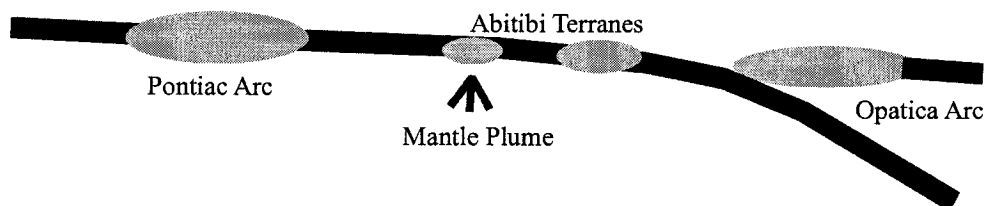
New information obtained from the Swayze greenstone belt, now considered to be the western continuation of the Abitibi greenstone belt (Heather et al., 1996; Ayer et al., 1999), defines a continuous stratigraphy (Figure 3). Geochronological evidence shows that volcanic rocks have inherited zircons from underlying crust and were deposited directly on top of underlying units (Ayer et al., 1999). These findings led to a new, Abitibi-wide study initiated by Ayer et al. (1999) utilizing and expanding upon existing geochronological data. The existence of older, inherited zircons in younger volcanic and plutonic rocks suggests that younger assemblages were emplaced directly on top of older assemblages. These 'convoluted layer cake' models (Heather et al., 1996) still fail to explain the low metamorphic grades within the Abitibi region.

Calvert and Ludden (1999) reviewed available data, including interpretation of deep-crustal seismic-reflection data and available geochronology in terms of an accretionary model. They interpreted shallow north dipping crustal reflectors as products of underthrusting and accretion, with interaction of a mantle plume. They suggested that a large horizontal reflector at approximately 10 kilometer depth below the Abitibi is a basal decollement above which supracrustal rocks of the Abitibi were emplaced onto older crust. Figure 6 shows a composite sketch from Calvert and Ludden (1999) which illustrates the formation of arc and oceanic plateau sequences (figure 6 – I), followed by accretion of the NVZ and SVZ and the Opatica and Pontiac Subprovinces (Figure 6 – II), followed by terminal collision (Figure 6 – III) and final extension and uplift of the Abitibi (Figure 6 – IV).

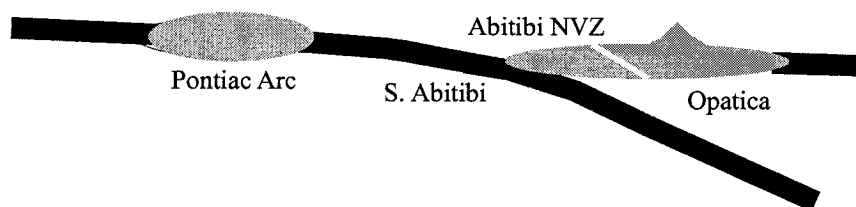
In summary, neither fixist/stratigraphic nor accretionary/dynamic models can adequately account for all of the data that are available for the Abitibi. Fixist models contradict observations on the low-grade regional metamorphism of the Abitibi; they require a volcanic pile 30 kilometers thick, which should lead to significantly higher metamorphic grades than exist, and to concordant metamorphic isograds. They also require some form of syn-volcanic folding of rocks, whereas all documented folding has been shown to post-date magmatism.

Accretionary models cannot explain observations in the Ontario portion of the Abitibi where lithologies can be traced across the PDDZ, a proposed terrane boundary (Jensen and Langford, 1985; Brisbin 1997; Ayer et al., 1999). In addition, the lack of a definitive

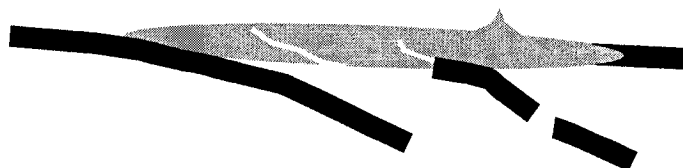
I. Arc and Oceanic Plateau Formation



II. Terrane Accretion and Opatica Orogen



III. Terminal Collision



IV. Extension and Subsequent Lower Crustal Modification

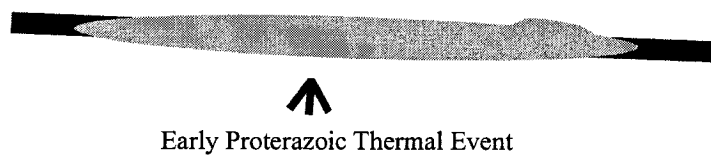


Figure 5. Diagram Illustrating the accretion of terranes during formation of the Abitibi greenstone belt, from Calvert and Ludden (1999).

accretionary wedge, the inheritance of zircons from older units and the observed conformable relationships between volcanic assemblages suggest that they were deposited on top of older units, contradictory to proposed plate tectonic models.

3.4 The Porcupine Destor Deformation Zone (PDDZ)

It is safe to assume that major regional shear zones such as the PDDZ and the Cadillac-Larder Lake Deformation Zone (CLLDZ), which can be traced for hundreds of kilometers, have played an integral role in the tectonic history of the Abitibi greenstone belt. A major focus of this study is to document features of the PDDZ in the study area in order for it to be better integrated into the regional tectonic framework. In the Abitibi, regional shear zones are elongate regions of heterogeneous deformation, with discrete zones of intense deformation surrounding larger lithons of relatively undeformed rocks (Dimroth et al., 1982; 1983a,b; Jensen and Langford, 1985; Smith et al., 1993; Wilkinson et al., 1999). The regional shear zones are commonly located on, or near to, the limbs of synclinoria and are spatially associated with Timiskaming assemblage sedimentary rocks and alkaline igneous rocks (Jensen and Langford, 1985; Thurston and Chivers, 1990; Mueller et al., 1994). Deep-seismic reflection data have been interpreted to suggest that the shear zones extend deep into the crust, 10 kilometers or more (Jackson et al., 1994).

In the fixist model proposed by Jensen and Langford (1985), the PDDZ and CLLDZ were master normal faults on the limbs of subsidence ('sagduction') related synclinoria. Several

models consider the major regional shear zones such as the PDDZ to be extensional normal faults forming the boundaries of a rift basin within which parts of the greenstone belts were deposited (Goodwin, 1977, 1981; Windley, 1977; Hodgson, 1983; Ludden et al., 1986).

Within plate tectonic models put forward by Chown et al. (1992), Kimura et al. (1993), Jackson et al. (1994), Mueller et al. (1994, 1997), and Calvert and Ludden (1999), the PDDZ is a suture along which two allochthonous terranes (the NVZ and SVZ) were juxtaposed or 'docked'. However, in the Timmins area rocks have been correlated across the PDDZ, excluding the possibility that it represents a suture, at least in the Timmins camp.

Neo-fixist models proposed by Heather et al. (1996) and Ayer et al. (1999) suggest that regional deformation zones accommodated predominantly normal fault movements as early as 2725 Ma, and were subsequently involved in strike-slip movements coincident with Timiskaming sedimentation, followed by reverse movement.

Clearly, at present there is no consensus on the role of the PDDZ within the regional tectonic framework. However, the regional deformation zones are fundamental features that may have multiphase kinematic histories. A surprisingly small amount of work has been completed on the PDDZ, considering its economic and tectonic significance.

3.5 Gold mineralization in the Abitibi greenstone belt

A long history of exploitation of gold within the Abitibi greenstone belt has made it a center for debates on the origin of gold mineralization within Archean cratons. The two primary debates concern the timing of gold deposition and the origin of gold mineralizing fluids. This section will provide an overview of the major types of gold deposits that have been identified in the Abitibi.

Four major types of gold deposits have been identified in the Abitibi. Robert and Poulsen (1997) identified three major types and a fourth has been identified by Berger and Amelin (1998). In order of the timing of formation, these deposits are: syn-volcanic and syn-sedimentary deposits; syenite associated deposits, syntectonic mesothermal vein deposits and remobilized post-tectonic vein deposits.

Early syn-volcanic deposits include the VMS related gold deposits with ocean floor alteration and replacement facies, and are typified by the Horne Deposit in Rouyn-Noranda, Quebec (Robert and Poulsen, 1997). At least one phase of gold deposition in the Aunor and Dome deposits of the Timmins camp is thought to be synsedimentary (Fryer et al., 1978).

Syntectonic syenitic plutons intruded near regional-scale shear zones became the focus of exploration and research due to their close spatial relationships with some gold deposits. Robert (1997) and Robert and Poulsen (1997) proposed a model in which fluids derived from

the plutons are the source for mineralizing fluids. Numerous examples of this type of deposit can be found in the Abitibi, including at least one phase of mineralization at the Aunor and Dome deposits, in the Timmins camp (Fryer et al., 1978), as well as deposits associated with the Bourlamaque pluton of the Val D'Or district, Quebec (Claoué-Long et al., 1990), the Kienna mine of the Val D'Or district (Morasse et al., 1995), the Kerr-Addison deposit in the Kirkland Lake district (Smith et al., 1993), the Hollinger-McIntyre deposit in Timmins (Burrows et al., 1986), as well as the Holt McDermott deposit (Robert, 1997) and the Holloway deposit (Guy 1996; Robert 1997).

Mesothermal syntectonic vein deposits are associated with carbonate + albite + tourmaline veins which cross-cut the regional foliation. The deposits are thought to have developed syntectonically, based on structural relationships, with deep crustal fluids that used active shear zones as conduits contemporaneous with orogenesis and peak metamorphism (Groves et al., 1987; Eisenlohr et al., 1989). Examples of such deposits include the Camflo mine in Kirkland Lake (Jemielitta et al., 1990; Corfu, 1993) and the Sigma mine in the Val D'Or district (Robert and Brown, 1984; Wong et al., 1991).

A fourth and less common type of deposit occurs in quartz veins with north-south strikes and steep dips, and are thought to be due to a remobilization of gold-bearing fluids along north-south fractures (Eisenlohr, 1989; Berger and Amelin, 1998). These deposits cross cut regional foliation and are interpreted to have formed contemporaneous with the Kapuskasing

structural zone located on the western boundary of the Abitibi greenstone belt (Berger and Amelin, 1998).

CHAPTER FOUR: METHODS

4.1 Field Mapping

Geological mapping was the primary source of data for the present study. Surface and underground mapping were completed over the summers of 1997-2000. During the first two field seasons mapping was focused within Holloway mine, as well as outcrop in the vicinity of the mine. Mapping was concentrated on the west lens of the Lightning zone above the 520-meter level during the summer of 1997. The major findings of the fieldwork were reported in Luinstra and Benn (1997) and Luinstra and Benn (1999). The eastern portion of the Lightning Zone was mapped between the 550 and 460-meter levels during the summer of 1998 and results were reported in Luinstra and Benn (1999). In addition, surface mapping at a scale of 1:50 000 was completed in Holloway township and reported in Berger et al. (2000). Work was concentrated primarily underground in the Holt-McDermott deposit from the 550-meter level to the 775-meter level during the summer of 1999 and was reported in Luinstra and Benn (2001). The summer of 2000 was spent extending mapping from the Holloway mine both east and west of the deposit along the PDDZ.

Underground mapping was performed at scales ranging from 1: 250 to 1: 25. All maps were located within mine coordinate grids set up for each deposit. Mapping located and identified different lithologies and alteration events, and subsequently identified,

measured and recorded structures. Wall maps (i.e geological relationships as seen in vertical planes) were prepared assuming a horizontal floor and heights to the back measured from the floor.

Where possible, surface outcrops were located within mine coordinate grids, or alternatively using UTM coordinates from Global Positioning Systems. Drill core from exploration and definition efforts were re-logged with emphasis on structural elements. Holes are located within mine coordinate grids, with observations, photographs and samples recorded as depths from surface (Appendix B).

Maps were digitized and are included in Appendix C. Structural measurements for the Holloway mine were assigned three-dimensional coordinates (mine grid) and entered into a database for structural analysis and projected onto lower hemisphere stereonet (figures 12, 24 and 25). Samples from underground and surface mapping were oriented upon collection in order to retain 'real-world' geographical reference for further structural analysis, especially microstructural studies.

4.2 Petrography

Oriented samples were cut for petrographical and microstructural analyses. Where necessary, two thin sections were cut for analysis per sample. A first thin section, designated with the sample number and the letter A, was cut perpendicular to the main macroscopic

foliation and parallel to the lineation. A second thin section, designated with the sample number and the letter B, was cut perpendicular to both the main foliation and any visible lineation.

Thin sections were prepared at the University of Ottawa, and were examined in order to assist in describing lithologies, alteration, mineralization and microstructures. Polished sections were prepared for detailed examination of ore minerals.

4.3 Scanning Electron Microscopy (SEM)

Samples selected for SEM analysis were cut into polished sections and coated with carbon in order to prevent charging of the surface during analysis. Samples were analyzed using a JEOL JSM-6400 scanning electron microscope at Carleton University, at up to 43 000 times magnification. The SEM was used to qualitatively identify and describe ore minerals related to gold. Measurements were carried out for 150 seconds at an accelerating voltage of 20 kV and a beam current of 0.8 nA, using Fe and S, NiAs and CoAs for standards.

4.4 Geochemical analyses

Samples were analyzed at the Ontario Geological Survey labs in Sudbury, Ontario. The abundance of refractory minerals in the samples required them to be digested before fusion. Samples were fused with lithium metaborate and tetraborate fluxes, which are non-oxidizing

and decompose refractory minerals. Molten fusion beads were digested with weak nitric acid before analysis. Rocks were analyzed using inductively coupled plasma mass spectrometry (ICP-MS) for major oxides, trace elements and rare earth elements (REE). Gold analyses were performed by instrumental neutron activation analysis (INAA). Results of geochemical analyses are recorded in Appendix A.

4.5 Geochronology

Zircons were processed at the Royal Ontario Museum (ROM) and dating performed by ROM personnel, Toronto, after separation from rock samples using standard heavy liquid and magnetic separation techniques. Geochronological data were obtained using the processes defined by Krogh (1973, 1982). All errors quoted in the text, as well as error ellipses in the Concordia diagrams, are given at the 95% confidence level. Discordia lines and Concordia intercept ages were calculated following the procedures described by Puchtel et al. (1999).

CHAPTER FIVE: HOLLOWAY MINE AND VICINITY

5.1 Exploration history

The history of exploration in this area is long and very interesting, involving tales of exploration and even suspected murder. Most information gathered for this section was gleaned from internal BMC reports by Broughton et al. (1991), government reports of Satterley (1953) and also from conversations with retired Matheson prospector Buster McChristie.

The first prospectors known to have explored in the area started in 1907-1908, when Russell Cryderman, William Cooper and William Woodney walked the 10 km distance from the south shore of Lake Abitibi to the 'Lightning River Area', which encompasses the present-day Holloway and Holt-McDermott mines. Only sporadic prospecting activity took place until Cochenour and Willans opened up a route from Matheson to the east around 1916, utilizing township boundaries which had been cleared and surveyed in the early 1900s.

Gold was first discovered in the area in 1917 in the southwest corner of Holloway Township by Cochenour and Willans. It was around this time that Willans went missing in the area, apparently after having won a substantial amount of money in a poker game. Willans was never found, and is believed to have been murdered. This early gold discovery led to an increase in prospecting activity in the area, and by 1922 all of the area had been staked. Gold showings were found on the Seagar's and Cryderman claims that

together comprise the present Holloway mine site as well as on the McDermott claim, site of the present day Holt-McDermott mine. In 1922, Mining Corp. took control of the Cryderman claim and stripped small outcrops, leading to the discovery of ENE-trending mineralized zones with a few good grades. In 1923, several holes were drilled to test the horizon at depth but intersected only narrow zones of alteration with poor grades. Further investigation into the claim was abandoned. These holes stopped only meters short of intersecting of the primary Lightning zone mineralization and the property was left idle.

While the Cryderman claim lay idle, the Seagar's Claim remained busy for a number of years. A number of pits and trenches followed the discovery of the 1922 gold showing, and in 1924 Abitibi Mines Ltd. (AML) was formed to explore the property. AML shortly discovered the 'Mammoth Vein'. This NNE-striking, moderately east-dipping quartz-carbonate vein ranged in thickness from 50 cm to 1m, and contained extremely high grades (up to 85 gpt over 0.9 m). Two small shafts were sunk on the vein in 1925, and 3 holes were drilled. Only narrow mineralized zones were found at depth and AML abandoned the property. In 1929, Teddy Bear Valley Mines Ltd (TBL) took over control of the property, and in 1934 they deepened one of the pre-existing shafts for underground exploration. Once again, disappointing results were returned and the property was subsequently left idle.

Not until 1980, when Lightvaal Mines Ltd. optioned the property, was the potential of the area re-examined. Various geophysical surveys were completed, including Magnetic, VLF and Max-Min surveys. Additional stripping and some 20 drill holes gave unimpressive results, and the property was again left idle. Renewed investigation began in 1984, with

Magnetic and IP surveys completed by D. Bell Geological Services. In addition, 7 holes were drilled to specifically test the Lightning zone stratigraphy, and only narrow mineralized zones were encountered. One hole, however, intersected visible gold in a quartz vein, 30 m below the present day ore zone footwall contact.

In 1985, Hemlo Gold mines took over the Cryderman claim and completed Magnetic, VLF-EM and geological surveys. The following year, 3 holes were drilled along a section that includes the present day production shaft. In 1987, drilling continued on both properties testing the Lightning Zone and related units. Drilling continued through 1988 and 1989 when Noranda and its subsidiary, Hemlo Gold Mines Ltd., took over exploration on both properties. Between 1989 and 1991, 51 holes tested the mineralized Lightning Zone. Only 4 additional surface holes were completed between 1991 and 1993. In 1993, a 441 meter exploration shaft was sunk on the Lightning zone on the Holloway mine site. A 750 meter drill drift was constructed, and drilling was undertaken at 25 meter sections. An 8500 tonne bulk sample was also taken from a crosscut and pilot drift. A feasibility survey was completed and identified an undiluted reserve of 5.2 Mt grading 7.9 gpt.

Exploration drilling has continued both underground and from the surface in recent years. A 1 km long drill drift was completed on the 750-meter level in the summer of 1999. This recent exploration has predominantly focused on the extension of the Lightning zone both at depth and to the east and west of the deposit.

5.2 Previous geological studies

The first geological survey of the study area began with an Ontario Geological Survey mapping program, and the first geological maps of the area were released at a scale of 1:50 000 (Satterly, 1953). Jensen and Langford (1985) re-examined the area as part of an Abitibi-wide program sponsored by the Ontario Geological Survey. Jensen and Langford's work has become an essential starting point for all further investigations in the Ontario portion of the Abitibi.

The first detailed work on the Holloway mine site was undertaken by Noranda Exploration and was published as an internal report (Broughton et al., 1991). Gold siting work was completed by Di Prisco (1993) as part of the feasibility study. An additional internal document was compiled as part of an in-house evaluation (Cooper et al., 1994). A Master's thesis was completed by Guy (1996), who studied the major lithologies of the mine, and the role of interpreted primary volcanic breccias in the formation of the deposit. Barclay Geological Services completed a reconnaissance structural investigation of the deposit in 1995. Subsequent geological maps of Michaud, Garrison, Holloway and Stoughton Townships were completed by the Ontario Geological Survey (Berger et al., 2000).

A substantial base of knowledge was compiled prior to this study; however, a detailed structural geology analysis of the deposit and a geochemical investigation of the alteration geochemistry had not been performed. The alteration geochemistry was the subject of a recent M.Sc. thesis published by Ropchan (2000).

5.3 Geological setting

The rocks that host the deposit have been tilted by folding into an east striking, steeply south dipping package. Figure 6 is a geological map of the Holloway mine vicinity, and a simplified lithological cross section through the Holloway deposit is shown in Figure 6.

The rocks are not part of a simple monocline, as isoclinal folding resulted in repetition of several units (see section 5.7). However, for ease of discussion of the lithologies, the rocks will be described beginning with the lowest structural position and ending with the highest, as shown in Figure 7.

Below the footwall contact which underlies the primary and most volumetrically important ore zone (Lightning Zone (LZ)), the lithology is a highly deformed and altered ultramafic volcanic rock. Locally, a mafic volcanic unit separates the ore zone and the footwall ultramafics. Volumetrically minor auxiliary ore zones are found at different stratigraphic levels. The LZ is overlain by pillowed and massive tholeiites as well as Timiskaming-type conglomerates, greywackes and mudstones. A series of interflow sedimentary rocks (mostly argillites) are found primarily at the contact between the ore zone and the underlying

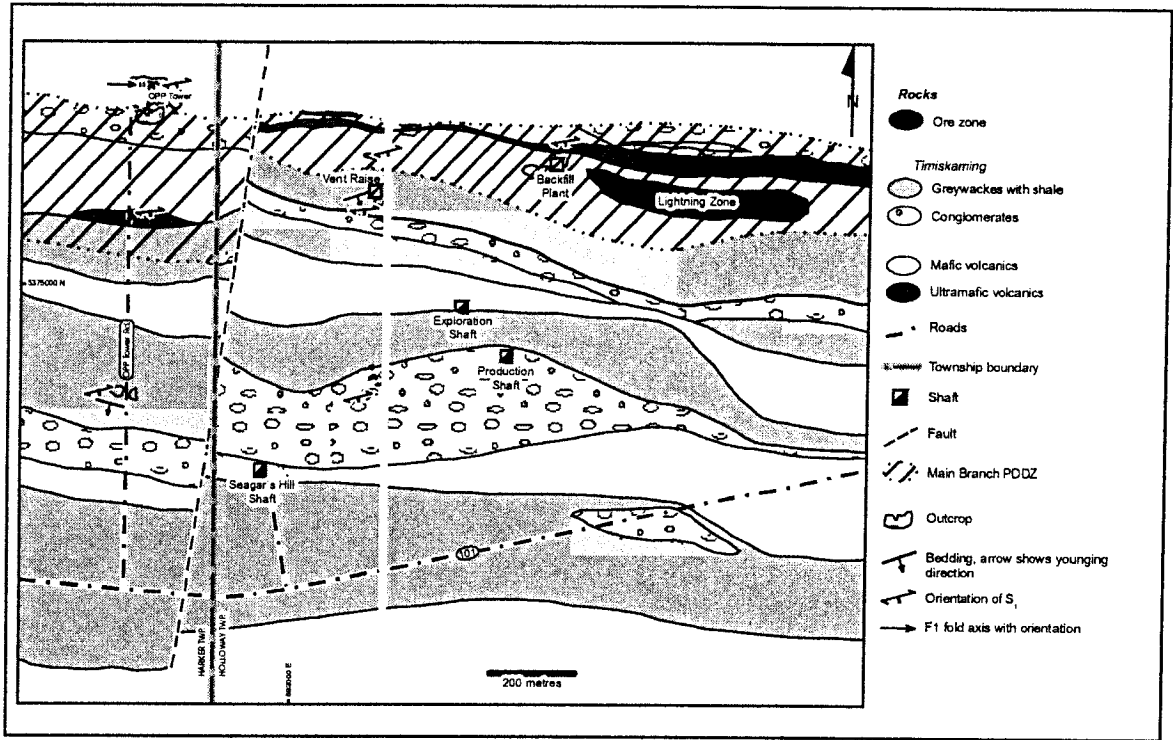


Figure 6. Geology of the Holloway Mine and vicinity constructed from field mapping, drill hole data and aeromagnetic surveys. Note the lenticular nature of stratigraphy and the presence of a D4 NNE striking fault which offsets stratigraphy.

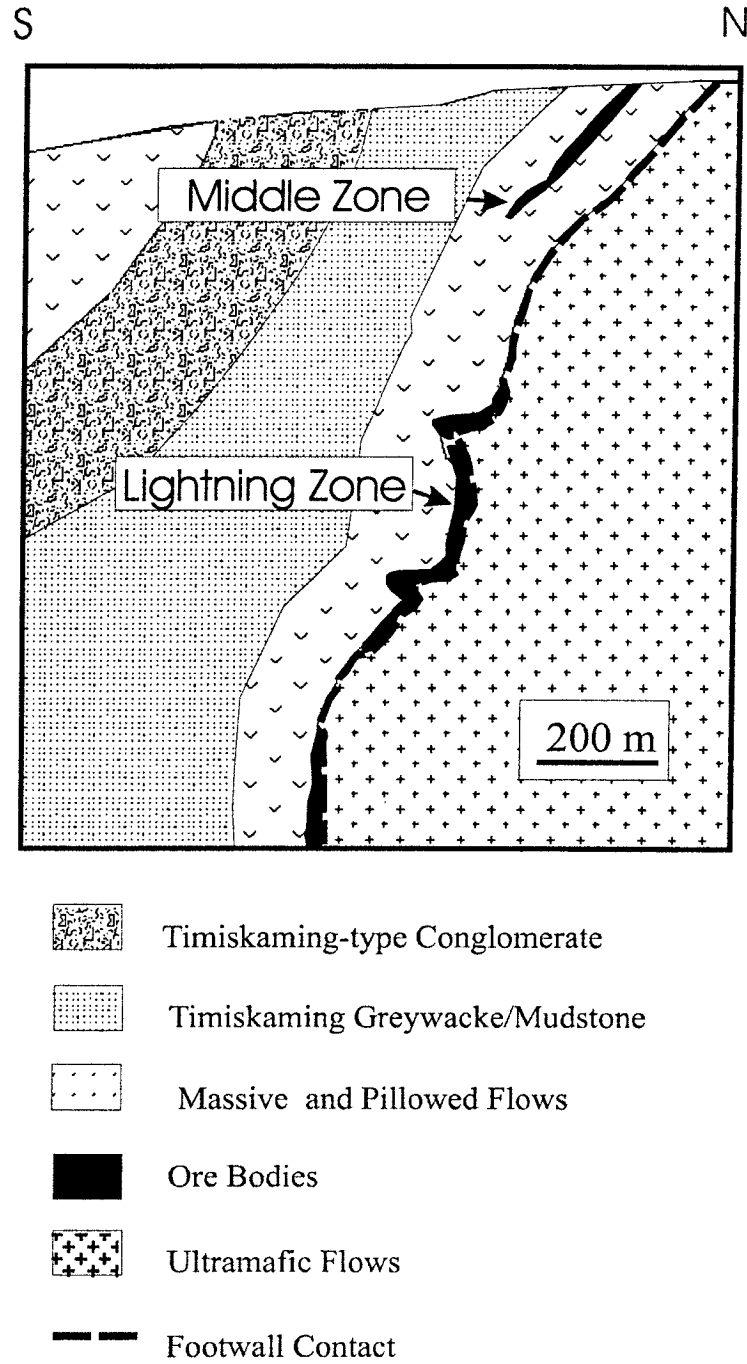


Figure 7. Simplified cross section looking west through the Holloway deposit after Luinstra and Benn (2000).

ultramafic volcanics. The interflow sedimentary rocks are not shown on figure 6. because of their small sizes. Dominantly north south striking mafic dykes that cross-cut stratigraphy are also not shown in Figure 6.

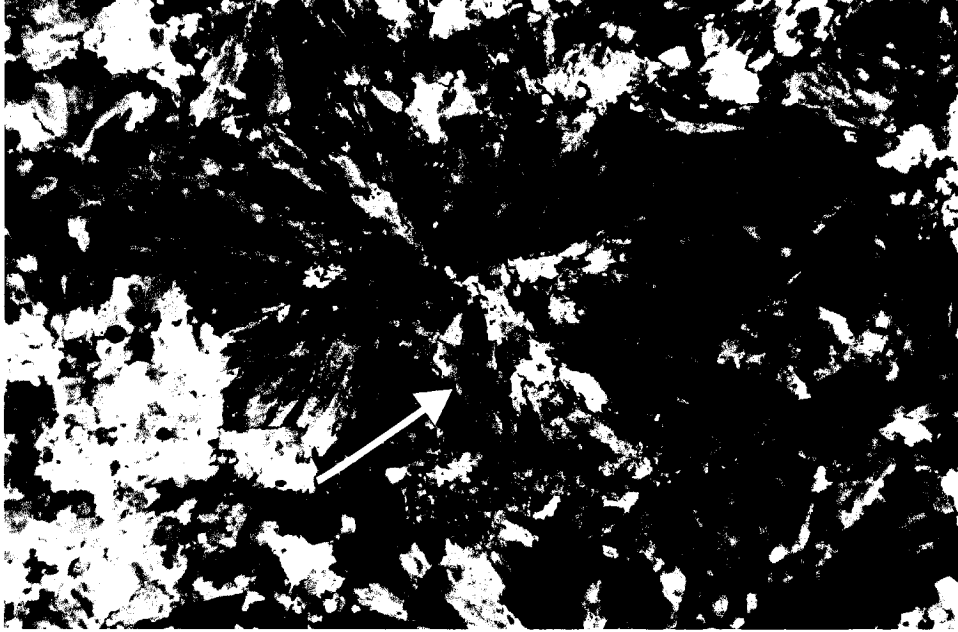
5.4 Ore zones

There are two major types of ore zones at the Holloway deposit. The first and most volumetrically important is the LZ, which is considered to be entirely hosted by a single variolitic hyaloclastite stratigraphic unit (Guy, 1996; Ropchan, 2000; Ropchan et al., 2002). The hyaloclastite unit is located on, or near the contact with underlying ultramafic volcanics. The LZ has undergone intense albite, hematite, sericite and carbonate alteration and contains pyrite mineralization. Gold is associated with albite alteration and pyrite mineralization, and is absent in areas where hematite alteration predominates. Plate 1 is a photograph of typical LZ albitized and mineralised rocks.

Volumetrically less important, and located at major lithological contacts is a second, vein-associated mineralization. The auxiliary zones are typified by sericite and carbonate alteration and pyrite mineralization occurring within haloes enveloping quartz and carbonate veining (Plate 2). The largest single auxiliary zone is the Middle Zone (MZ), located at a flow contact between pillowed and massive volcanic rocks within the volcanic sequence which hosts the Lightning Zone (Figure 6).

Plate 1. Albitized and mineralized rocks from the Lightning Zone. 520 east level draw point #4. Arrow indicates a varivole.

Plate 2. Sericitic alteration typical of auxiliary zone mineralization. Middle Zone, 485 east sublevel. Pyrite mineralization is found within halos of predominantly sericitic±carbonate alteration surrounding veins of quartz and ferroan calcite.



5.5 Lithologies

5.5.1 Ultramafic volcanics

The ultramafic volcanics are now composed of about 60-70 % carbonate minerals, mostly calcite. Carbonate minerals occur as anhedral, very fine grained (<0.1 mm on average) grains with heavily altered crystal boundaries. Sericite and fuchsite comprise an additional 20-25 % of the rocks. Sericite crystals are generally between 0.1 and 0.3 mm long and have anhedral habits, though the crystals are generally elongate. The remaining 5 % of the rock is composed of very small, equant euhedral pyrite grains.

Ultramafic footwall rocks are generally green in colour and aphanitic, with porphyroblasts of bright green fuschite. The top of this unit corresponds to a discrete zone of intense shearing (the Footwall Contact Shear Zone (FCSZ), Figure 7). The green colour of the rocks is due to a pervasive carbonate and fuschite alteration. Where not heavily carbonated, the rocks are talc-chlorite schists. Occasional relics of original spinifex texture are locally present, indicating that the rock is volcanic in origin. There are no other preserved primary textures.

5.5.2 Ore zone hyaloclastites

The LZ is a distinctly translucent grey colour and weathers to a rusty reddish brown. The rock is extremely hard due to the largely albitic composition. The LZ is composed predominantly of albite (from 60 to 95 %), along with variable amounts of carbonate (5 to

30 %) and pyrite (5-10 %). Variation of modal percentages is largely dependant on the amount of late carbonate alteration the rocks have undergone.

Primary features in these rocks include varioles and preserved hyaloclastite textures. Plate 1 is a photograph of the ore zone and the preserved primary textures. These host rocks represent mafic, variolitic hyaloclastite, which have been almost entirely replaced with albite and subsequent carbonate alteration.

Albite occurs as radiating, acicular grains that are generally 0.3 to 0.8 mm long, replacing original feldspars in varioles. Veins of albite are also observed within the ore zone, and are made up of euhedral albite grains (up to 1 mm in size) displaying both polysynthetic and simple albite twinning. Carbonate minerals (calcite and/or ankerite) occur in two distinct modes, the first as small anhedral crystals found throughout the groundmass and the second as inclusions around grains of albite. Pyrite also occurs in two temporally distinct habits in these rocks. The first generation of pyrite (Py1), is euhedral and located in the interstices of radiating albite microstructures (varioles). The second generation of pyrite (Py2) occurs as large, subhedral grains, and are found associated with sericite and carbonate veins.

5.5.3 Mafic volcanic rocks

Pillowed mafic volcanics

Pillowed mafic volcanics are grey-green and display pillow selvages of orange ankerite and dark green chlorite. These rocks are strongly deformed and are commonly carbonate-altered; they are recognizable only by the presence of pillow selvages, which gives them a banded appearance. Plate 3 shows some strained pillows on the east face of 415 west level.

Pillowed mafic volcanics are composed of albite (40%), chlorite (35%), variable amounts of carbonate (5 to 25 %), leucoxene (5 to 10%), sericite (5 to 10%) and pyrite (1 to 10%).

Albite forms small (<0.1 mm) subhedral laths in the groundmass and more rarely large (1 to 5 mm) euhedral phenocrysts. Chlorite occurs as anhedral grains throughout the groundmass, ranging in size from 1 to 3 mm, and is the main mineral constituting the pillow selvages. Small anhedral carbonate grains are found along grain boundaries of pseudomorphed primary minerals. Sericite replaces albite in large phenocrysts and in small veins which cross cut the rocks. Leucoxene in 1 mm to 3mm linear clusters of opaque material, has totally replaced unidentified minerals. Subhedral to euhedral pyrite is restricted to haloes around cross-cutting carbonate veins.

Plate 3. Flattened pillows in volcanic rocks. Pillow selvages are dark black and have been transposed parallel to the S_1 foliation. 430 west level, main drift, west wall. Pencil for scale. Trace of S_1 foliation indicated on the photo by white line.

Plate 4. Massive, leucoxene-bearing tholeiites from the 430 level, main drift, west wall. Note the well developed S_1 foliation and the F_2 crenulation. Traces of major fabrics indicated by white lines on photo. Pencil for scale.



Massive mafic volcanics

The massive volcanic rocks are identical in mineralogical composition to the pillowed volcanic rocks (This section). They contain large amounts of albite as both microlaths and phenocrysts, as well as large amounts of carbonate alteration products. Leucoxene is more abundant than in pillowed rocks (10 to 20%), and appears to have pseudomorphed an acicular mineral, possibly amphibole, titanite or ilmenite.

Massive mafic volcanics are grey to black, with visible grains of bright yellow leucoxene creating a "speckled" texture as seen in Plate 4. The amount of leucoxene, larger overall grain size and lack of pillow selvages distinguish these rocks from pillowed volcanic rocks.

Geochemistry of mafic volcanics

A M. Sc. Project was completed by Ropchan (2000), focusing primarily on the litho-geochemistry of the Holloway Deposit. Ropchan (2000) divided the mafic tholeiitic rocks of the deposit into types I, II and III, based on their chemical compositions. Type I have flat lying REE profiles 10x chondrite, and are characterized by Fe/Mg ratios of 2 and high Al, V and Ni values. Type II basalts have flat lying REE profiles 50x chondrite, Fe/Mg of 8 and high concentrations of Th and Zr. Type III rocks are variolitic (ore zone hyaloclastite) tholeiites with flat, 100 times chondrite REE profiles (Figure 8). Ropchan

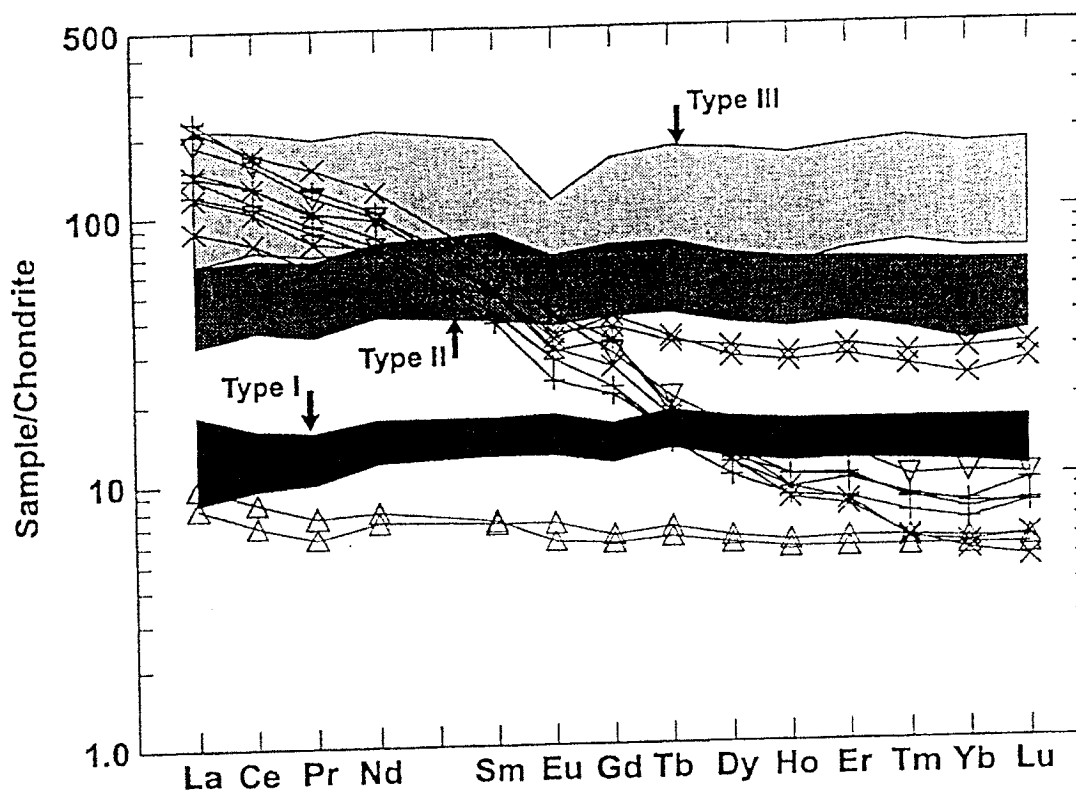


Figure 8. Chondrite normalized REE profiles for rocks of the Holloway Deposit, from Ropchan et al., (2002). Type I, II and II tholeiitic fields are shown and labeled. Open triangles for komatiitic volcanics; inverted triangles for sedimentary rocks; asterisks and crosses for basal timiskaming breccias from the west and east side of the deposits, respectively; plus-signs for the intermineral dyke.

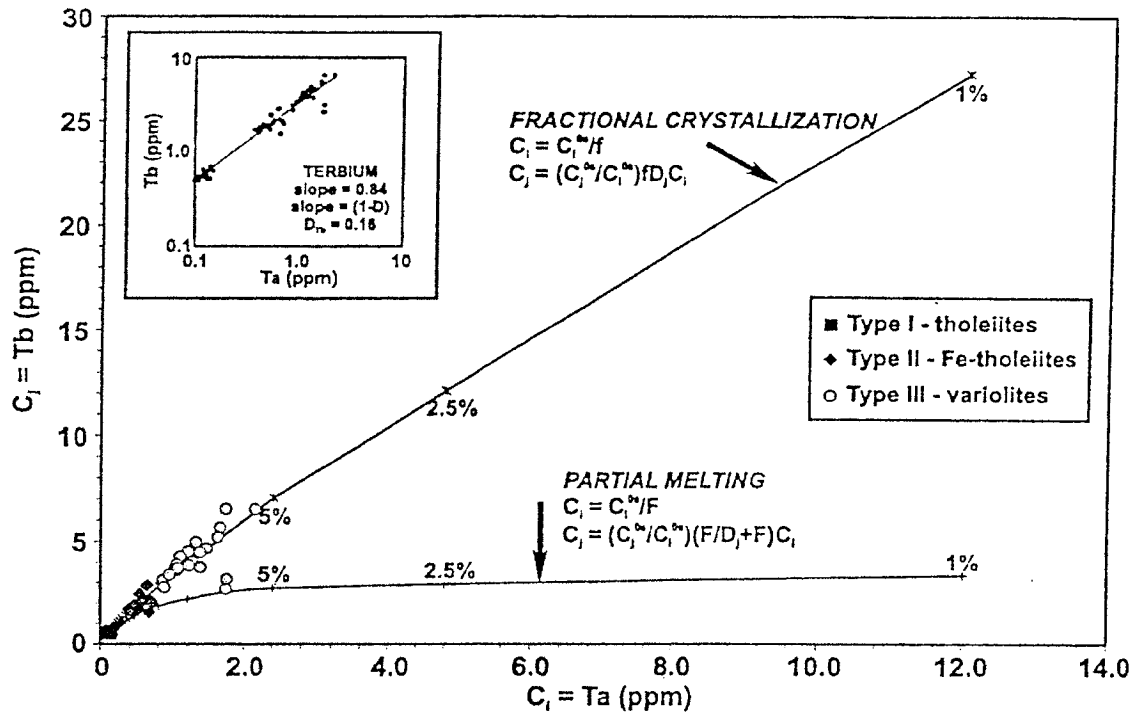


Figure 9. Variation of trace element concentration by different degrees of partial melting and fractional crystallization for Holloway mine tholeiites. The trend of the Holloway samples is best explained by the fractional crystallization model (Ropchan et al., 2002)

suggested that type II and type III volcanic rocks evolved from 70-80 % and 85-92 % fractional crystallization, respectively, of a tholeiitic parent magma. Figure 8 shows a Tb versus Ta plot for tholeiitic rocks, plotted against expected curves for both fractional crystallization and partial melting, which suggests that the variation in REE profiles is a function of fractional crystallization, rather than partial melting.

5.5.4 Sedimentary Rocks

Argillites

Argillites are black, finely laminated and occur as a subordinate lithology at all structural levels. They commonly form small lenses that are only rarely more than 5 m thick and 10 m in length. They are fissile due to their predominantly micaceous mineralogy that defines a strongly developed foliation. Clusters of framboidal pyrite, interpreted to be diagenetic, are often found within individual layers. The cryptocrystalline nature of these rocks makes ascertaining their precise modal mineralogical composition difficult. Thin section observations indicate that they are composed mostly of micaceous minerals with only a minor amount of very small (< 1mm) grains of quartz and feldspar.

Greywackes

Greywackes occur as interflow units and as larger, map scale units (see figures 6 and 7). They are light to dark grey, competent rocks with beds, commonly graded between 1 and 10 cm in thickness. Angular grains of plagioclase are visible with the unaided eye. The matrix of the greywackes is dominated by small (0.5 to 1 mm) plagioclase, carbonate and quartz clasts, surrounding larger clasts (1 to 4 mm) of plagioclase. Matrix minerals (quartz, plagioclase and carbonate) are uniformly rounded to subrounded. Rare larger clasts display microcline cross-hatch twinning and have angular, fragmented habits. All feldspars in the matrix and as larger clasts have been variably sericitized.

Conglomerates

Conglomerates in the mine sequence are commonly grey, with large, cobble sized, polymictic clasts. The matrix is made up of small (1-5 mm), well-rounded clasts of quartz and plagioclase and comprises between 40 and 95 % of the rock volume. Large well rounded clasts range in size between 5 and 20 cm and are composed of albitized volcanic and other mafic rocks, fuchsitic and chloritic ultramafic clasts, syenite, granodiorite, chert and jasper clasts (Plate 6). Accordingly, these rocks are considered to be of Timiskaming type (Hyde, 1978). A sandy interlayer from this package of rocks was dated and the U/Pb age of the youngest detrital zircon grains suggests a depositional age of 2684.3 ± 1.3 Ma, consistent

Plate 5. Heterolithic breccia, looking north, 505 west level drawpoint W10. A large clast of variolitic basalt is present in the bottom right hand corner. Brown rock bolt at bottom of picture is 15 cm across.

Plate 6. Timiskaming conglomerates from hole HW 113 at a depth of 540.6 metres.

White line with arrow indicates younging direction, starting with large, cobble size clasts on the right to smaller, coarse grained sand sized clasts to the left. Clasts of mafic volcanic, porphyry, chert, jasper, syenite and many other lithologies are present.



with the interpretation that they belong to the Timiskaming Assemblage (Ropchan et al., 2002).

Polyolithic breccia

A polyolithic breccia was found both within the LZ (but not mineralized) and structurally above the LZ. The breccia has a composition similar to that of Timiskaming type conglomerates, yet lacks any jasper or syenite clasts. Clasts of leucogenitic massive volcanic and mafic volcanics have been documented (Plate 5). The structural relationship with surrounding units is often difficult to ascertain. A sample of this material was collected and processed for geochronological analysis and a Timiskaming-assemblage detrital age of 2686.6 ± 1.8 Ma was determined (Figure 10). This suggests that the units unconformably overlie the volcanic rocks and were folded into the ore zone. They may represent a member of the Timiskaming assemblage.

Geochemistry of the sedimentary rocks

Sedimentary rocks of the Holloway deposit typically show LREE enriched profiles typical of Timiskaming assemblage rocks (Ropchan et al., 2002). In combination with the composition of the clasts in the rock, this suggests that all of the sedimentary units in

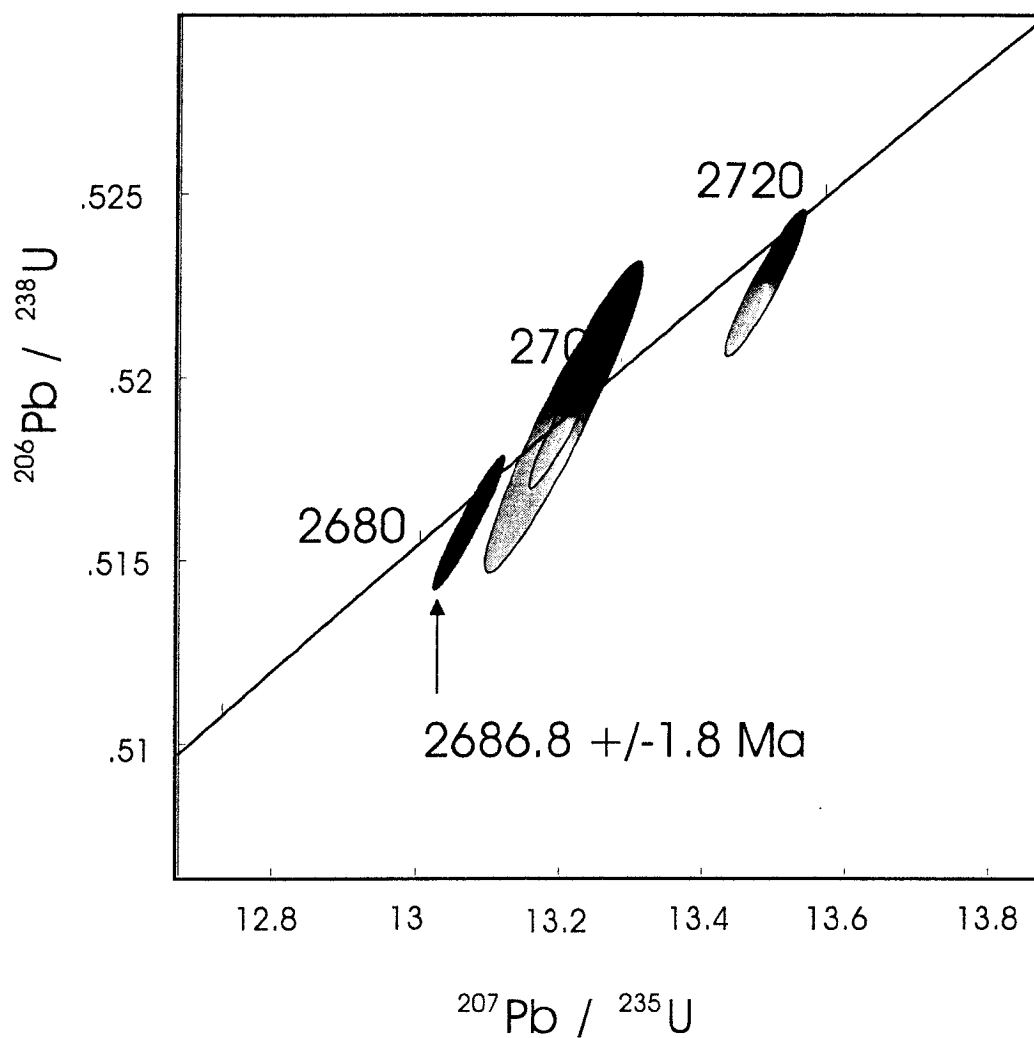


Figure 10. U/Pb Zircon plot for sample BL-021 of heterolithic breccia located within the Holloway mine stratigraphy in the hangingwall of the lightning zone, 550 west level. A best fit crystallization age of 2686.6 +/- 1.8 Ma is reported for this unit.

the mine are part of the Timiskaming assemblage. Figure 8 shows REE profiles of the polyolithic breccia of samples taken from both the east side (crosses) and from the east side (asterisks). These REE patterns are consistent with a sedimentary provenance for these rocks.

5.5.5 Dykes

Numerous dykes cross-cut the rock units, including several intermineral dykes. The term intermineral is reserved for dykes that can be shown by structural relations to have been intruded between distinct episodes of alteration and mineralization (Kirkham, 1971; Morasse et al., 1995).

The dykes are green, heavily carbonate altered and have round albite "eyes" which are visible to the unaided eye. Large amounts of chlorite are found in these dykes, and can exceed 50 % volume, forming anhedral clusters, interpreted to have replaced ferromagnesian minerals.

The dykes are altered but have an ultramafic composition and show LREE enriched profiles and are therefore considered to be lamprophyres (Ropchan 2002; Figure 8). A sample of an intermineral dyke provided an U/Pb zircon crystallization date of 2671.5 ± 1.9 Ma (Figure 11). This age is important for constraining the timing of mineralization for the deposit, and it is discussed in more detail in Section 5.8.

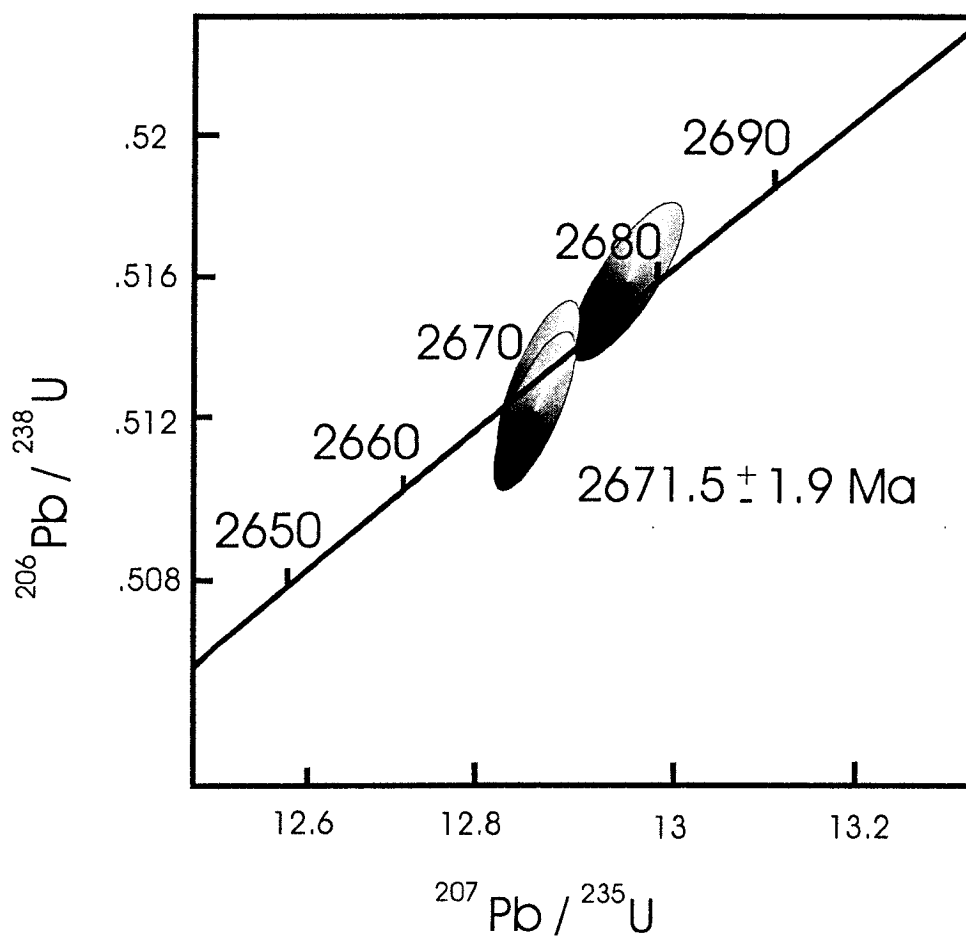


Figure 11. U/Pb Zircon plot to concordia from a sample of a deformed intermineral dyke found crosscutting albite alteration and gold mineralization in the Holloway mine, 505 east, drawpoint 4. A best fit crystallization age of $2671.5 \pm 1.9 \text{ Ma}$ is reported for this dyke.

5.6 Alteration

All rocks within the Holloway deposit have been heavily altered. Observations of altered rocks underground and in drill core, and petrographic examination of the rocks, were used to determine the principal alteration events associated with the deposit, as well the relative and absolute timing of alteration events with respect to structures and mineralization.

Cross-cutting relationships constrain the relative timing of the major alteration events. The alterations will be described in order of oldest to youngest, followed by a brief discussion of mineralization.

5.6.1 Early carbonate alteration

Ubiquitous carbonate alteration in the deposit overprints primary mineral assemblages. In the field, carbonate alteration is manifested by a buff brown colour in mafic volcanic rocks, which quickly weathers to a rust brown. In ultramafic rocks the carbonate alteration displays a bright green colour, with large amounts of the mineral fuchsite visible, suggesting that there is a small component of potassic alteration (sericite) associated with the carbonate alteration. Sedimentary units tend to take on a more yellowish brown colour when carbonatized.

Petrographic examination of carbonated rocks reveals a large degree of replacement. In some units, greater than 50% of the modal volume is composed of calcite. Calcite grains have anhedral crystal forms, occur as small grains (< 1mm), filling interstitial spaces throughout the rocks. In mafic volcanics small calcite grains can be seen to have

completely replaced relic feldspars. Likewise, in sedimentary units calcite replaces feldspar clasts and occupies interstitial spaces. In ultramafic volcanic rocks the alteration is more pervasive, and nearly complete replacement of original minerals has occurred. Very fine grained calcite makes up to 80% of ultramafic rocks, where only minor amounts of chlorite and amphiboles can be seen.

Carbonate alteration cross-cuts and is cross-cut by all other types of alteration within the mine sequence. This suggests that carbonate alteration started early in the history of the deposit, and either continued for a long period, or represents a number of discrete events.

5.6.2 Hematite alteration

Patchy hematite alteration occurs within and outside of the main ore zone, as a replacement of previously carbonatized rocks. It is of particular interest to this study, as it often corresponds with a reduction in gold grade within the mine sequence. Hematite occurs as a pervasive alteration that adds a deep purple hue to volcanic rocks, and a reddish brown hue to sedimentary units. In thin section the alteration exists as rims around minerals such as calcite and amphibole. All rocks that are hematized have been previously carbonatized. Very fine grained and amorphous hematite fills interstitial spaces and appears to be the insoluble product of an iron-rich, oxidizing fluid.

Hematite occurs in irregular and inherently unpredictable patches of already carbonatized rocks. Where rocks have undergone subsequent alteration, the hematite alteration may be obscured. Later albitization and carbonatization overprints the hematite alteration.

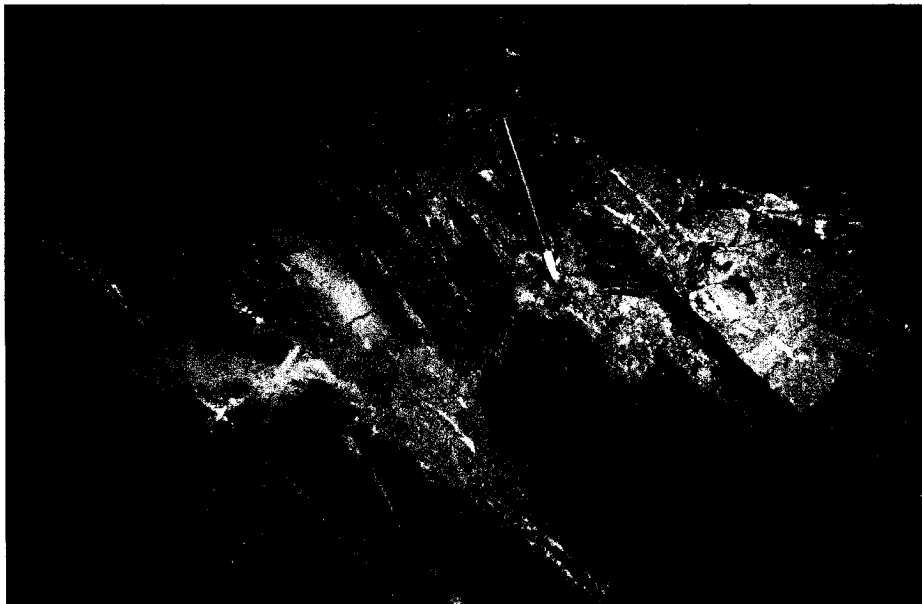
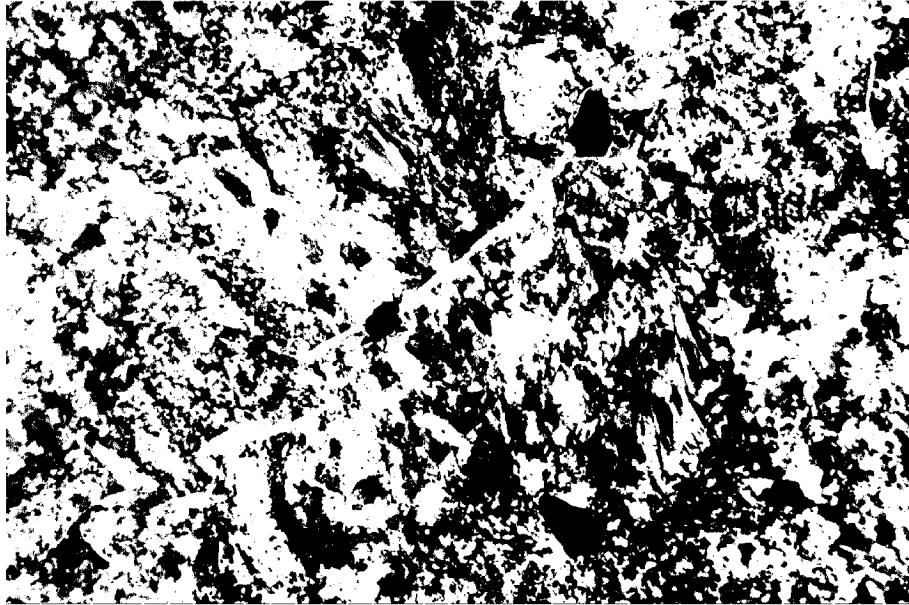
5.6.3 Albite alteration

Albite alteration typically is spatially associated with gold mineralization within the Holloway deposit. There are two major types of albite alteration. An early, pervasive alteration (Ab 1) involves complete replacement of previously carbonatized and hematized rock with albite. A second albitization event is (Ab 2) characterised by small veinlets of albite and carbonate which cross cut the earlier albite alteration. These alteration events share both mineralogy and timing relationships and are therefore considered to be penecontemporaneous.

Primary mineralogy in pervasively albitized rocks (Ab 1) is completely replaced. These units are light grey to light brown, and are extremely hard. They are composed of almost 90 % albite, with only accessory pyrite, quartz and some late carbonate alteration occupying interstitial spaces. Relics of primary textures can be seen (Plate 7). Albite forms interlocking clusters of radiating crystals, unique to this style of alteration. An example of this texture can be seen in Plate 7, taken from an albitized hyaloclastite from 520 west sublevel.

Plate 7. Albite alteration and replacement of primary minerals. Large amounts of calcite are associated with the albite in this sample. Albite alteration is cross cut by veins of sericite and pyrite. Field of view is 2 mm. Sample 005b, 415 level main drift.

Plate 8. Shallowly south dipping quartz and carbonate veins with halos of sericitic and carbonatic alteration. 505 east Drawpoint 5, west wall.



Small albite veinlets (Ab 2), less than 1 mm in thickness cross-cut the Ab 1 altered rocks. These veinlets contain large (up to 1 mm) crystals of albite and small amounts of calcite. Albite alteration is exclusive to the ore zone hyaloclastite and does not occur in other lithologies. However, the albite alteration is not confined to a single horizon. Several smaller zones of 'albitite' have been observed in the hangingwall of the deposit.

Ropchan (2000) suggested that albite alteration is associated with increases in Au, W, As, S, and CO₂, which is consistent with known associations in the LZ of albite with gold, arsenian pyrite (As and S) as well as carbonate alteration which is ubiquitous throughout the deposit.

5.6.4 Late carbonate and sericite alteration

Small (1 to 5 cm thick) carbonate veins are proximal to D₂ fold hinges and faults. These veins cross-cut previously carbonated, hematized and albitized rocks. Enveloping these veins are haloes of sericite and carbonate. The veins have flat to moderately dipping orientations and haloes with thicknesses roughly three times that of the vein thickness. The veins themselves are typically composed of calcite, ankerite and sericite while haloes are composed of mostly carbonate and sericite, as well as small amounts of pyrite. Haloes in mafic volcanic and sedimentary rocks are buff brown, while in ultramafic rocks they are distinctively bright green. Ropchan (2000) shows that this alteration is associated with elemental increases in CO₂, K₂O, Rb, Ba, Cs, Sb and occasionally Au, S, As, and W.

Plate 8 shows this late alteration surrounding carbonate veins and crosscutting metamorphosed and hematized volcanics. Occasionally, economic grades are associated with this alteration.

5.7 Gold mineralization

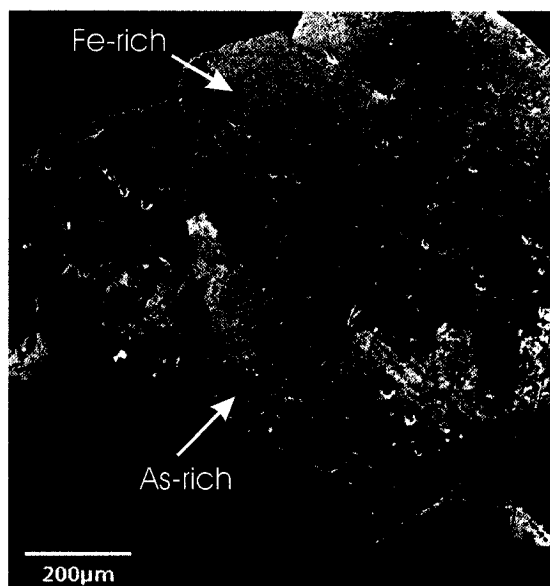
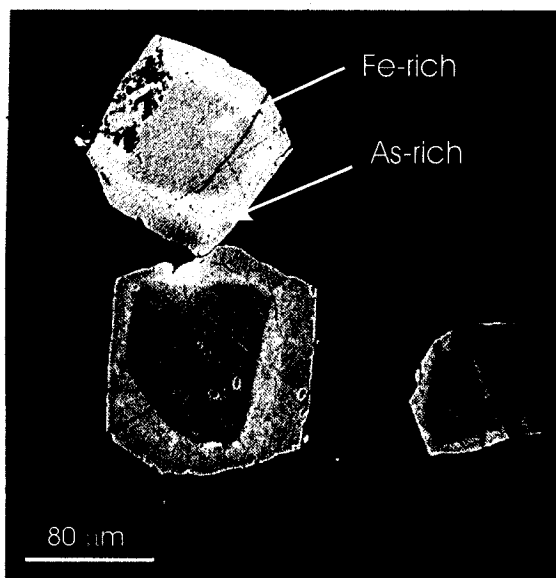
Gold Mineralization within the Holloway deposit is spatially associated with pyrite and albite alteration. The mine geologists, in order to accurately estimate gold values, have traditionally used modal pyrite percentages. Tetrahedrite, chalcopyrite, arsenopyrite, molybdenite and native gold also occur but are extremely rare in comparison to pyrite, the most important opaque mineral associated with gold mineralization.

5.7.1 Pyrite mineralogy

Pyrite occurs in two types, each coeval with one alteration style. The first major type (Py1) occurs as small (0.1 - 0.5 mm) euhedral crystals which are spatially confined within albitized (Ab1 and Ab2) rocks. Py1 pyrites commonly occupy interstitial spaces between radial albite clusters as well as between minerals within Ab2 veinlets. Volume percentages of Py1 rarely exceed 5%. Plate 9 shows an SEM photomicrograph of Py1 crystals. Compositional zoning of pyrite visible in this picture corresponds to small Fe-rich cores and larger As-rich rims.

Plate 9. Scanning Electron Microscope image of Py1 pyrite showing zonation. Cores of pyrite are iron-rich; rims are arsenic-rich. Scale bar is 80 microns. Sample 017a, 505 west, drawpoint 3.

Plate 10. Scanning Electron Microscope image of Py2 pyrite showing iron-rich and arsenic-rich areas. The irregular boundary between arsenic rich and iron rich portions of this pyrite suggest that pyrite mineralizing fluids were remobilized during precipitation of Py2 pyrite.



The second type of pyrite (Py2) is found within the haloes of the sericite + carbonate vein (Sr) alteration. These pyrites range in size from 0.5 to 2 cm and are subhedral to euhedral. They are commonly found in greater volumes closest to the Sr veins and can reach volume percentages of 25-30 % locally. These pyrites are also associated with anomalously high grades in the deposit. High concentrations of arsenic are also common within rocks that contain large percentages of Py2 pyrite. Py2 is found throughout the deposit, within, as well as outside of, the ore zones. SEM analysis of the Py2 pyrites indicates that they are composed of arsenic and iron rich segments (Plate 10).

It is important to note that the two pyrite mineralization types are also temporally distinct. Each type is associated with separate mineralizing events. Gold is associated with both Py1 and Py2 pyrites. However, the relative importance of the two mineralizing events has not as yet been ascertained. Zones with Py 1 mineralization often have lower, more uniform gold values. Areas characterized by Py2 mineralization tend to have higher local Au grades. This suggests that gold was introduced by an early, pervasive mineralizing event (Py1), and may have been subsequently remobilized and locally concentrated during Py2 mineralization.

5.7.2 SEM analysis

Several samples were analyzed qualitatively using Scanning Electron Microscopy in order to distinguish zoning within them. Results of this investigation show that Py1 pyrites are more abundant and consist of Fe-rich cores and As-rich rims. This suggests that there was a transition from Fe-rich to As-rich fluids during precipitation of pyrite, or that pyrite

formed as part of two distinct events, one Fe-rich and one As-rich. Plate 9 shows an example of py 1 pyrites with dark (Fe-rich) cores and lighter (As-rich) rims.

Py2 pyrites are larger, have anhedral crystal habit and are composed of both Fe-rich and As-rich portions (Plate 10). This is consistent with the interpretation of these pyrites as being remobilized from earlier (i.e. Py1) mineralizing events.

5.7.3 Gold siting

Gold siting work was completed by Di Prisco (1993) as part of the feasibility study for the Holloway deposit, and he suggested that gold is located preferentially at pyrite grain boundaries. Polished sections prepared for the present research revealed no gold grains in either petrographic or SEM examination.

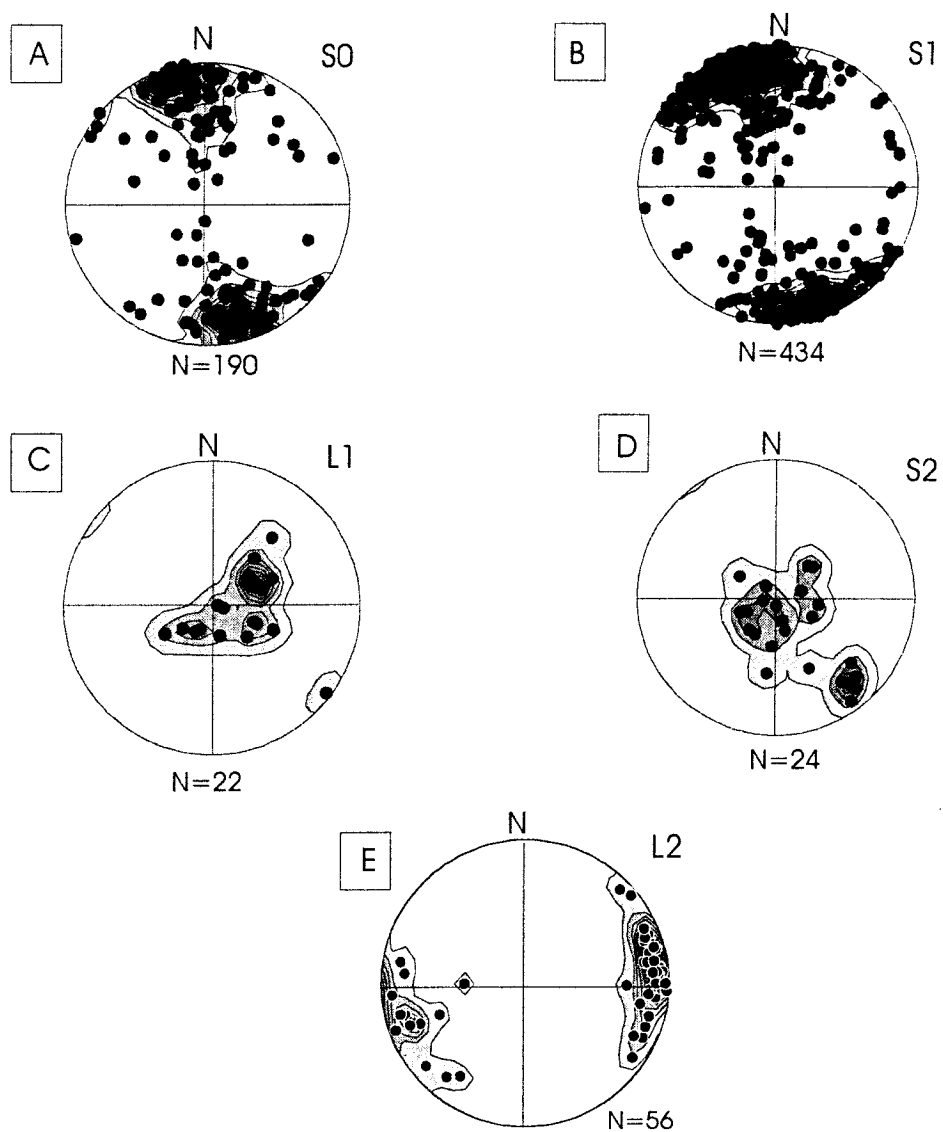


Figure 12. Lower hemisphere equal area stereonets of major structural features from the Holloway Mine.

5.8 Structural geology

The main ore zones of the Holloway deposit are enveloped by 080° striking, steeply south-dipping zones of intense deformation and fabric development. The ore lenses contain the same generations of structural fabrics as the surrounding rocks, and therefore they have undergone both of the main deformation events (D_1 , D_2) that have been documented on the mine property. The intensely deformed rocks that surround the ore lenses are characterized by a strong foliation and, locally, by an associated extension lineation (Figure 12). They are

considered to be shear zones that are tens of meters wide. The ore lenses are interpreted represent lithons that were formed by boudinage of the more competent mineralized zones, which are pervasively albitized, within the surrounding rocks that are generally richer in more ductile components such as carbonate minerals and sericite.

The zone of intensely deformed rocks that contains the ore-bearing lithons is considered to represent the PDDZ, which, in the Holloway area, is made up of a system of shear zones that anastomose around the ore-bearing lithons. The PDDZ extends to at least 250 meters to the south of the main ore zone, and to an unknown distance (at least 30 meters) north of it. Therefore, it is determined that the PDDZ in the area of the mine has a structural thickness of at least 280 meters; however, its thickness may be much greater, since its northern and southern boundaries were not observed.

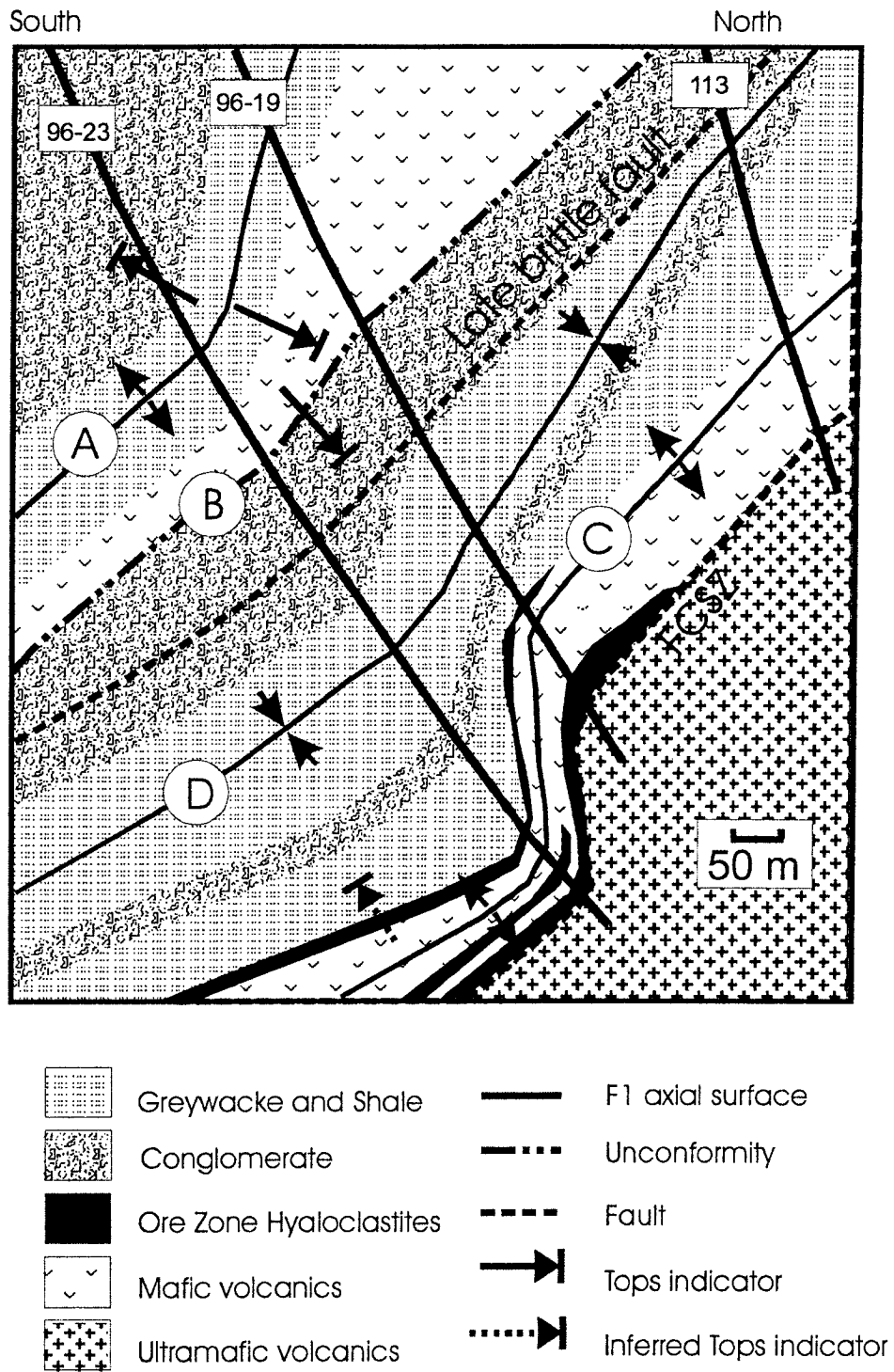
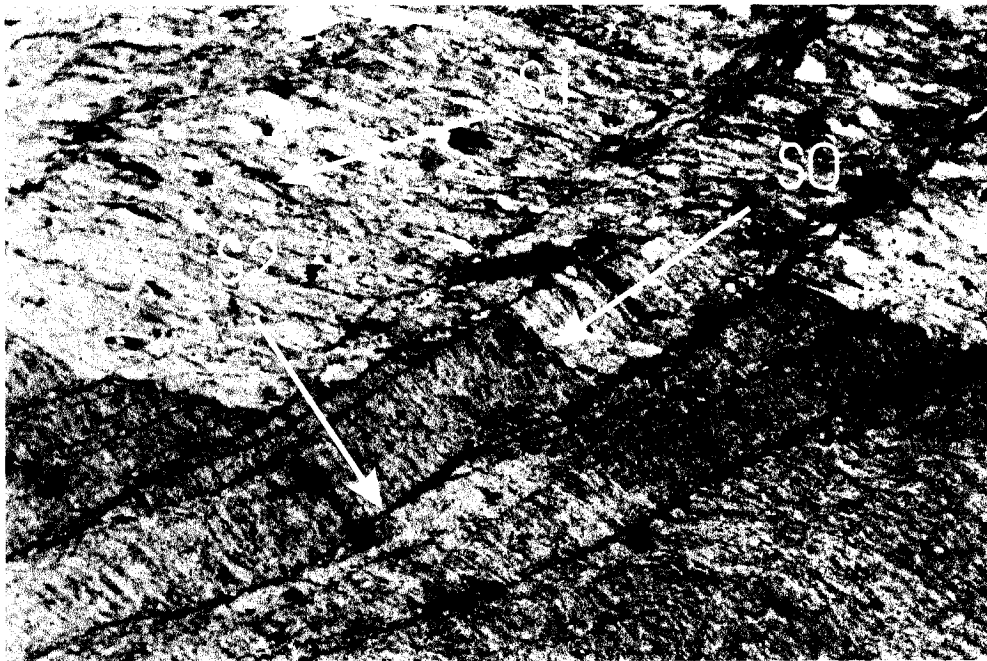


Figure 13. Structural Profile through the Holloway deposit looking west. Observed F1 folds are located at A, and interpreted at C and D. Tops are downhole at point B.

Plate 11. Photomicrograph of foliation in the ore zone. Foliation is defined by dissolution bands of opaque minerals. Field of view is 4 mm. Sample 018a, 505 west, Drawpoint 5.

Plate 12. Photomicrograph showing relationships of S_0 , S_1 and S_2 . S_0 is defined by the compositional change, S_1 is defined by the alignment of minerals parallel to S_0 and is cross cut by S_2 pressure solution cleavage, which runs from the top right to the bottom left.

Field of view is 5mm.



5.8.1 D_1 structures

Tight, isoclinal, steeply (85° to vertical) east-plunging F_1 folds are identified at the deposit scale. The folds were defined by the recognition that lithological units are repeated in structural profiles (Figure 13), and by documented reversals in facing directions that were determined using sedimentary structures (mainly graded bedding) that are preserved within the greywackes.

A penetrative S_1 foliation is axial planar to the F_1 folds. Both S_0 (bedding in sedimentary rocks) and S_1 strike 080° and dip 75° (to vertical) to the south (Figure 12 A,B), indicating that the intense D_1 deformation resulted in complete transposition of the primary depositional structures parallel to S_1 . Small-scale, rootless intrafolial folds that are commonly observed within sedimentary rocks are also interpreted to be F_1 folds. The S_1 foliation is most strongly developed within the sheared rocks that are in immediate proximity to the hyaloclastites of the ore zone. It is defined by the alignment of fuchsite and sericite crystals in ultramafic volcanic rocks. In the mafic volcanic rocks, S_1 is defined by the alignments of albite, calcite, chlorite and leucoxene crystals, and also by flattened pillows. In the sedimentary rocks, S_1 is defined by the alignments of sericite and calcite crystals and by flattened clasts. S_1 is only locally preserved within the ore zone hyaloclastites, where it is mainly defined by stylolitic

Plate 13. L_1 extension lineation defined by strain shadows surrounding pyrite grains. Sense of shear is dextral. S_1 foliation indicated by line.

Plate 14. S_1 in a pillowed volcanic rock folded by F_2 folds. Spaced crenulation cleavage developed on limbs of F_2 crenulation folds. 415 west level, main drift, west wall. Traces of S_1 and S_2 are indicated by white lines. Pencil for scale.

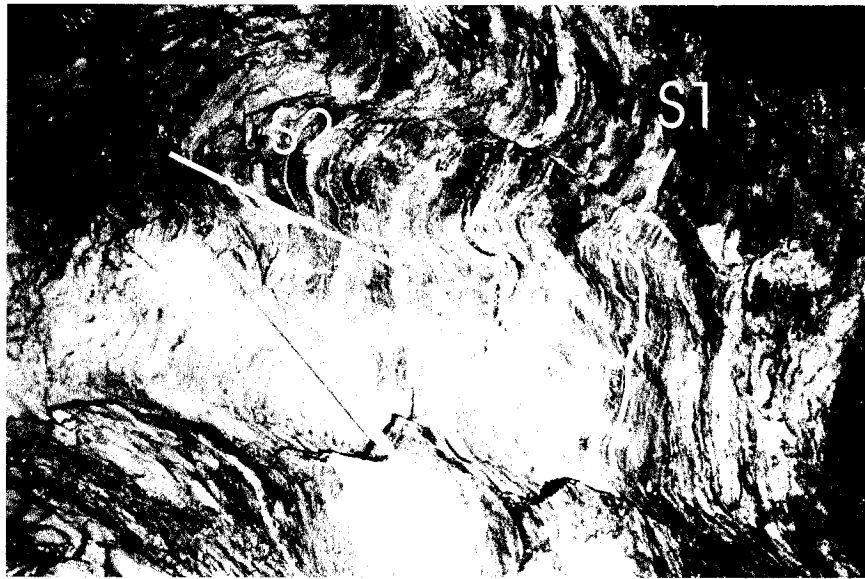
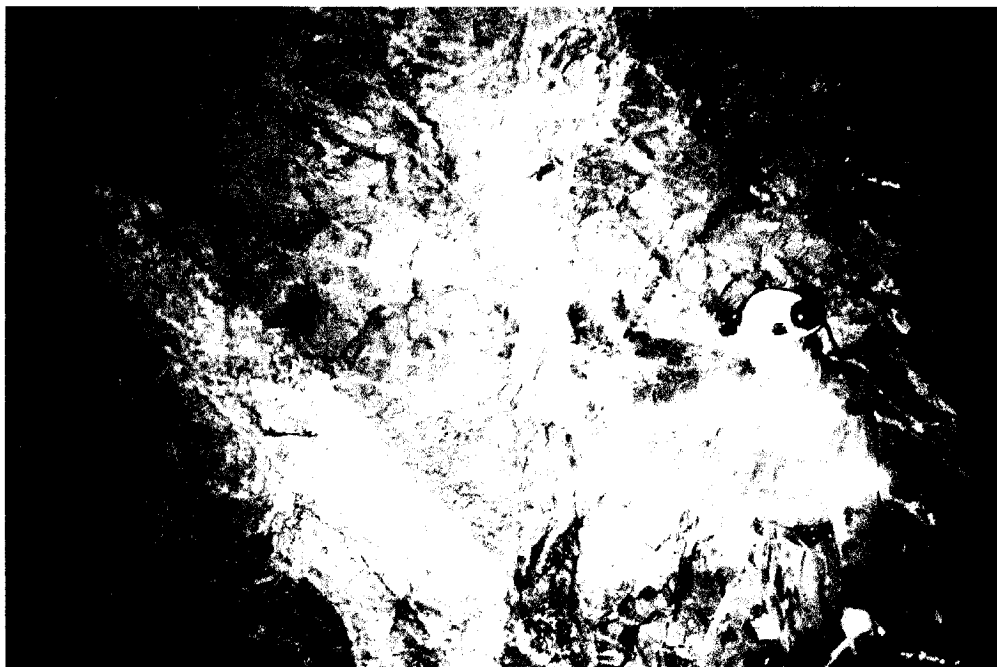


Plate 15. Photograph taken from 675 14 stop face. Albite alteration surrounding veins cross cuts previously hematized rocks on right side of picture. Albitized rocks are intruded by a dyke that has been subsequently deformed and carbonatized. Dyke is 50 cm thick.

Plate 16. Deformed intermineral dyke cross cutting albitized ore zones. Sample BL-021 of the polyolithic breccia was taken from this location for geochronological analysis (Section 5.6.2).



foliation bands, rich in opaque minerals (Plate 11). S_1 is also seen in dikes that cross-cut the ore zone, where it is defined by the alignments of calcite and sericite crystals.

An L_1 extension lineation plunges down-dip within the S_1 foliation plane (Figure 12 C), and is found in all lithological units in the mine. It is defined by prolate-shaped varioles in mafic volcanic rocks and clasts in sedimentary rocks. L_1 is also defined by elongate minerals and mineral aggregates including leucoxene, albite and chlorite in mafic volcanic rocks, and by strain shadows, composed of fibrous quartz, that are attached to pyrite crystals within the ore zone (Plate 13).

Asymmetrical microstructural features demonstrate that the D_1 event included a non-coaxial strain within the PDDZ, at least within the Holloway deposit. The sense of shear associated with D_1 non-coaxial strain can be determined from microstructural observations made in oriented thin sections. Shear sense indicators, including asymmetrically folded extensional veins, displacement of dikelets within mesoscopic-scale shear zones and the strain shadows attached to pyrite crystals, all show a south side up, reverse sense of displacement associated with D_1 .

5.8.2 D_2 structures

All lithological units, primary depositional structures and D_1 structures are deformed into open F_2 folds that have subhorizontal axial planes (Figure 12, D), and axes that plunge very shallowly to the east (Figure 12 E; Plate 14). F_2 folds have half-wavelengths of approximately 400 meters. S_2 cleavage is axial planar to the F_2 folds (Figure 12 D) and is

most strongly developed within the hinge zones of the folds and on their sheared limbs. The S_2 foliation is a subhorizontal (Figure 12 E), disjunctive pressure solution cleavage. It is defined by narrow cleavage bands (containing abundant opaque minerals) that bound millimeter-scale microlithons wherein the S_1 foliation, and in sedimentary rocks S_0 , are well preserved (Plate 12). No extension lineation has been observed to be associated with S_2 . The limbs of most F_2 folds are sheared and attenuated, resulting in a strong development of S_2 , and offsets that displace ore bodies on the order of tens of meters.

5.8.3 D3 Structures

Stratigraphy, S_1 foliation, and F_2 fold axes have all been folded by large scale, open staircase F_3 folds. These folds are recognized by a deflection of stratigraphy within the mine sequence and surface geology (Figure 6). The 650 west exploration drift was extended several hundred meters to the west of the main mining areas for definition and detailed underground exploration drilling; it intersected one such F_3 fold where stratigraphy changed strike to a NE orientation. These folds have limited control on the geometry and distribution of ore zone material.

5.8.4 D4 structures

The deposit is cross-cut by a series of late brittle faults. The first set of brittle D4 faults strikes 075° to 085° , and dips 75° to 85° south. The faults are defined by thin bands

(<10cm) rich in chlorite and graphite. No reliable sense of displacement could be determined within these faults.

5.8.5 D5 faulting

A set of brittle D₅ faults strikes north and is subvertical. The D₅ faults are defined by thin chloritic bands, and they consistently offset units with an east side down sense of displacement. The relative ages of the D₄ and D₅ brittle faults is not unequivocally proven; however, observations of drill core from holes spaced 25 to 50 meters apart suggest that the east to northeast striking D₄ faults are offset by the north-striking D₅ faults.

5.9 Relative and absolute timing of alteration and gold deposition.

An intensely deformed, intermineral dyke cross-cuts albitized ore zone rocks. This dyke has a well-developed S1 foliation and because it has been dated, it provides an absolute time reference to which the relative timing of alteration and mineralization can be compared. Plate 16 shows a photograph taken underground at the 505 west sublevel of the dyke where it cross cuts albitized and mineralized rocks. A sample of this dyke was sent for U/Pb zircon

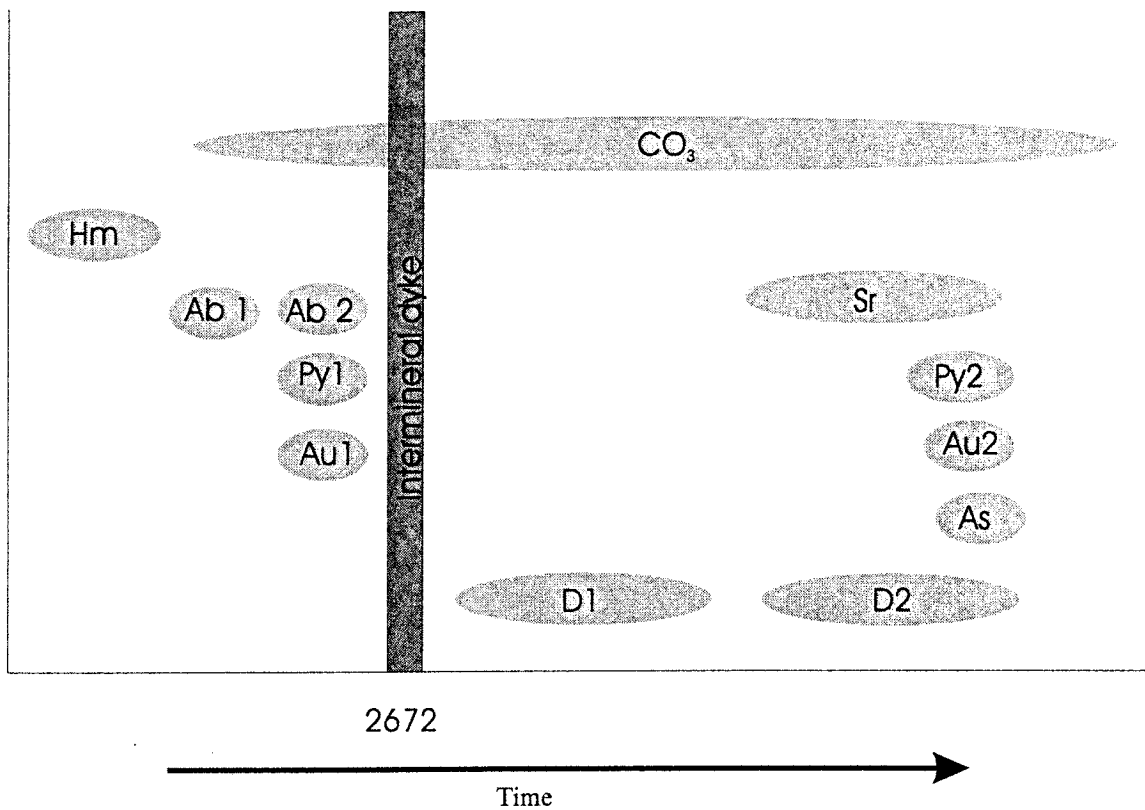


Figure 14. Diagram showing timing relationship of alteration and mineralization events with respect to the principal structures. Hm - hematite; CO₃ - pervasive carbonate; Ab - albite; Py - pyrite mineralization, Sr - Sericite/carbonate; Au - gold mineralization; As - Arsenic; D - deformation events.

geochronological analysis. A crystallization age of 2671.5 ± 1.9 Ma was obtained (Ropchan et al., 2002).

Using the dyke as a reference, the relative timing of alteration and mineralization events can be given absolute age brackets. Figure 14 is a diagram showing the relative and absolute timing of these alteration and mineralizing events as well as metamorphism and deformation events. Carbonate (CO_3) and hematite (Hm) alteration clearly predate intrusion of this dyke. The dyke also cross-cuts both albitized (Ab 1 and Ab 2) and mineralized (Py 1) hyaloclastites, providing a minimum age of mineralization. Py 2 mineralization, as well as the later carbonate and sericite (Sr) alteration, cross cut and therefore postdate intrusion of the dyke. Plate 15 shows an intermineral dyke which cross-cuts hematized and albitized rocks, which have been subsequently deformed and cross-cut by shallowly dipping veins and associated sericite and carbonate haloes. A minimum age for hematization, albitization and Au1 mineralization and a maximum age for D1 deformation is established at 2671.5 ± 1.9 Ma.

CHAPTER SIX: HOLT-MCDERMOTT MINE AND VICINITY

6.1 Location and access

The Holt McDermott Mine is located just south of Highway 101, 15 km west of the border between Ontario and Quebec. Initial surface mapping was carried out during the summer of 1998 as part of this project and a larger scale, OGS mapping project which led to the publication of a revised 1:50 000 scale geological map (Berger et al., 2000). Additional investigation, including surface mapping, underground mapping and examination of existing drill core were completed for this study in the summer of 1999. A B.Sc. thesis by Jones (2000) investigating the alteration geochemistry of the deposit was carried out in collaboration with geologists from Saint Mary's University.

Access to the surface was primarily along the mine's major access road, as well as from numerous other roads throughout the property which access the tailings pond and various other installations on site. A significant amount of mapping was completed around the tailings pond, just south of the mine on the property. During this project, mining activity was concentrated within the South Zone. Accordingly, mapping was carried out in this area. Access to the previously mined McDermott zone was limited to the 550 meter level, in use for ventilation purposes at the time of study. Deepening of the shaft was on-going during the investigation, providing access to the newly developed 1160m shaft station. There, the

footwall sedimentary rocks were correlated with the hangingwall sedimentary rocks of the Holloway deposit.

6.2 Exploration history

P.A. McDermott first discovered gold in the area of the Holt-McDermott mine in 1922. McDermott found visible gold at the surface, dug a small trench, drilled at least one diamond drill hole with anomalous values and sank a 6m shaft just west of the present headframe. An unknown amount of gold was mined during this period. The property was optioned by Sylvanite gold mines in the late 1940s and was subjected to a diamond drill exploration program. The drilling program outlined gold mineralization hosted by “silicified basic” volcanic rocks over widths up to 8.5 meters. Mining and exploration were interrupted by World War II, and the property lay idle until the resurgence in gold investment and exploration during the flow-through share era in the late 1970s to mid 1980s. In 1981, Camflo Inc. optioned the property and recommenced drilling. Initial results of this program identified gold mineralization over widths of up to 13.7 m and strike lengths up to 800 m.

In 1984, American Barrick Resources Corporation (now Barrick Gold Corporation (BGC)) acquired Camflo Inc. A comprehensive reevaluation of the property was undertaken, followed by a renewed drilling effort. Initial results defined reserves of 2.5 Mt at 6.8 g/t proven and probable. After completion of the feasibility study, an initial shaft was sunk to 420 meters on the McDermott zone.

In 1984, step-out drilling by Canamex Resources, designed to test for the along strike extension of the McDermott Zone, delineated the Mattawassaga ore zone, 500 meters east of the McDermott zone along strike in what is referred to herein as the McDermott Shear zone. The Mattawassaga claims were acquired by BGC in 1988 and operation of an open pit began. Step-out drilling initiated by BGC in 1985 delineated the Three Star/Worvest ore zone, 600 meters west of the McDermott zone, along strike. An underground drift was established and mining of the Three Star/Worvest zone began in 1986.

In 1992, deep drilling tested for the down-dip extension of the McDermott zone, leading to the discovery of the Central Zone (or “Vertical Sector”). Follow-up drilling of this zone led to the discovery of the South Zone (SZ), just 200 meters below and directly down dip of the McDermott zone. The shaft was extended to 870 meters and mining began on the SZ in 1994. In 1999, the shaft was extended another 400 meters in order to access the Central zones of mineralization, the apparent extension of the SZ. At the time of publication, definition drilling continues on the central zone.

Immediately south of the Holt-McDermott property, on a package of land owned by Franco-Nevada Mining Corp., drilling revealed another zone of mineralization (Natress, 1999). This zone contains favorable alteration and is situated in the same stratigraphic package as the McDermott, South and Central Zones.

6.3 Geology of the Holt-McDermott mine

The Holt-McDermott deposit is located 1 kilometer south of the Holloway mine (Figure 15) within basalts considered to be part of the Kinojevis assemblage (Workman, 1986; Robert 1997; Ayer et al., 1999). The deposit comprises several lenses of albitized and gold-mineralized volcanic rocks located within the McDermott shear zone, a splay of the regionally extensive Ghostmount fault (see Figure 2). The host rocks to the deposit form a steeply south dipping, upright homocline of pillowed and massive tholeiitic rocks, trachytes and minor sedimentary rocks.

Past production came from the Worvest/Three star, Mattawassaga, and McDermott zones, present production is from the South Zone (SZ) and future production is planned on the Central Zones. The Worvest/Three star, Mattawassaga, and McDermott zones are all relatively shallow ore bodies (less than 500 meters depth) located within the McDermott Shear Zone.

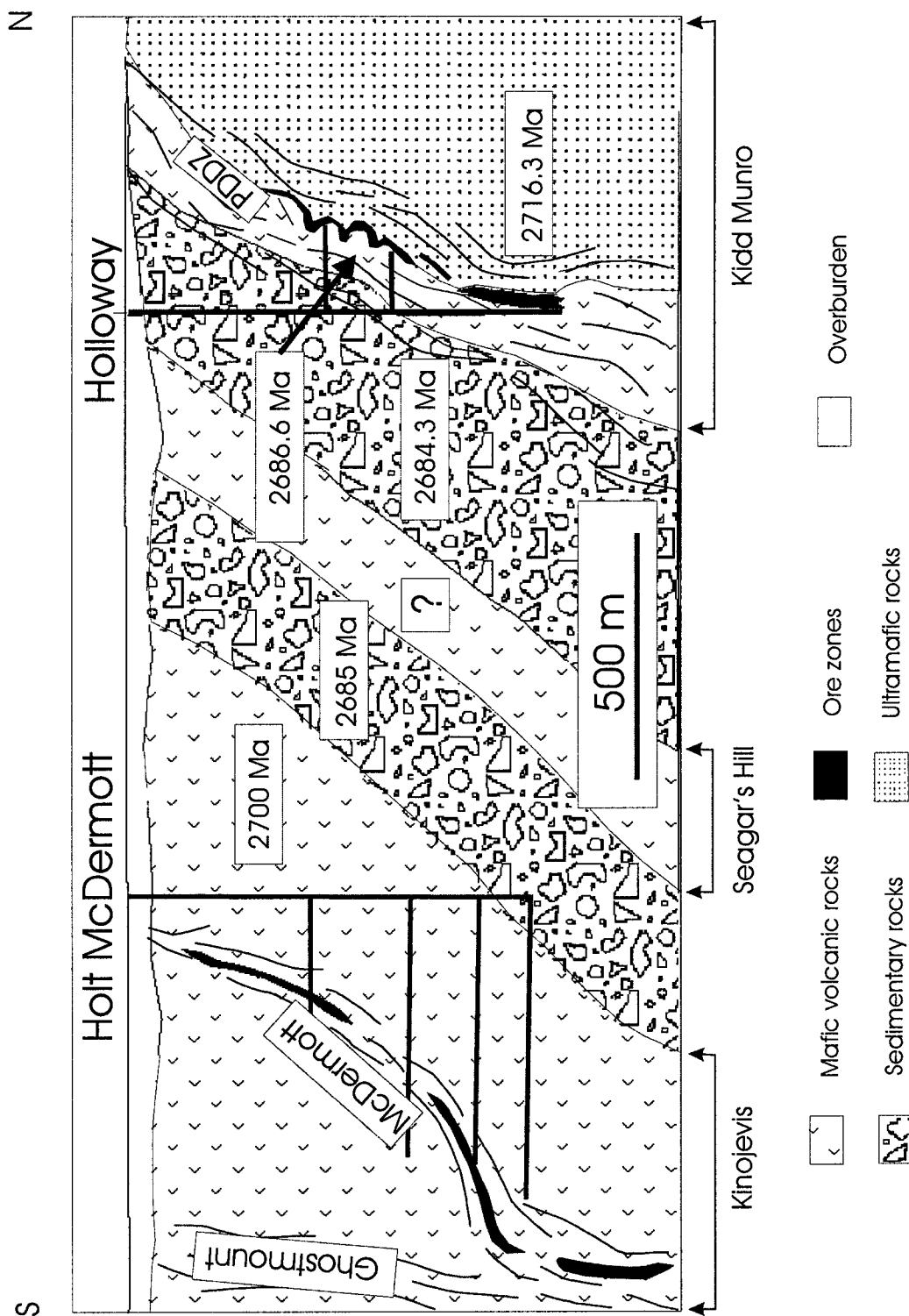


Figure 15. Cross-section through the Holloway and Holt-McDermott Deposits. U-Pb ages taken from Ropchan et al. (2002). Volcanic rocks divided into Kinojevis and Kidd-Munro assemblages. Seagar's Hill Tholeiitic basalts are thought to be part of the Kidd-Munro assemblage.

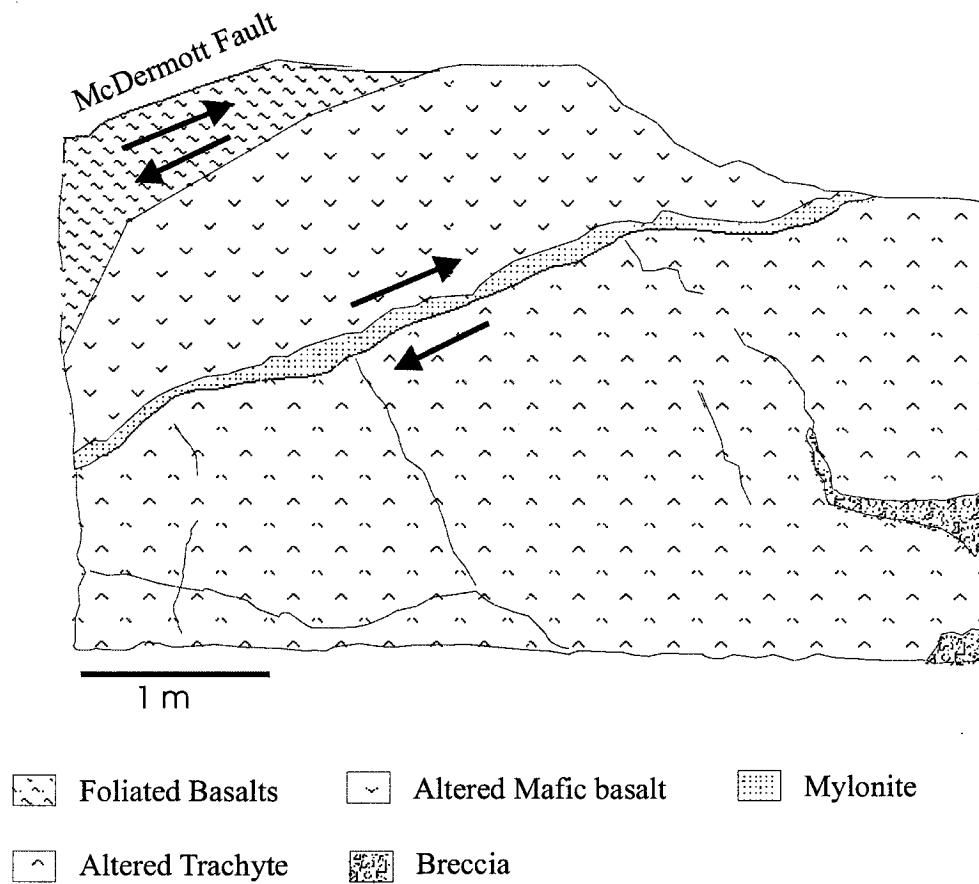


Figure 16. Wall map of 3200 sublevel, 3216 haulage looking west. The upper contact of the South Zone's altered basalts and trachytes is defined by a zone of intensely sheared mafic basalts and cross-cut by a mylonitic shear zone, both with reverse sense of shear, herein named the McDermott Fault.

The South and Central zones are considered to be down-dip extensions of the McDermott zone. Ore zones consist of competent lithons of hematite, albite and carbonate altered rocks with associated pyrite mineralization, surrounded by discrete zones of intense fabric development.

Figure 16 is a wall-map (vertical section) of the 3216 haulage showing the relationship of the mineralized to the McDermott Shear zone. The intensely altered basalts have undergone minimal deformation and are enveloped by zones of intense fabric development.

Mineralization in the deposit was previously interpreted to be genetically associated with the intrusion of syenites, largely due to the apparent spatial association of gold mineralization and syenite distribution (Robert, 1997). In addition, previous work identified syenites as the host mineralization in the deposit (Robert, 1997). However, the high degree of alteration, ubiquitous in the deposit, has replaced almost all primary mineralogy and rendered identification of the host lithology extremely difficult. Further discussion of the origin of the mineralization is reserved for section 6.4.

6.4 Lithologies

The major lithologies within the deposit are pillowed and massive tholeiites, trachytes, greywackes and mudstones and various generations of dykes. Samples of all lithologies were

studied petrographically and selected samples were sent to the OGS laboratories in Sudbury for geochemical analysis.

6.4.1 Mafic volcanic rocks

Pillowed tholeiites

This, the most abundant lithology, occurs throughout the host stratigraphy of the Holt-McDermott mine. Pillowed tholeiites range from almost black to light green with textures indistinguishable to the naked eye. Plate 17, a photomicrograph of an unaltered pillowed tholeiite from just east of the Holt-McDermott mine, shows the textures typical of these basaltic rocks. Selvages composed of chloritic and graphite surround pillows, which are typically 3-4 meters in length and 2 meters in height where not deformed. Well-defined cusps are ubiquitous and provide reliable south facing tops indicators in undeformed rock units. Additional macroscopic features include concentric cooling cracks, typically spaced at 2 to 5 cm intervals, and varioles seen in only a few locations in drill cores (Plate 18). Larger, decidedly spaghetti like (~5 meter X 5 meter) lava tubes have been observed in surface outcrops in the area.

Unaltered pillowed tholeiite consists of a very fine-grained mineral assemblage of chlorite+albite+calcite+epidote+pyrite. Chlorite occurs as amorphous aggregates, elongated where significant deformation has occurred. These aggregates of chlorite are typically

Plate 17. Photomicrograph under PPL of an unaltered, metamorphosed basalt from the Holt-McDermott mine vicinity. Plagioclase laths are well defined with most mafic minerals having been replaced by chlorite during regional metamorphism. Sample MAT-1 taken from DDH H-167, 305m. Field of view is 5 mm.

Plate 18. Photomicrograph under PPL of varioles in altered metabasalt. Varioles consist of radiating, acicular crystals of plagioclase and are surrounded by chlorite, the product of metamorphosed ferromagnesian minerals, as well as hydrothermal alteration mineral assemblages (albite + ferroan calcite + pyrite). Sample MAT-3, DDH H-167, 856. Field of view is 1 cm.

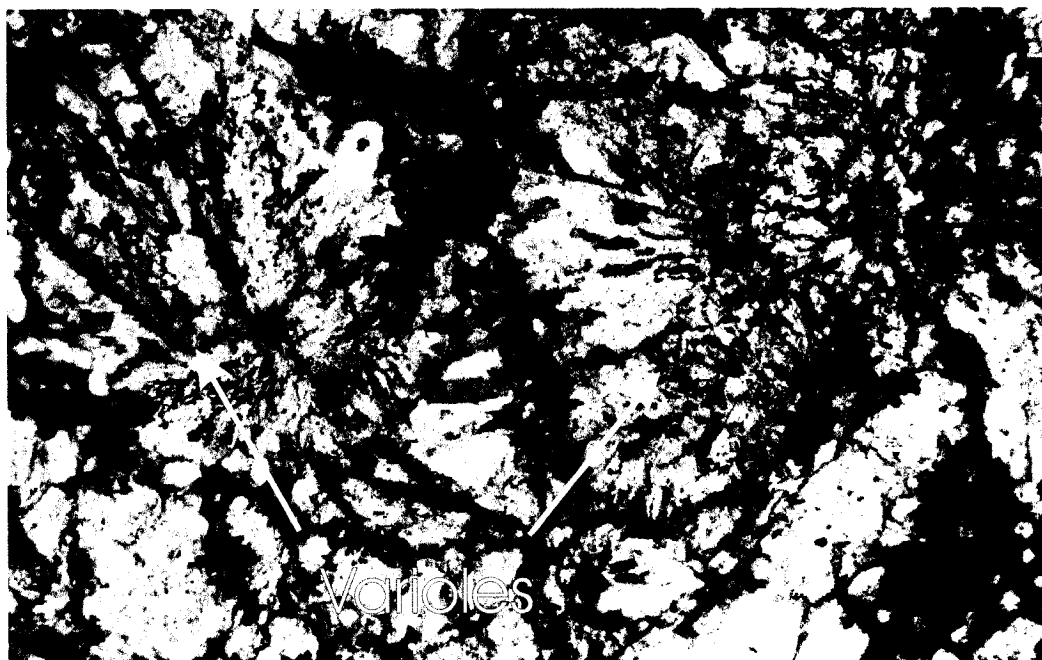
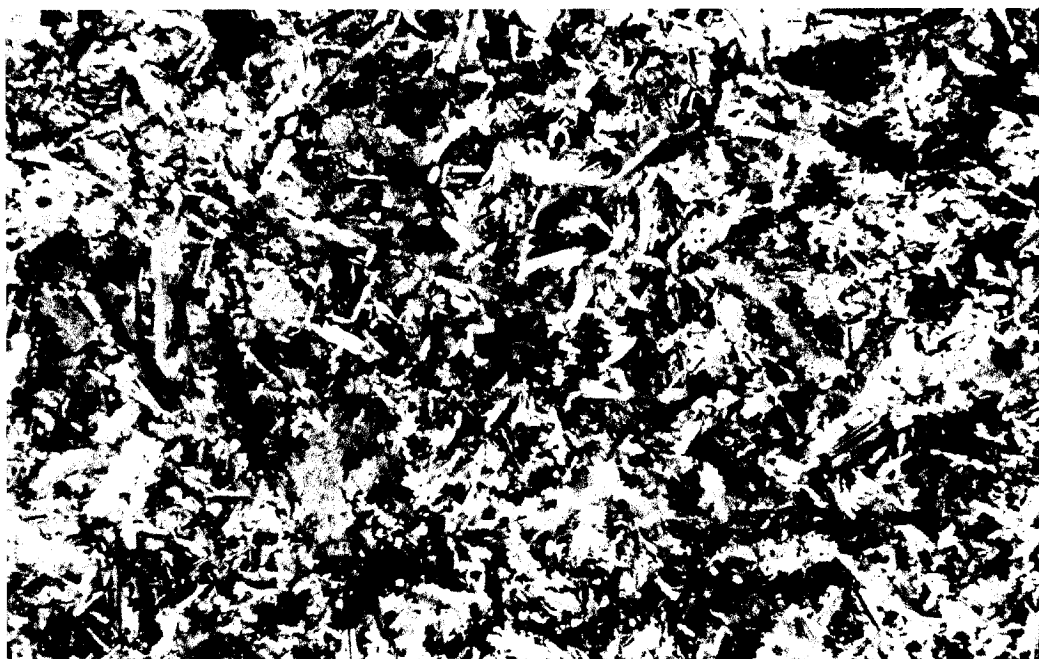
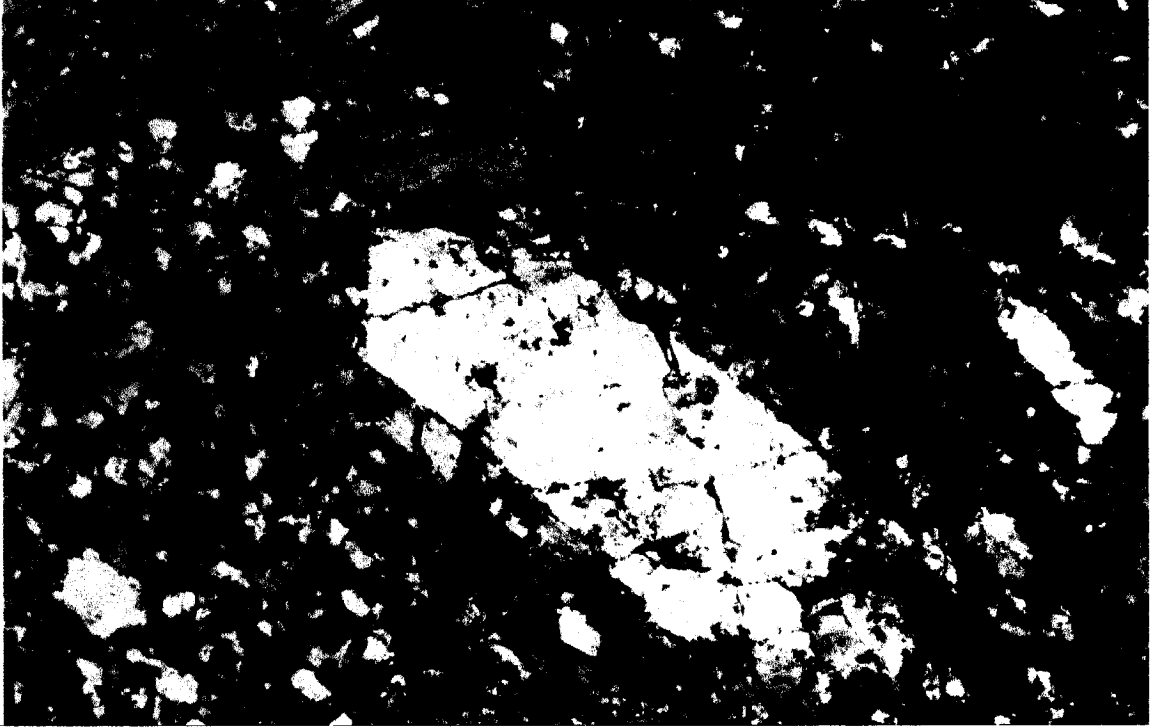


Plate 19. Photomicrograph under XPL of altered trachyte showing relic phenocryst of plagioclase. Groundmass is intensely altered fine-grained albite and quartz with traces of calcite and pyrite. Sample MAT-4, DDH H-167, 903m. Field of view is 1 cm.



between 0.5-1mm in size and tend to envelope other minerals. Chlorite is green to blue pleochroic and displays first order grey birefringence. Chlorite is the only mafic mineral present in these rocks, and it is likely to have formed from regional hydrous metamorphism of primary mafic minerals.

Albite occupies 40-60% volume of samples as fine-grained crystals in the groundmass, typically < 0.1mm. Albite crystals are translucent with low relief under plane polarized light, with first order grey and blue birefringence under crossed nichols. Albite is distinguishable from quartz by a biaxial optical figure, but this is only rarely visible due to the very fine-grain size. All plagioclase is of albitic composition, suggesting that extensive sodic alteration has occurred.

Calcite occurs in the groundmass as fine-grained (< 0.1 mm), translucent, anhedral crystals. Calcite occurs within small veins which cross-cut all lithologies throughout the deposit. The habit of calcite, integrated within the cryptocrystalline groundmass and within cross cutting veins suggests that it is likely a secondary mineral, the result of metamorphism and/or hydrothermal alteration.

Epidote is found in thin veins, less than 0.5 mm in thickness, that cross-cut the all observed foliations.

Pyrite occurs as 1-2 cm euhedral crystals within pillow selvages. This pyrite has an almost perfectly cubic form and is more common within pillow cusps, or at pillow triple junctions.

Massive tholeiites

Tholeiites of the Holt-McDermott mine are part of a newly redefined, predominantly basaltic Kinojevis lithotectonic assemblage (Ayer et al., 1999), thought to be transitional from abyssal plain basalts of the Kinojevis assemblage to the calc-alkalic arc-type volcanism of the Blake River Assemblage (Ayer et al., 1999). The tholeiites of the Holt-McDermott mine are a basal member of the assemblage, likely extruded onto an abyssal plain. An U-Pb zircon crystallization age for a Kinojevis assemblage rhyolite in the area is 2701.7 ± 2.2 Ma (Ropchan et al., 2002).

Massive tholeiites are much less abundant in the Holt-McDermott mine than the Holloway mine. They are found in the hangingwall of the deposit above the McDermott shear zone as well as in surface outcrops south of both the host stratigraphy and the Ghostmount fault zone (Figure 15).

Massive basalts are dark green to black when unaltered, and coarse grained with gabbroic subophitic textures. Interlocking laths of plagioclase and mafic minerals are visible to the unaided eye, forming a homogeneous texture.

The massive tholeiites are composed of albite + chlorite + calcite. Albite forms acicular, subhedral grains between 0.1 and 0.5 mm in length and 0.1-0.2 mm in width. Albite appears to be pseudomorphic after primary plagioclase laths.

Chlorite occurs both as subhedral to anhedral pseudomorphs after amphibole and pyroxene and anhedral aggregates surrounding albite, comprising 30-40 modal volume in the massive tholeiites. The aggregates of chlorite are typically between 0.5-1mm in size and tend to envelope other minerals. Chlorite is interpreted to replace primary mafic minerals as a result of regional metamorphism. Calcite occurs in interstitial spaces as fine-grained (< 0.1 mm), translucent, anhedral crystals.

Ore zone trachytes

The trachytes found within the mineralized zones at the Holt-McDermott Mine are the host to the economic mineralization. Trachytes have been recognized within ore zones in this study as well as in the McDermott, Mattawassaga and Three Star/Worvest zones (Workman, 1984). These rocks have also been identified in drill core east of the mine property in BMG hole 167.

Where found, trachytes are completely altered. They range in colour from dark black (chlorite rich) to pink (albite rich), and are extremely fine grained, with phenocrysts of plagioclase (albite) visible to the unaided eye. Plate 19 shows a well-defined relic

plagioclase phenocryst which has been completely replaced by cryptocrystalline albite with uniform extinction. Contacts of this unit are difficult to discern due to the high degree of alteration, with the exception of the upper boundary where the unit is cut off by the hangingwall McDermott fault. Numerous alteration fronts can be observed within the unit. Their contacts range from discrete, vein-related contacts to more cryptic contacts that are diffuse on the scale of meters.

It is important to note that a significant debate exists over the widespread presence of syenite in this deposit. These rocks, with their pink colour, and rare phenocrysts have often been considered to be intrusive, yet through the course of this study, the lack of intrusive contacts with chilled margins, combined with the fine-grained nature of these rocks, suggest that syenites are not a major host of gold mineralization in the Holt-McDermott deposit. Rather, the majority of rocks which have been labeled “syenite” by mine geologists appear to be heavily altered trachytes, and could easily be interpreted as extrusive rocks.

The original mineralogy of the trachytes has been completely replaced. They are composed of 75-85% albite, 15-25% calcite as well as trace amounts of pyrite. Two forms of albite have been identified, the first in the groundmass and the second as pseudomorphs of plagioclase phenocrysts. Groundmass albite grains are generally < 0.1 mm in size, subhedral to anhedral and range from elongate to equant in form. Albite is distinguishable from quartz only on rare occasions where the biaxial optical figure is evident. Where trachytes are less

altered, albite appears to be pseudomorphic after plagioclase in the groundmass, occurring as fine microlaths within a porphyritic trachytic texture.

Large phenocryst relics composed of albite are dispersed throughout these rocks. The large plagioclase phenocryst pseudomorphs are composed of fine-grained albite crystals that display uniform extinction under XPL. These phenocrysts are occasionally visible with the naked eye in hand sample. Relic phenocrysts range between 5 and 8 mm in length and have preserved Carlsbad twinning.

Calcite occurs in interstitial spaces as fine-grained (< 0.1 mm), translucent, anhedral crystals. Calcite is light brown with pleochroic 'rainbow' albite twins, and has high relief with rhombic cleavage occasionally visible.

Fine-grained (<0.1mm), euhedral crystals of pyrite are disseminated throughout these rocks, comprising 1-5 % of modal volumes.

6.4.2 Argillites

Argillites form a single horizon, visible in drill core and underground as a 2-3 m unit located 5-10 meters structurally below the ore-bearing horizon. Argillites are black and extremely fine grained, with visible laminations (less than 1mm in thickness), alternating layers of

lighter and darker material. Framboidal pyrite occurs as anhedral to euhedral grains up to 2 cm in diameter.

6.4.3 Greywackes

Accessible only on the 1160 meter shaft station and for a short distance (25m) south of the shaft, a sequence of interlayered greywackes and siltstones was mapped. Greywackes occur in beds commonly 5-7 cm thick, with occasional beds reaching 15cm in thickness. They are grey to brown, have graded bedding and visible clasts of feldspar in the coarser-grained lower parts of individual beds. Interlayered with the greywackes are finer beds of siltstone to fine grained sandstone. The bands are typically 2-3 cm in thickness and have well preserved internal lamination (< 0.5 cm). Darker than the surrounding greywackes, no individual grains can be distinguished in hand sample. The rocks have a relatively restricted grain size distribution, composed of sub rounded to well-rounded grains of quartz and plagioclase, from 0.4 to 0.8 mm in size. Drilling records from both the Holloway and Holt-McDermott mines indicate that the greywackes are part of the same sequence of sedimentary rocks that overlie the Seagar's Hill volcanic sequence.

6.4.4 Dykes

Mafic dykes.

Mafic dykes cross-cut all other lithologies. They strike west and dip steeply to the north. The dykes are black, fine-grained to aphanitic and extremely hard. An example of these dykes can be seen on the 700-meter level, within the safety bay located just south of the main rail junction.

Lamprophyric dykes

Lamprophyric dykes throughout the deposit cross-cut stratigraphy at an acute angle. The dykes range from green where carbonate rich, to grey, where less altered. They have visible 'eyes' of blue quartz or albite and well-defined chilled margins. Lamprophyric dykes can be seen cross cutting all other lithologies in the mine sequence. They are similar in composition to those described at the Holloway mine that returned a U-Pb Zircon crystallization age of 2671.5 ± 1.9 Ma (Section 5.5.5).

Syenite dykes

Syenite dykes are distributed throughout the mine sequence. In particular, they have been identified by Robert (1997) in the center of the mineralized South Zone. In this study,

syenite dykes were found only within the hangingwall of the deposit, not within the ore-bearing horizons. Syenite dykes are medium grained and equigranular, with interlocking crystals of albite, 0.5 to 1 cm in length and <0.5 cm in width. Quartz represents up to 5 % by volume of these rocks and may be of primary or secondary origin.

6.5 Geochemistry

6.5.1 Introduction

Variably altered mafic tholeiites (both pillowed and massive) were sampled for geochemical analysis in order to characterize these rocks. Jones (2000) suggested that REE chemistry was modified by hydrothermal fluids and this hypothesis warranted comparison to any new data generated during the course of this study. Additionally, samples of trachytic rocks identified in thin section were sent for geochemical analysis in order to characterize them and compare them with tholeiitic rocks of the deposit. An effort was made to find suites of unaltered to altered samples of both tholeiitic and trachytic rocks by stepping out to the east along strike of the deposit and sampling the stratigraphy. Hole H-167, drilled in the summer of 2000 by BMG on the adjacent Mattawassaga claim, provided an example. H-167 shows an apparent progression from unaltered tholeiites to heavily albitized and mineralized rocks. Four samples, Mat-1, Mat-2, Mat-3 and Mat-4 were taken from the hole, recording a progression from unaltered (Mat-1), weakly altered (Mat-2), strongly altered (Mat-3) to

intensely altered and mineralized (Mat-4). These samples were analyzed with the intention of documenting trends (particularly in REEs) due to alteration and/or mineralization.

6.5.2 Major Elements

Major element data for all samples are tabulated in Appendix A. Mat-1, the least altered sample, shows a relatively high degree of calcite alteration, with CaO value of 7.75 wt%. Tholeiitic rocks show a variable amount of calcite alteration with values ranging from 5.75 to 11.75 wt% CaO. Mafic volcanics also show a net increase in Na₂O as a result of albite alteration. Na₂O values range from 1.88 to 10.63 wt% in the mafic volcanics. This reflects the varying degrees of alteration as seen in the petrographic examination, with modal percentages of albite ranging from 40 to 60 %.

Trachytes are located only within areas of intense alteration. Petrographic examination shows that trachytes have been completely replaced by albite. Accordingly, the major element analyses of trachytes resembles that of the composition of albite, with Na₂O values of 8.72 to 10.63, SiO₂ values ranging from 60.84 to 65.66 %. The addition of pyrite also is reflected by the Fe₂O₃ values of 10.24 to 15.66 wt %.

6.5.3 Rare earth elements (REE)

Mafic volcanic rocks throughout the Holt-McDermott deposit show REE element patterns that are consistent with tholeiitic volcanic rocks of the Kinojevis group (Jensen and Langford, 1985). Figure 17 shows REE profiles, normalized to chondrite values found in Sun and McDonough (1989), for tholeiites of the Holt-McDermott deposit. They show relatively flat patterns around 10 times chondrite values. Samples show only a minor depletion of Eu versus chondrite values, which may be the result of a very small amount of fractional crystallization of plagioclase. One sample is distinct from the other tholeiites, having a slightly enriched yet still flat lying REE pattern near the 100 times chondrite level.

Figure 18 shows REE plots for trachytes from the Holt-McDermott deposit, normalized to chondrite values found in Sun and McDonough (1989). Trachytes are distinguished from tholeiitic rocks by their enrichment in LREEs. The smooth slope of this LREE enrichment is more consistent with a small degree of partial melting from a tholeiitic source versus fractional crystallization (Rollinson, 1993). Additionally, the heavy REEs show no depletion and are relatively flat in the 10 times chondrite range. This further suggests that the trachytes are derived from a tholeiitic source via a small degree of partial melting (Rollinson, 1993).

Jones (2000) suggested that this enrichment of LREE might be the result of mobility of LREE and addition of LREE via the hydrothermal fluids associated with alteration.

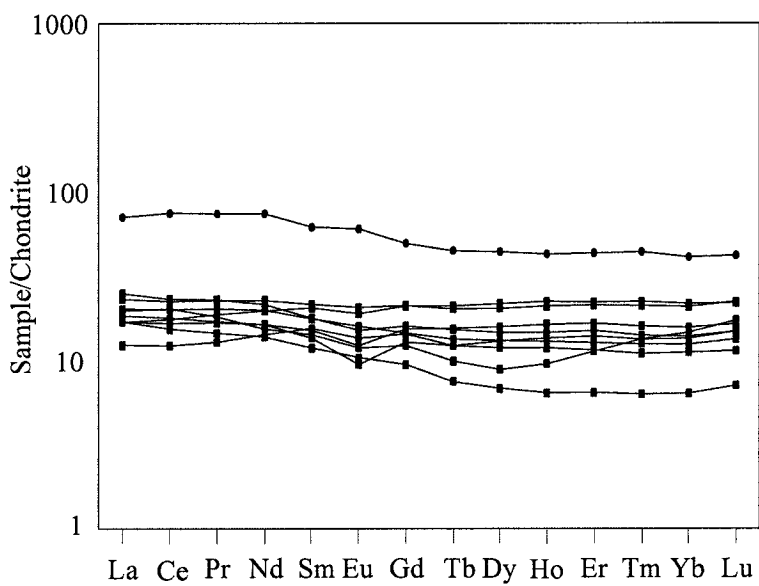


Figure 17. REE profiles of tholeiitic volcanics from the Holt-McDermott Mine. Elements normalized to chondrite values from Sun and McDonough (1989).

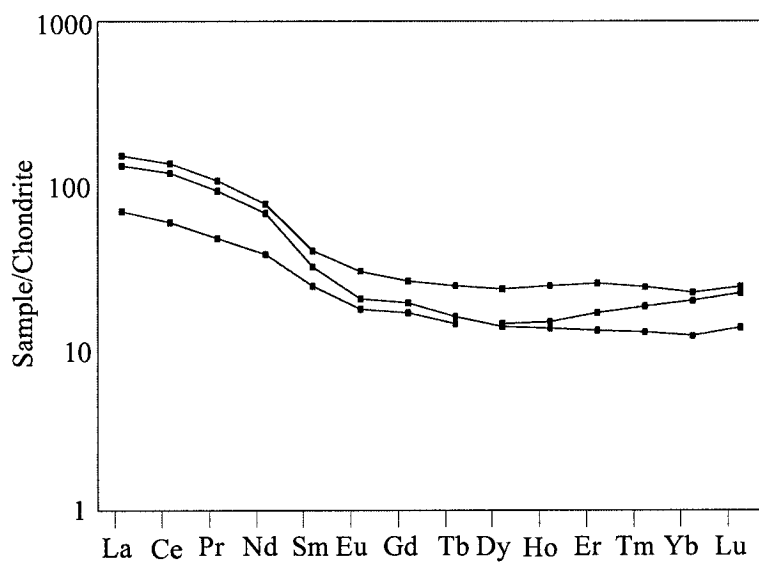


Figure 18. REE profiles for trachytes from the Holt-McDermott deposit. Elements normalized to chondrite values taken from Sun and McDonough (1989)

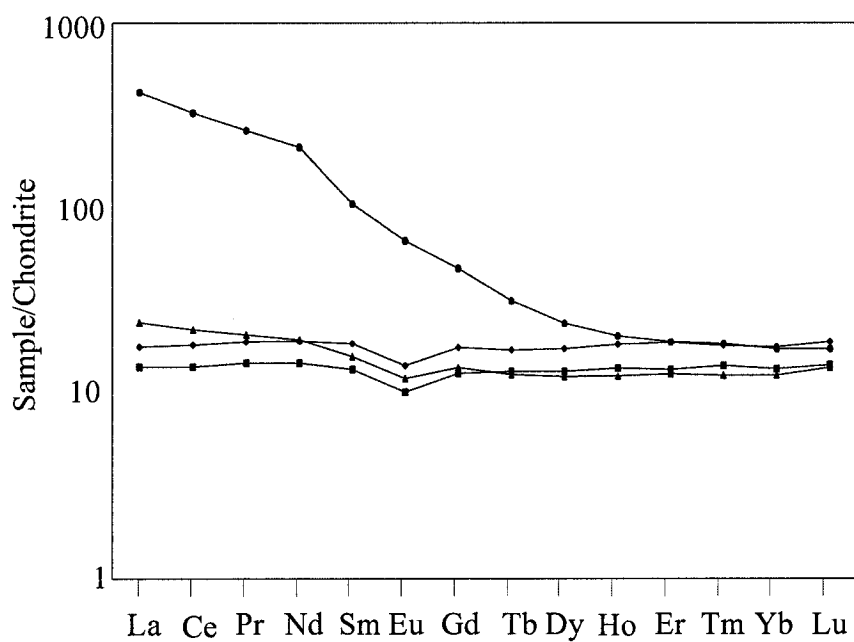


Figure 19. REE profiles of samples Mat -1 (Squares); Mat - 2 (Triangles); Mat - 3 (diamonds) and Mat - 4 (circles). Mat - 4 is clearly a different lithology, see discussion in text. Elements normalized to chondrite values taken from Sun and McDonough (1989).

In order to test this hypothesis, REEs were measured for samples Mat-1 through Mat-4, which show a gradual increase in alteration over a distance of <100m. Figure 19 shows REE profiles from these samples normalized to chondrite values. Two distinct groups of rocks can be identified based on their REE profiles. The first group (Mat-1, Mat-2 and Mat-3) resembles tholeiitic rocks seen in Figure 17 and have flat lying REE patterns near 10 times chondrite. This group also has a minor depletion of Eu, which is commonly interpreted to be due to fractional crystallization of plagioclase from the tholeiitic melt (Sun and McDonough, 1989). The second group, composed of just one sample - Mat-4, shows enrichment in the LREE with a smooth slope, and no depletion of the HREE similar to the trachytes of the South zone. Although a gradual increase in both alteration and mineralization was observed in drill core, the host of the strongest alteration and mineralization is clearly a distinct lithology. This evidence further supports the notion that the primary, wide spread economic mineralization at the Holt-McDermott deposit is lithologically controlled and confined to a specific lithological, stratigraphic horizon.

6.5.4 Trace elements

Trace element spider diagrams were produced for tholeiitic volcanics, trachytes and the Mat-1 through Mat-4 sample series (figures 20, 21 and 22 respectively). Spider diagrams show the general variation amongst similar samples of specific elements normalized to known values for the purpose of comparison (Sun and McDonough, 1989)

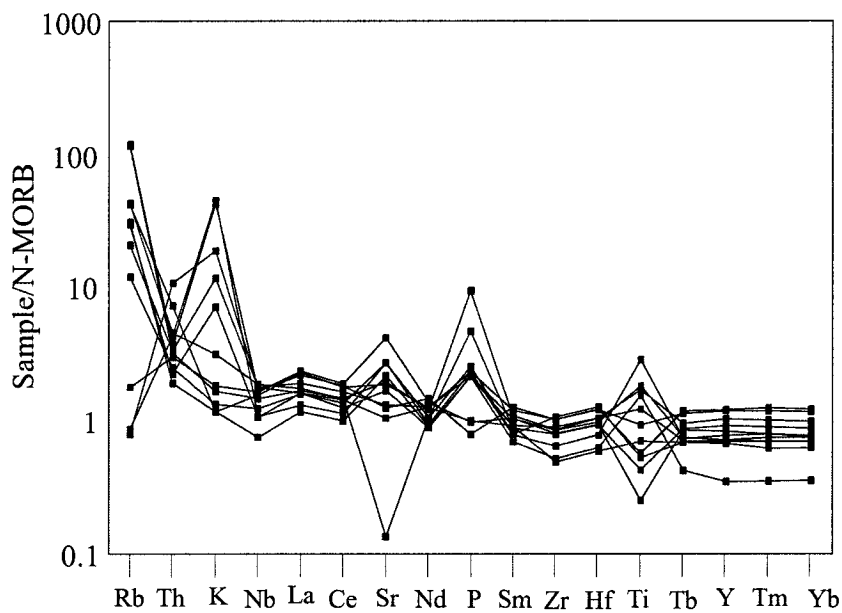


Figure 20. Normalized spider plot of elements from tholeiitic volcanics in the Holt-McDermott mine. Normalized to N-Morb values taken from Sun and McDonough (1989).

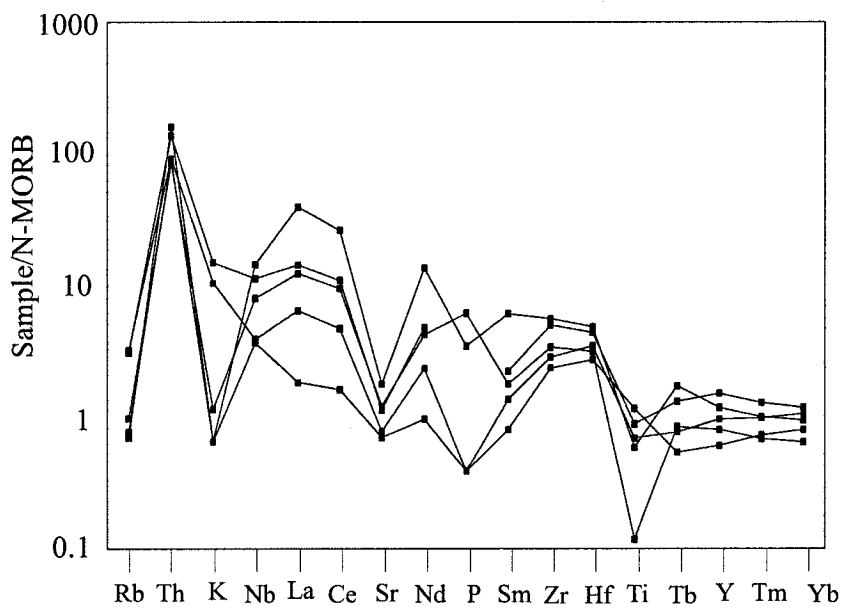


Figure 21. Normalized spider plot of elements from trachytes in the Holt-McDermott Mine. Normalized to N-Morb values taken from Sun and McDonough (1989).

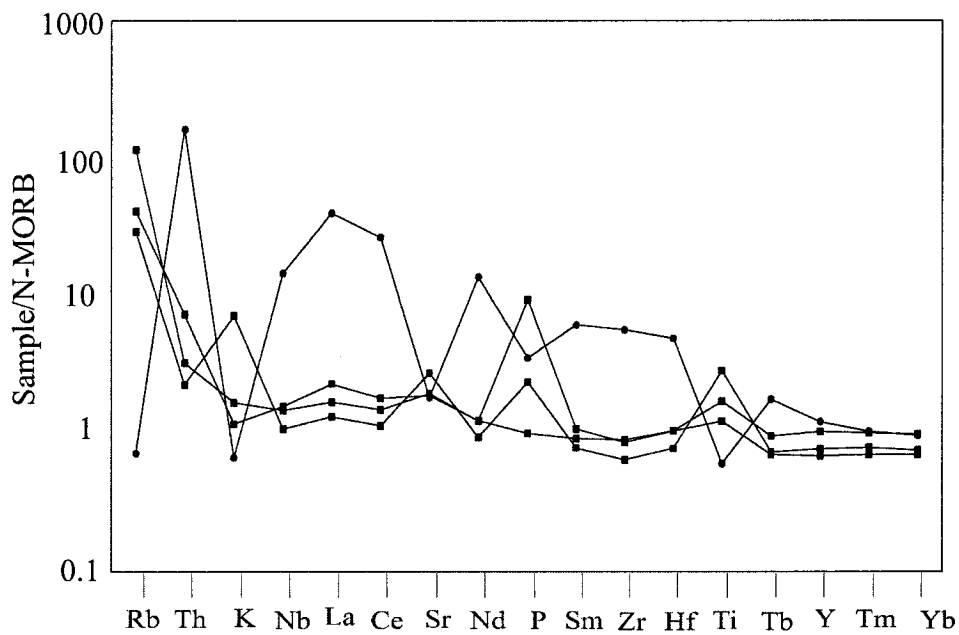


Figure 22. Normalized spider plot of elements from samples Mat- 1, Mat -2, Mat - 3 (Squares) and Mat - 4 (Circles). The data are consistent with Mat - 4 forming from fractional crystallization of Mat - 1 through 3, see discussion in text. Normalized to N-Morb values taken from Sun and McDonough (1989).

Tholeiites (figure 20) were normalized to N-MORB values from Sun and McDonough (1989) and show a well-developed pattern with variations in Ti, P, Sr, K and Rb. The variation in Ti levels can be accounted for through crystallization of ilmenite and/or titanite from the original magma. These minerals have been subsequently altered to leucoxene which is consistent with the modal percentages of leucoxene in the rocks (section 6.4.1). The addition of P to the samples is best explained by the addition of apatite and other phosphate minerals, interpreted to be the result of secondary alteration of the rocks. Varying normalized amounts of Sr, K and Rb are likely the result of a net addition of albite and calcite to the overall bulk composition of the rocks. A slight variation in Th can be observed in the rocks and is likely the result of the addition of hydrothermal monazite, not directly observed in thin section from the Holt-McDermott deposit, but noted as part of the hydrothermal mineral alteration assemblage in the Holloway Deposit by Ropchan (2000).

Trachytes, normalized to N-MORB from Sun and McDonough (1989), show a distinct pattern with variations in Ti, P, Sr, K, and Th in figure 21. Trachytes show a variation in Ti in one sample, which is interpreted to be associated with the crystallization of ilmenite and titanite from tholeiitic source material. Variations in P, Sr, and K are interpreted to be a result of hydrothermal alteration and the addition of varying degrees of albitic material. The extreme enrichment of Th is likely the result of an addition of hydrothermal monazite during alteration of the rocks (Ludden et al., 1984). The lack of depletion of Nb and a relatively small depletion in Ti in only one sample suggest that these rocks were not produced within a subduction environment. The patterns here likely represent the modification of the original

patterns of the trachytic rocks by secondary alteration fluids, but may be attributed to small degrees of partial melting from a tholeiitic magma.

Figure 22 shows trace element spider plots for the Mattawassaga sample series. The plots of these samples define two distinct groups. Tholeiitic rocks, previously identified both in thin section and by their distinct REE patterns, show very little variation. They have a slight enrichment in Ti, interpreted to originate from secondary hydrothermal alteration, corroborated by the presence of titanite and monazite in small fractures throughout these rocks. Likewise, variations in phosphorous are the result of secondary crystallization of apatite, xenotime and other phosphate minerals during alteration of these rocks, evidenced by the presence of these minerals in fractures and interstitial spaces. Variations in K and the enrichment of Rb are the result of varying degrees of albite alteration.

Sample Mat-4 is distinct from the tholeiitic rocks. The high levels of Th is directly related to the hydrothermal precipitation of monazite and other U-bearing minerals. The sample is depleted in Ti with respect to the tholeiites, suggesting a decrease in the amount of crystallization of titanite/ilmenite. Additional depletions of K and Rb are consistent with a provenance of partial melting from a tholeiitic source. No signature that can be attributed to subduction (depletion in Ti or Nb) was observed.

6.5.5. Discussion

The petrology and the geochemistry define two distinct types of mafic volcanic rocks in the Holt-McDermott mine. Zones of most pervasive mineralization and alteration are confined exclusively to a package of trachytic rocks, defined by smoothly sloping LREE enriched patterns and almost complete albite alteration. Spider plots of these trachytic rocks show enrichment in Th and P, likely associated with the addition of monazite, apatite and xenotime as observed during petrographic and SEM examination. Variations in K, La, Sr and Rb are associated with the intense albite alteration. Tholeiites show relatively flat patterns with variation in Ti due to ilmenite crystallization, P variation due to the addition of secondary apatite and xenotime, as well as Sr, K and Rb due to varying degrees of albite alteration.

6.6 Alteration

All major lithologies in the Holt-McDermott deposit have been subjected to some form of hydrothermal alteration. They are distinguished from metamorphic mineral assemblages by comparison with unaltered, metamorphosed equivalents outside the effective region of hydrothermal alteration.

6.6.1 Hematite alteration

Hematite alteration was the earliest alteration event in the Holt-McDermott mine. It is found within the host trachytes as well as in tholeiites near the contacts with ore zones, and is preserved only in rocks that have not been subject to subsequent albite or carbonate alteration. The 'hematized' rocks are dominantly chloritic, with only minor hematitic alteration. This form of alteration has been historically labelled "Hematite" alteration based on the black to deep purple colour of the rocks.

All primary mafic minerals have been replaced by chlorite, leucoxene and to a lesser degree hematite.

6.6.2 Albite alteration

Albite alteration is the predominant alteration in the Holt-McDermott deposit and is associated with gold mineralization. Albite alteration is confined to the host trachyte unit, with only minor amounts of albite alteration identified within tholeiitic rocks. This alteration cross-cuts the earlier hematite alteration.

Albite alteration shows two major habits. The first is within pink to reddish haloes around small veins of albite cross cutting hematized rocks. These haloes are typically 2 to 3 times the width of the vein and are confined to tholeiitic mafic volcanics on the peripheries of ore

zones. Within the haloes, original mineralogy of the previously hematized rocks has been totally replaced with an albite+calcite +pyrite+gold alteration mineral assemblage.

Contemporaneous with the first form, a second, more pervasive form of albite is prominent within the host trachytic unit, and is associated with ore grade mineralization. This second form of albite ranges from white to buff brown to red, and has completely replaced primary mineralogy with an albite+calcite+pyrite+gold alteration mineral assemblage. A variable amount of carbonate alteration is always found associated with the albite alteration, often leading to the brown colour observed in hand sample. These two forms of alteration are likely coeval, with the vein related albite haloes located on the peripheries of zones of more intense and pervasive albite mineralization.

6.6.3 Carbonate Alteration

Carbonate alteration throughout the deposit is progressively more pervasive closer to the ore-bearing trachytes. It is generally associated with haloes around thin (2-5 cm) veins of quartz and calcite. Veins are generally located in a band 5 to 25 meters thick in tholeiites located in the hangingwall of the ore zone. Within the haloes of these veins, primary mineralogy has been entirely replaced by calcite. These veins both cross cut and have been folded parallel to the S_1 foliation, suggesting that they are synchronous with S_1 fabric development. This form of carbonate alteration is separated from metamorphic carbonate by its close spatial association with carbonate veins and its cross-cutting relationship with the metamorphic

assemblage. Although minor amounts of mineralization have been noted, extensive sampling by mine geologists have revealed no ore grade material within these haloes.

6.7 Mineralization

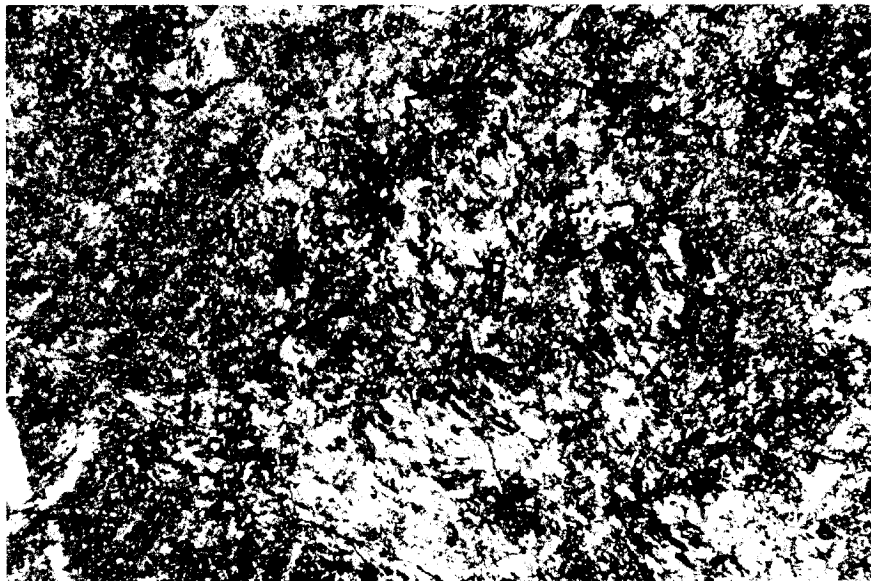
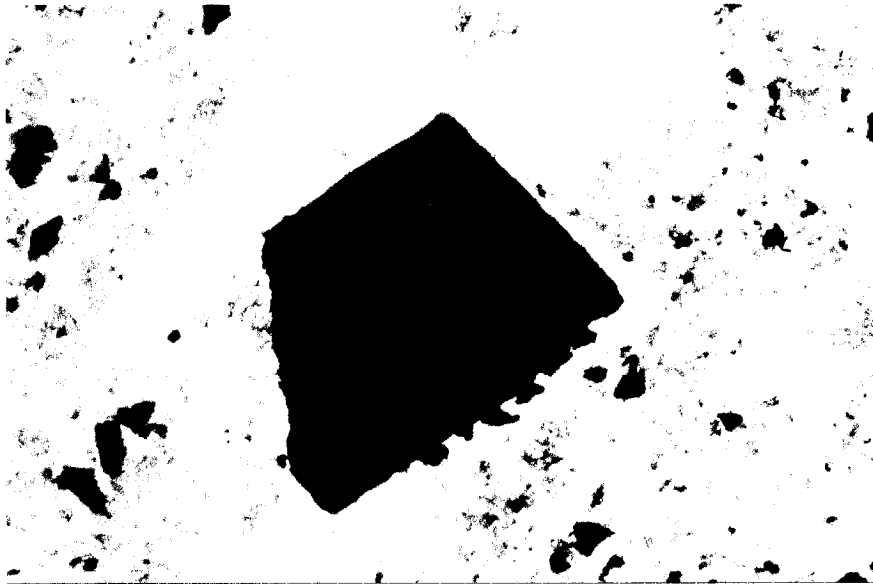
Pyrite is the primary mineral associated with gold in the Holt-McDermott deposit as in the Holloway deposit. The modal percentage of pyrite is an accurate tool for estimating relative values of gold in underground exposures. Occuring as small, < 0.2 mm, and euhedral crystals in highly albitized rocks, the distribution of pyrite in the deposit is remarkably homogeneous and occurs in consistent quantities (between 4-8 %). SEM investigations of these pyrites show them to be homogenous, with no zoning and very little arsenic. Plate 20 shows a typical pyrite from the Holt-McDermott's South zone, demonstrating the well-defined crystals and the homogeneous nature of the mineralization. A SEM image of a typical pyrite grain from the South zone is shown in Figure 23.

SEM investigation also revealed small, subrounded grains of the Yb phosphate mineral xenotime, as well as accessory chalcopyrite on or near grain boundaries of individual pyrite grains.

No gold grains were observed either in polished section or during the SEM investigation in this study (22 samples of up to 32 g/t were studied).

Plate 20. Intensely albite altered and pyrite mineralized trachytes from the Holt-McDermott mine. Photomicrograph under XPL shows pyrite pressure shadows surrounding and unusually large, euhedral pyrite. The pressure shadow defines an L_1 extension lineation within the S_1 foliation. Sample HMC 29, 7300 level, cut perpendicular to the S_1 foliation and near perpendicular to the L_1 lineation. Field of view is approximately 3 mm.

Plate 21. Intensely albite altered trachyte with pyrite mineralization. Original mineralogy and textures have been completely replaced by extremely fine grained albite + quartz + calcite + pyrite. HMC 32 B, perpendicular to the S_1 foliation and parallel to the L_1 lineation, 680 level. Field of view is 2cm, XPL.



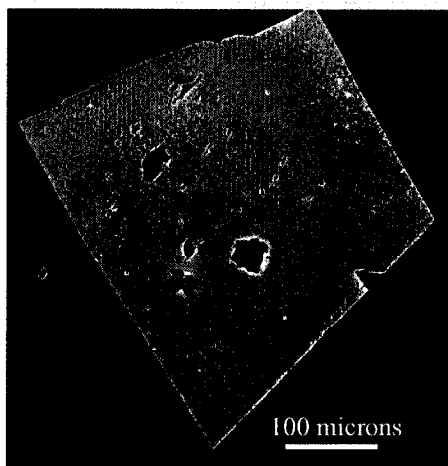


Figure 23. SEM photomicrograph of Pyrite taken from sample HMC 13, a highly altered and mineralized trachyte, from the 2320 main drift, 730 level, South Zone, Holt McDermott Mine.

6.8 Structural Geology

A comprehensive mapping program of the Holt-McDermott mine, both underground and on the surface, was carried out in the summer of 1999. This mapping concentrated on the structural geology of the deposit, as well as the lithologies, alteration and mineralization. For the purpose of presentation, structures will be discussed in sequence. Readers should be aware that the designation of deformation events (i.e. D₁, D₂, etc) are strictly for the area studied, and include only data gathered in the process of this investigation. Earlier deformation events conceivably could have been overprinted by the deformation events described here.

6.8.1 D₀ structures

Stratigraphic contacts are rare in the Holt-McDermott deposit. Individual flows within the sequence of tholeiites are generally thick, with contacts rarely observed underground.

Surface mapping in the area and immediately south of the deposit shows that individual massive volcanic flows are between 10 and 35 meters thick. Massive tholeiites typically have a layer of chlorite and epidote at upper and lower flow contacts, and more rarely vesicles or flow top breccias. However, massive tholeiites typically alternate with pillowed flows close to the Holt-McDermott Mine, making flow contacts more readily observed.

Within pillowed flows, S_0 can be observed as contacts between flows that are typically brecciated and therefore are easily traced at an outcrop scale. Measuring the long axis of pillows (where these rocks are not intensely deformed) and mapping brecciated zones, which typically have irregular contacts but can approximate bedding if mapped on a larger scale, are two methods which can also approximate S_0 . In sedimentary rocks, bedding can be measured directly as laminations within argillites as well as bedding in greywackes.

The entire Holt-McDermott deposit is located within a steeply to moderately south dipping, ENE striking stratigraphic sequence. Orientations of bedding, pillow long axes and flow contacts strike slightly (< 20 degrees) north of east and dip moderately to steeply to the south. Figure 24A shows a stereographic projection of poles to S_0 bedding planes. As in the Holloway deposit, S_0 is roughly parallel to S_1 , and may have been transposed and isoclinally folded parallel to S_1 . The poles are tightly clustered but appear to be somewhat bimodal, consisting of a steeper population and a more moderately dipping population. This apparent variation in dip of the foliation is a product of D_2 folding, and will be discussed later in section 6.8.4.

6.8.2 S_1 Regional Foliation

Throughout the deposit, located in discrete zones up to 100 meters wide, is a well developed, ENE striking and steep to moderately dipping S_1 foliation. Two of these zones are extremely

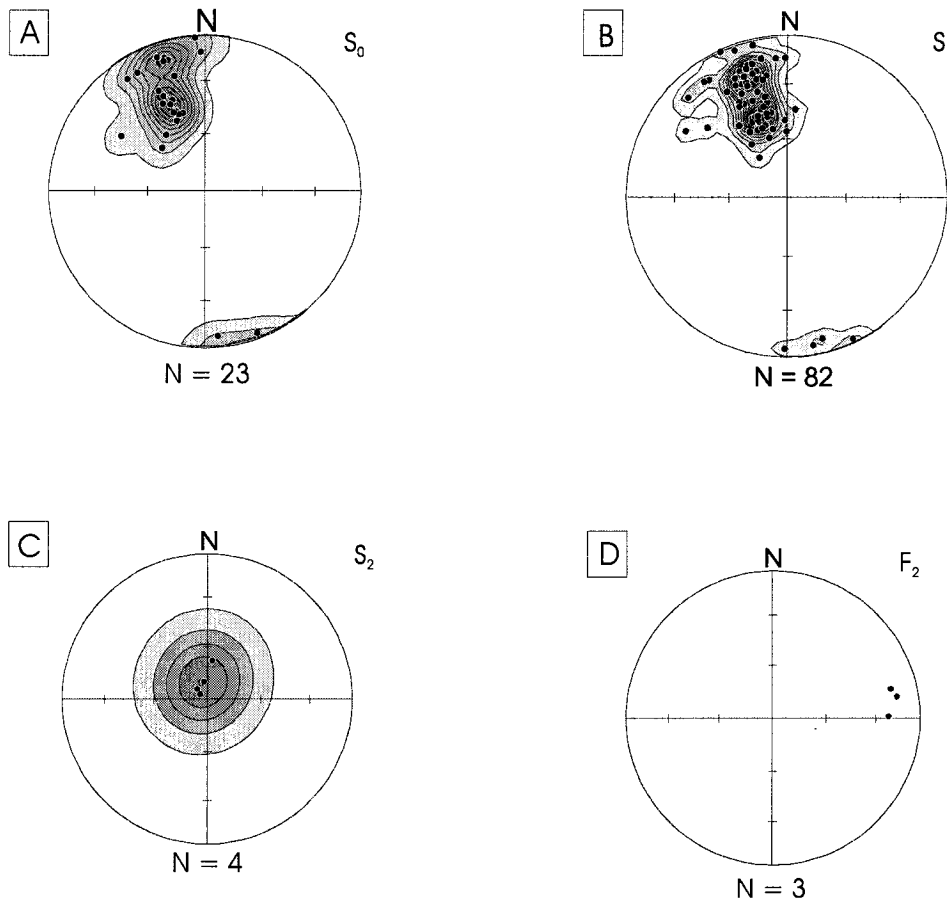


Figure 24. Lower hemisphere stereographic projections and density distribution via the Gaussian (3 sigma) method of: A) poles to bedding planes in the Holt-McDermott mine measured from pillows in volcanic rocks and lithological contacts, B) S_1 foliation, C) poles to S_2 cleavage planes and D) axes to F_2 crenulations approximated from thin sections.

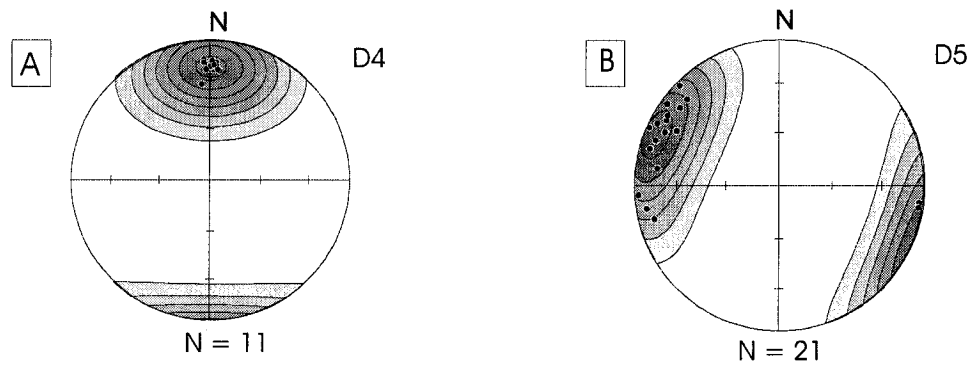


Figure 25. Lower hemisphere stereonet projections of poles to planes for the:
A) The (D4) McKenna Fault and related structures and B) Late north south (D5) faults

Plate 22. S_1 defined by chlorite in a photomicrograph from an altered tholeiite from the Holt-McDermott mine. This sample is cut perpendicular to S_1 and vertical. Sample HMC 26A, 700 meter level. Field of view is 3cm.

Plate 23. Photomicrograph taken at the same scale as plate 24 from the same sample, but cut perpendicular to S_1 and horizontal. Chlorite cut at this angle forms globular aggregates, suggesting that the L_1 lineation plunges directly down dip of the S_1 foliation. HMC 26B, 700 meter level, field of view is 3 cm.

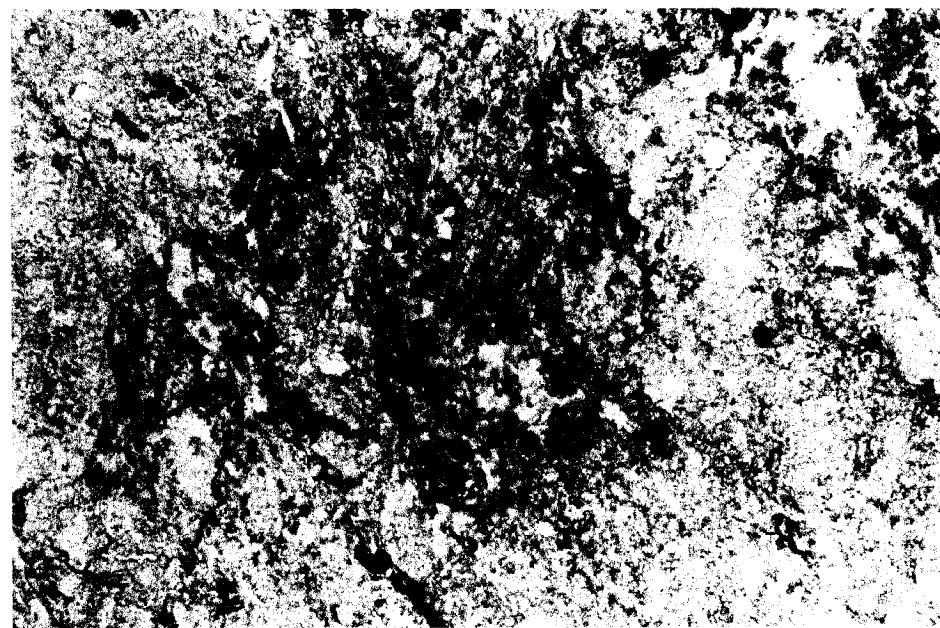
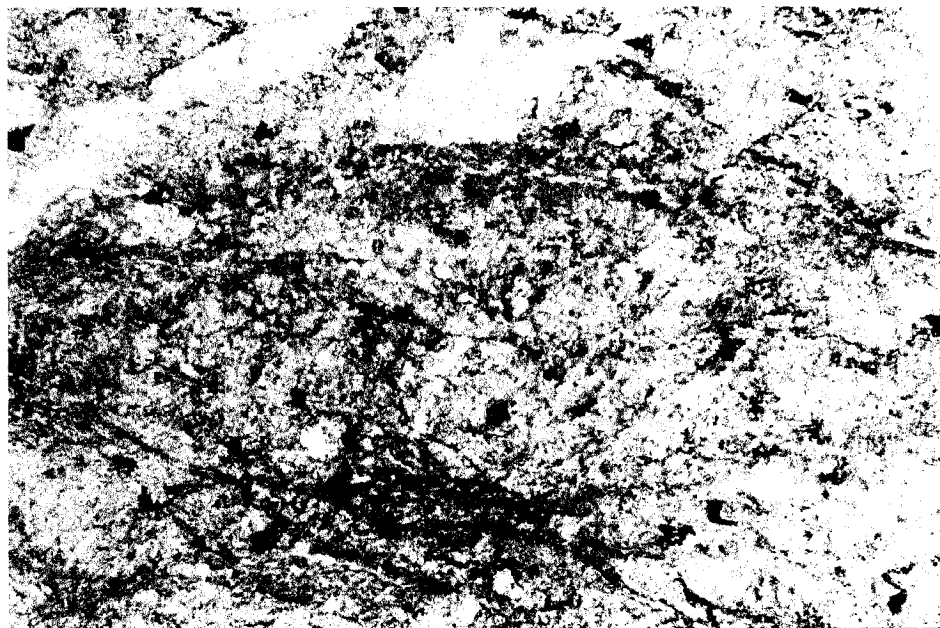
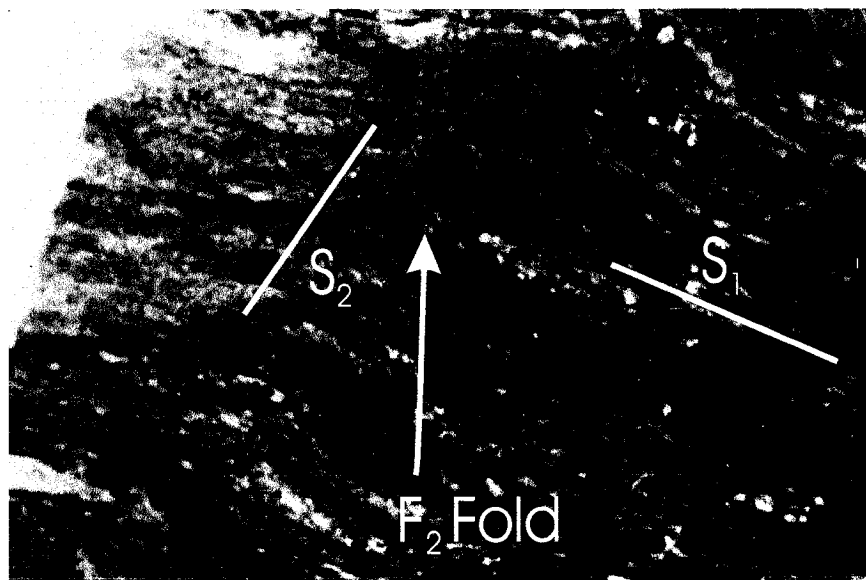


Plate 24. S_1 defined by fine-grained albite and quartz in previously altered trachyte. Calcite veins cross-cut the albitised rocks and the S_1 foliation. HMC 16, 730 level. Field of view is 1 cm.

Plate 25. S_1 defined by cryptocrystalline minerals in sedimentary rocks and subsequently folded by F_2 folds with subhorizontal axes. Sample HMC 22, 700 meter level, west wall. Field of view is 3 cm.



well defined, the large (>100 m thick) Ghostmount Fault located just south of the mine stratigraphy and the McDermott Shear Zone, within which all the mineralization is found (Figure 15). Figure 24b shows stereographic projections of poles to S_1 foliation planes. This foliation is roughly parallel to bedding planes and surrounds large blocks of relatively undeformed lithons.

Stretched and flattened pillows, pillow selvages and early carbonate veins folded into S_1 define S_1 macroscopically. S_1 is also defined by alteration banding in mafic volcanics and compositional banding in sedimentary rocks.

Microscopically, S_1 is defined by the alignment of minerals such as chlorite, albite and leucoxene in mafic volcanics, and chlorite and clay minerals in sedimentary rocks. Within the ore zone itself, particularly close to the contact with the country rocks, a foliation is well-developed in the host trachytes and is defined by alternating bands of parallel extinction within cryptocrystalline, recrystallized and annealed albite crystals.

6.8.3 L_1 extension lineation

Not visible macroscopically, an extension lineation is documented within the S_1 foliation plane in thin section. This L_1 extension lineation is defined by the elongation of minerals such as leucoxene and chlorite in mafic volcanics. Viewing the geometry of these minerals in two thin sections; one oriented perpendicular to S_1 and vertical, and one oriented

perpendicular to S_1 and horizontal, can be helpful in approximating the orientation of this extension lineation. Plate 22 shows a thin section cut perpendicular to S_1 and vertical (parallel to L_1). In this section chlorites appear as stretched, amorphous mineral aggregates. Plate 23, however, shows a thin section, which has been cut perpendicular to S_1 and horizontal (perpendicular to L_1). In this section the amorphous chlorites aggregates are equant. With no lineations apparent macroscopically, L_1 is approximated from thin sections, which suggest that it is a steeply dipping, east plunging extension lineation.

6.8.4 D_2 structures

The stratigraphy, as well as the S_1 foliation are all folded by D_2 folds. D_2 folds are gentle, open folds with large half-wavelengths (>300m) in this area. They have shallowly plunging axes that trend roughly east west (Figure 24d). The South zone is located on the limb of one of these large folds. Within the stratigraphy surrounding the South zone, S_0 and S_1 have more moderate dips than those surrounding the McDermott zone, located higher up in the stratigraphy. This shallowing of dip is visible on the regional scale (see Figure 15). No macroscopic features can be found associated with D_2 folds.

Smaller scale D_2 folds can be observed microscopically, particularly in rocks which are less competent (i.e. sediments) or which have been heavily carbonate altered. These folds are open, with horizontally to nearly horizontally plunging axes and can be seen folding earlier

S_1 foliations as seen in Plate 25. D_2 fold axes plunge shallowly to the east when plotted on the stereographic projection shown in Figure 24d.

Developed near or within the hinge zone of large D_2 folds is a near horizontal S_2 pressure solution cleavage. This finely spaced cleavage is defined by insoluble, aphanitic material located in stylolitic bands and is axial planar to D_2 folds. Figure 24c is a lower hemisphere stereographic projection of poles to S_2 foliation planes, approximated from thin sections.

6.8.5 D_3 Faulting

Cross-cutting the S_1 foliation, F_2 folds and forming the hangingwall contact with the South Zone is a series of steeply dipping, east striking faults. These faults are related to development of the McKenna fault, a steeply south dipping fault defined by a 1 to 5 meter wide band of milled graphitic material and cut by calcite veins. The McDermott fault, which acts as the hangingwall contact to the South Zone, is interpreted as a splay of the McKenna fault and likely developed at the contact of the relatively competent ore zone rocks and the incompetent, carbonate-altered and S_1 foliated McDermott Shear Zone rocks. Figure 25a shows stereographic (lower hemisphere) projections of the D_3 McKenna fault measured in different locations. Deflection of foliation, asymmetrically folded tension gash veins, and offset of S_1 foliations within and across the ore zone bounding McDermott shear zone suggests latest movement in a south over north, or a reverse sense of shear. However, caution must be used when interpreting the sense of shear along the McDermott shear zone,

as shear zone indicators near the contact with the South zone may record flexural slip as a result of D₂ folding.

6.8.6 D₄ North-south faulting

The deposit is transected and divided into three sections by two major NNE trending faults, the Mr. Bean fault and the No. 2 fault. Measurements of these faults plotted on a lower hemisphere stereonet in Figure 25b shows that these faults dip steeply to the ESE and strike ENE. These faults are defined by thin (10cm to 2 m) wide bands of graphitic material and occasionally, by a spaced cleavage in carbonate altered rocks. Slickensides and displacement of the McKenna fault suggest that latest movement across these almost vertical faults have a consistently east-side down sense of shear.

6.9 Timing of alteration, mineralization and structures

Figure 25 is a timeline showing the progression of alteration, mineralization and deformation in the Holt-McDermott Deposit. Initial 'hematite' alteration is pervasive throughout the deposit and likely replaced all major primary mineralogy. Clearly cross cutting this early hematite alteration, pervasive and vein related albite alteration and associated pyrite and gold

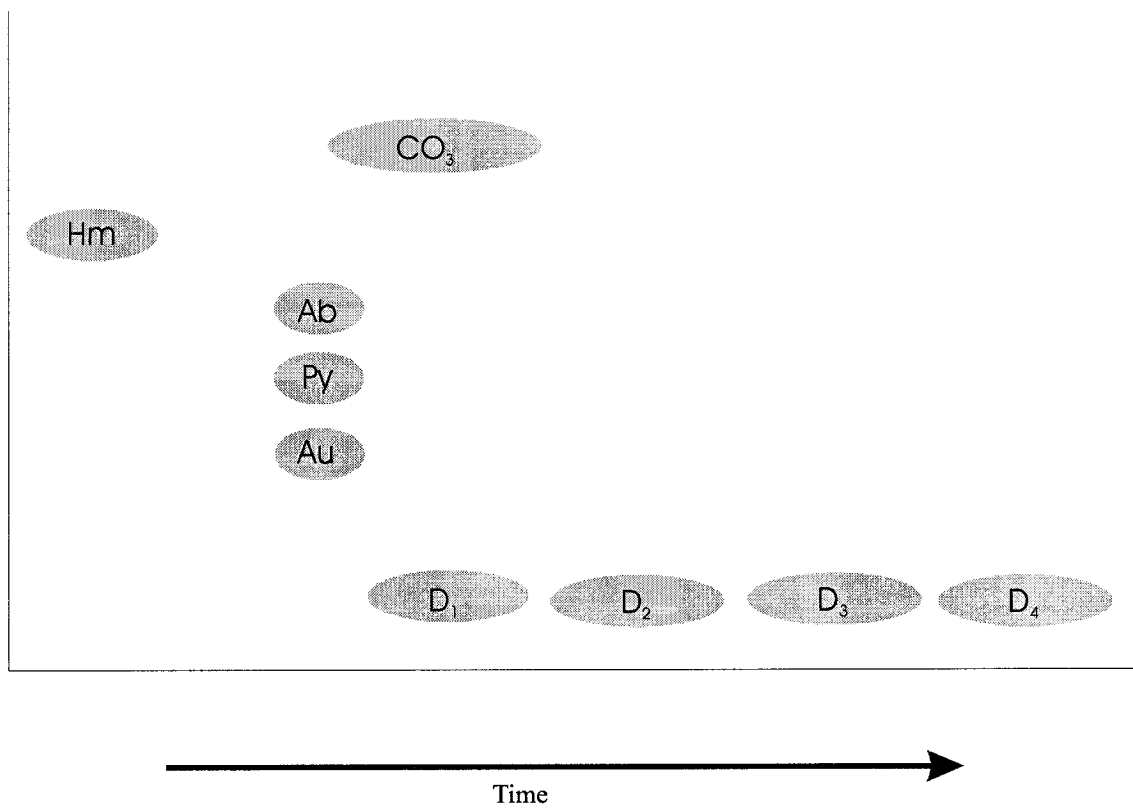


Figure 26. Diagram showing timing relationship of alteration and mineralization events with respect to the principal structures. Hm - hematite; CO₃ - carbonate; Ab - albite; Py - pyrite mineralization; Au - gold mineralization; D - deformation events.

mineralization are preferentially distributed within the host trachytes. Subsequent to albite alteration and gold mineralization and contemporaneous with S_1 development within the McDermott Shear Zone, veins of carbonate are intruded with associated carbonate altered haloes. Hematite, albite, and carbonate alteration, pyrite and gold mineralization and S_1 are all folded into gentle, open D_2 folds and subsequently cross-cut by late lamprophyric dykes. The entire stratigraphy is offset by the reverse McKenna and McDermott faults. Additional north-south faults (Mr. Bean and the No. 2 fault) offset the stratigraphy.

CHAPTER SEVEN: SYNTHESIS

7.1 Comparison of the Holloway and Holt-McDermott mines.

To gain further insight into gold mineralization in the Harker-Holloway gold camp, comprised of two active deposits and several other showings, a comparison of the two major deposits is warranted. Tectonic and gold mineralization models will be developed to account for the similarities and differences between these two deposits. The preceding chapters describe the two deposits separately in a systematic fashion that shall be adopted in this chapter to highlight the differences and similarities of the two deposits.

7.1.1 Regional setting and geology

Both mines are located within the vicinity of a narrow band of mixed sedimentary and volcanic rocks that separate the Kidd-Munro Assemblage to the north from those of the Kinojevis Assemblage to the south. This zone, originally named the Destor-Porcupine Complex (Jensen and Langford, 1985), is herein considered to be composed of volcanic components of both the Kidd-Munro and Kinojevis volcanic assemblages and Timiskaming assemblage sedimentary rocks. Figure 15 shows a cross section through both deposits that illustrates the relationship between Kidd-Munro, Kinojevis and Timiskaming rocks.

The Lightning zone of the Holloway mine is considered to be located entirely within the Kidd-Munro Assemblage, based on the presence of a komatiite flows in the footwall of the deposit, and recent U-Pb zircon crystallization ages of 2719 to 2711 Ma from volcanics to the west of the mine along strike (Ayer et al., 1999) and recent U-Pb crystallization age of 2716.3 ± 1.5 Ma from a crystal tuff immediately north of the Holloway deposit (Ropchan et al., 2002).

The Holt-McDermott Mine was previously been correlated within the Kinojevis Assemblage (Workman, 1984, Robert, 1997), and the prevalence of tholeiitic rocks in its hangingwall and absence of any ultramafic volcanics as shown in this study, support this interpretation. In addition, a U-Pb zircon crystallization age of 2701.7 ± 2.2 Ma (Ropchan et al., 2002) for felsic volcanic units south of the deposit confirm this association.

Timiskaming assemblage rocks form a narrow band between the two deposits (Figure 15). In the Holloway mine, Timiskaming greywackes, siltstones and conglomerates are folded into the mine stratigraphy. Abitibi wide detrital zircon U-Pb analysis has determined that Timiskaming rocks were deposited between 2685 and 2675 Ma (Ayer et al., 1999). Additional U-Pb zircon analyses led provided a date of 2686.6 ± 1.8 Ma (Ropchan et al., 2002) for what is interpreted herein to be a basal member of the Timiskaming assemblage within the Holloway mine.

All of the significant deposits in the Harker-Holloway gold camp (Lightning Zone, South Zone, McDermott Zone, Mattawassaga Zone, Three Star/Worvest Zone) form competent zones (lithons) bounded by ductile shear zones. The Lightning Zone is located within a main branch of the PDDZ itself, whereas the ore zones of the Holt-McDermott Mine are located within the McDermott Shear Zone, interpreted herein to be a splay of the PDDZ, based on similar deformation styles and orientations.

It is important to note that all economically significant deposits in the study area are associated with volcanic rocks of either the Kidd-Munro or Kinojevis assemblages, and that no economically significant mineralization has been identified within Timiskaming assemblage rocks. Additionally, mineralization in both mines is confined to specific lithological units. In the case of the Holloway mine, mineralization is confined to a variolitic hyaloclastite unit, whereas in the Holt-McDermott mine mineralization is confined exclusively to a trachytic volcanic unit.

7.1.2 Lithogeochemistry

The volcanic and sedimentary rocks of the gold camp can be classified according to their geochemistry. Work done in this study should be compared with that completed by Nattress (1999), Jones (2000) and Ropchan (2000) who completed geochemical studies of the Lightning Zone, South Zone and Central Zone (Holt-McDermott) respectively. The most comprehensive of the lithogeochemical studies is that of Ropchan (2000).

An important conclusion of the work completed by Ropchan (2000) was that primary REE patterns were preserved in highly altered rocks. Ropchan (2000) identified 3 types of tholeiitic rocks based largely on REE patterns, as most of the major and the other trace element patterns are obscured by alteration. Figure 27A shows REE plots of the major volcanic units as defined by Ropchan (2000), which are compared with the REE patterns of rocks analyzed during this study (Figure 27B). Type I volcanics have flat patterns typical of tholeiites in the area, whereas Type II volcanics have flat patterns which are slightly enriched, interpreted by Ropchan (2000) as being the product of a moderately large degrees of fractional crystallization of a tholeiitic magma. Type III volcanics, which were the most altered and mineralized rocks, show an enriched REE pattern interpreted as the product of large degrees of fractional crystallization of a tholeiitic parental magma.

By comparison, rocks in the Holt-McDermott mine (Figure 27B) have patterns similar to those of the Type I volcanics identified by Ropchan (2000). These rocks have flat REE patterns near 10 times chondrite, with only a minor depletion of Eu, likely due to a small degree of fractional crystallization and/or partial melting. One sample displays a slightly enriched, flat REE pattern similar to Type II tholeiites defined by Ropchan (2000). The similar REE patterns for tholeiites of both the Holloway (Kidd-Munro) and Holt-McDermott (Kinojevis) deposits suggest that these rocks were formed under similar geodynamic conditions.

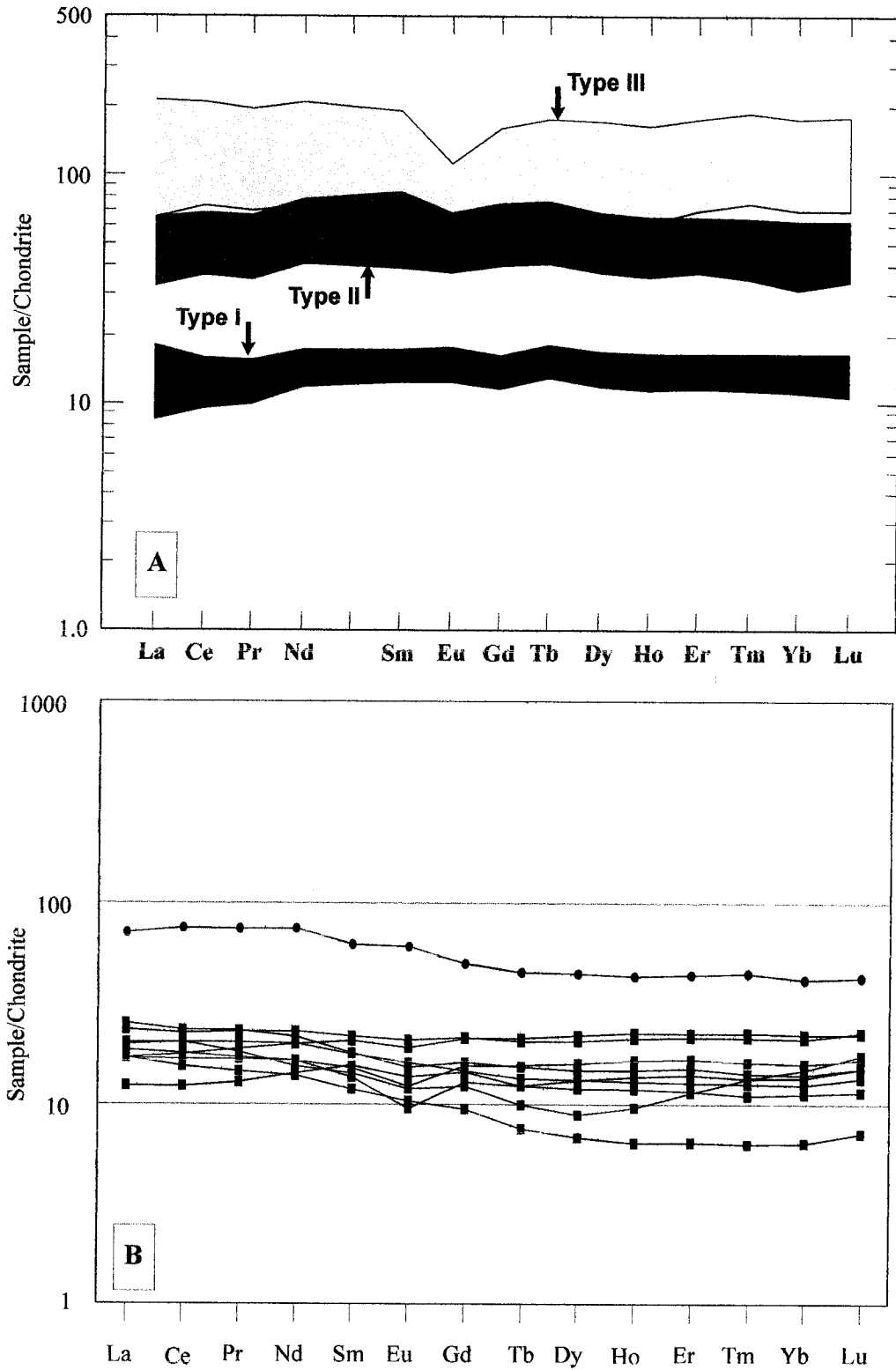


Figure 27. Comparison of REE patterns from tholeiitic volcanic rocks from the: A) Holloway Mine (from Ropchan et al., 2002) and B) Holt-McDermott Mine. Note that the volcanics at the Holt-McDermott mine correlate best to Type I volcanics at the Holloway mine.

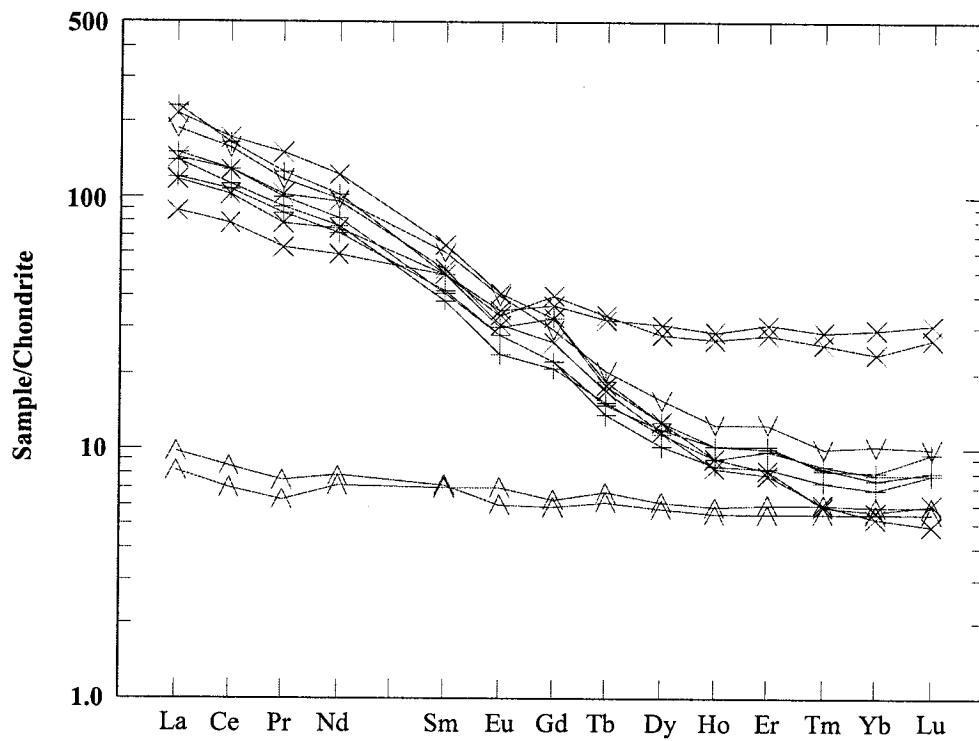


Figure 28. REE patterns of non tholeiitic rocks from the Holloway mine, after Ropchan et al., 2002. Triangles, komatiitic rocks; inverted triangles, sedimentary rocks; asterisks and crosses, Timiskaming basal conglomerates; plus signs, intermineral dyke. Note the LREE enriched patterns of sedimentary rocks and the flat patterns of komatiitic rocks.

Ropchan also described sedimentary rocks of the Timiskaming assemblage. These sedimentary rocks show LREE enriched patterns that are remarkably consistent throughout the deposit, irrespective of the different facies of sedimentary rocks. Figure 28 shows the REE patterns for sedimentary rocks in the Holloway mine (Ropchan, 2000).

Nattress (1999) and Jones (2000) completed limited geochemical studies of the South and Central zones, respectively. These studies identified a minimum of two different lithological units, one with flat lying REE patterns similar to that of the Type I tholeiites defined by Ropchan, and another unit with LREE enriched patterns. Confusion exists over the origin of these rocks. Nattress (1999) interpreted them as sedimentary rocks while Jones suggest that the LREEs were mobilized and reconcentrated during mineralization.

Further analysis of the South Zone rocks as part of this study has identified two major volcanic units as defined by REE patterns. The first major unit is defined by flat lying REE patterns typical of tholeiites for the area, and a second unit defined by LREE enriched patterns, as seen in Figure 17. Comparing REE data from this study with those from Ropchan (2001) shows three major volcanic units in the area. Figure 26 shows the major units, Type I and Type II tholeiites from Ropchan (2001), with flat REE patterns that correlate best with the tholeiites in the Holt-McDermott Mine.

This accumulated data leads to two important conclusions for understanding the Harker-Holloway gold camp. Firstly, the presence of phenocrysts in the trachytic units of the Holt-McDermott mine, along with the fractionated trend identified by spider plots for those rocks, support the contention of Ropchan (2000) that REE patterns are preserved in highly altered rocks. Secondly, given that the original REE patterns have been preserved, the bulk of alteration and mineralization is confined to specific stratigraphic horizons, which have distinct REE patterns.

7.1.3 Alteration

Areas of alteration are concentrated within splays of the PDDZ in the Harker Holloway Gold Camp, with increasing intensities near ore zones. Underground mapping, surface mapping and examination of drill core from the deposits show a consistent sequence of alteration events. Both deposits have undergone similar phases of alteration, with only minor variances.

Hematite alteration, which is composed of both hematite and chlorite in varying amounts is the earliest alteration in both deposits. Hematite alteration tends to be more prevalent within the Holt-McDermott mine, especially outside of the main mineralized zones. This difference is largely a function of the lower amount of late carbonate alteration in the Holt-McDermott Mine, which overprints the hematite alteration at the Holloway Mine.

Carbonate alteration is ubiquitous. Carbonate alteration is dominantly composed of the mineral calcite, with some ankerite indicated by the orange staining of carbonate-altered rocks exposed to air.

Albite is the primary alteration product associated with pyrite and gold mineralization in the camp. Albite alteration is defined by replacement of primary minerals with albite and minor amounts of quartz and carbonate. In both deposits, albite alteration can be found as veinlets of albite and also as a pervasive alteration type. All zones of albite alteration have a variable degree of carbonate alteration associated with them that is responsible for the dramatic differences in colour. Different degrees of albite alteration, combined with an additional later carbonate alteration event noted in the Holloway mine, account for most of the observed differences in colour of altered rocks between the deposits.

The Holloway mine has undergone an additional carbonate alteration associated with calcite and ankerite cross-cutting veins that are not seen in the Holt-McDermott Deposit. The second carbonate alteration event, recorded both within and outside of the main mineralized zones, consists of envelopes of carbonate alteration and pyrite mineralization surrounding predominantly horizontal carbonate veins. This additional alteration event is responsible for the visible difference between similar lithologies and alteration styles between the mines.

7.1.4. Alteration geochemistry

Several attempts have been made to quantify the chemistry of hydrothermal fluids which have been the source of mineralization in the area. Nattress (1999), Jones (2000) and Ropchan (2000) all implemented mass balance calculations in order to estimate the composition of mineralizing fluids. Results and interpretations of these calculations are tenuous due to the lack of an unaltered sample with which to compare the altered samples. Further complications arise from the number of alteration events that the mineralized rocks have undergone.

Some general statements can be made based on the results of these mass balance calculations. First, rocks that have undergone albite alteration and mineralization have seen an increase in Na, Al and SiO₂ consistent with observed petrographic increases in albite mineralogy. Second, gold mineralization is intimately associated with albite alteration, as observed in field mapping and petrographic examination. Nattress (1999) also concluded that gold was associated with reduced iron, likely associated with pyrite mineralization.

7.1.5. Mineralization

As previously mentioned, gold mineralization is intimately associated with pyrite mineralization throughout the deposit. In fact, modal pyrite estimates are considered

reliable indicators of gold concentration for mine geologists in the area. Observations from previous studies indicate that gold is located along pyrite grain boundaries or within fractures in pyrite grains.

A key difference between the Holloway and Holt-McDermott mines is the amount of arsenic associated with ore rocks. Arsenic increases the refractory qualities of the ore during milling, resulting in reduced recoveries. South Zone ore typically has As levels below 50 ppm whereas LZ ore commonly has levels in excess of 1000 ppm (R. Labine, Pers. Comm.). Another key difference between the two ores is the size of pyrite grains. Pyrite grains at the Holt-McDermott mine are typically less than 0.2 mm, whereas at Holloway the pyrite grains range from 0.2 mm to 20 mm.

SEM analyses of pyrite grains indicated that pyrite grains from the Holloway mine are zoned, having cores of low arsenic content, usually less than 0.2 mm in size and rims of higher arsenic content. Outside the LZ, additional large pyrite grains that are associated with carbonate veins and alteration are distinctly arsenic rich. Pyrite grains at the Holt-McDermott mine are generally low in arsenic, and usually are less than 0.2 mm in size.

The differences in both pyrite composition and size are interpreted to be a result of the secondary mineralization/carbonate alteration event identified at the Holloway Mine that did not affect the Holt-McDermott Mine. The source of arsenic was likely sedimentary rocks, as was suggested by Van Hees et al. (1997) for the Giant mine. According to this interpretation, circulating fluids leached arsenic from nearby As-rich sedimentary rocks,

which had been folded into the stratigraphy prior to remobilization, incorporating As into the mineral lattice of the pyrite.

7.1.6. Structural geology

The structural geology of the study area can be synthesized from the structural geology of the two mines. It should be noted that the synthesis proposed is based on the structures documented within the mines. Earlier deformation may have affected the Abitibi greenstone belt, and the resulting structures may have been overprinted by later deformation within the PDDZ.

D₁ structures

D₁ structures are the dominant features of the study area. The main penetrative fabrics within the PDDZ and other related shear zones are all categorized as being D₁. As mentioned previously, ore zones are located within D₁ shear zones which are defined by a well-developed E to ENE striking, south-dipping S₁. Flattened pillows, flattened varioles and the alignment of various minerals, dependent upon lithology, define the S₁ foliation. These shear zones range from meters to hundreds of meters in thickness. The dominant shear zone, the PDDZ, is exposed on the surface and underground within the Holloway Mine. The Ghostmount fault, identified only from drill core in the hangingwall of the Holt-McDermott deposit, and the McDermott Shear Zone, within which the Holt McDermott deposits are located, are interpreted to be splays of the PDDZ.

No cross cutting relationships were observed between the PDDZ, Ghostmount and McDermott shear zones, and the deformation styles and orientations of the S_1 foliations within them are compatible with a single fault system.

Isoclinal F_1 folds are also identified within the shear zones. The folds can be interpreted from facing reversals in drill core, and in surface outcrop mapping where S_1 is perpendicular to S_0 in F_1 fold hinges. Because S_1 is generally parallel to S_0 in the study area, and because it is not possible to map out F_1 folds within the shear zones, the F_1 folds are thought to be rootless and the stratigraphy transposed parallel to S_1 . The juxtaposition of Timiskaming-age sedimentary rocks within the Holloway mine volcanic sequence is interpreted to be a result of F_1 folding in that deposit. Small-scale rootless folds and intrafolial folds provide further evidence for transposition within the shear zones. Though not observed directly at the Holt-McDermott mine, F_1 folding cannot be precluded due to the lack of potential tops indicators in the rocks.

A locally defined L_1 lineation has been observed in both the Holloway and Holt-McDermott mines. This L_1 lineation is defined on a gross scale by the geometries of the ore zones, and in field mapping by stretched pillows, varioles, minerals and pressure shadows. It should be noted that the L_1 lineation is not ubiquitous throughout the area, and that locally the finite strain is oblate.

The prevalence of isoclinal folds within the shear zones complicates kinematic analysis, as opposite senses of shear would be expected on opposing hinges of the fold. However, asymmetric strain shadows around pyrite grains, deflection of apophyses from dykes and the deflection of stratigraphic contacts indicate a south over north, reverse sense of shear where the rocks have undergone a non-coaxial shearing.

D₂ Structures

D₂ features include open folds, with shallowly east dipping axes and nearly horizontal axial planes. The folds are visible at the micro, macro and mega scales, ranging from small scale crenulations (with locally developed crenulation cleavages) to the large-scale folding seen in the Holt-McDermott mine's South Zone (Figure 14). The F₂ folds control the location and geometry of ore zones, and have reoriented the S₁ foliation and L₁ lineation where present. In the Holloway mine, more intense D₂ folding has produced faulted limbs and displaced hinge zones to the south. These folds are spatially associated with a secondary, As-rich pyrite and gold mineralization at the Holloway Mine.

It is important to note that sense of shear indicators on the limbs of the F₂ folds record shearing on the fold limbs and possibly flexural-slip reactivation of lithological contacts and/or the S₁ foliation. Accordingly, caution must be used when interpreting the sense of shear along S₁ when in proximity to D₂ folds, because shear may record D₂ rather than D₁ deformation. The McDermott fault forms the upper contact of the south zone, and records a south over north, reverse sense of shear (Figure 15). This sense of shear is

likely a product of flexural slip between the relatively competent ore zone and the relatively incompetent rocks of the hangingwall during D₂ folding.

D₃ Structures

D₃ structures have been identified at the Holloway mine. S₁ foliation, F₂ fold axes and stratigraphy have been folded by F₃ folds. F₃ folds are recognized by a deflection of stratigraphy within the mine sequence and surface geology (Figure 5). F₃ folds are large scale, open folds with 'staircase' geometries.

D₄ Structures

D₄ structures include the McDermott fault (hangingwall contact of the South Zone), the McKenna fault (D₃ at the Holt-McDermott mine) and a number of other brittle-ductile faults observed in drill core from the Holloway mine. The D₄ faults strike east, dip moderately to the south and are defined by a 10cm to 2 m layer of fault gouge and/or graphite. Few reliable shear sense indicators have been identified within the D₄ fault zones.

D₅ Structures

D₅ is represented by NNE to N striking, steeply dipping faults which cross cut all other structures (D₄ at the Holt-McDermott mine). The D₅ faults are readily identified on

airborne magnetic maps and can be observed directly within the Holloway and Holt-McDermott mines. They include the No. 2 and Mr. Bean faults of the Holt-McDermott mine as well as a number of unnamed minor faults within the Holloway deposit.

The D_5 faults are defined by a thin (usually less than 5cm) band of fault gouge and, as is the case with the Mr. Bean fault, are locally accompanied by a weakly developed spaced cleavage. D_4 faults typically show an east side down sense of displacement on subvertical fault planes. Displacement of the south-dipping stratigraphy downward along these faults could be incorrectly interpreted as a sinistral strike-slip sense of shear.

7.1.7. Relative and absolute timing of structures, alteration and mineralization

The timing of mineralization relative to deformation is important for understanding the nature of gold mineralization in the Harker-Holloway gold camp, as well as for developing exploration models. Relative timing of deposition of rocks, alteration, deformation, mineralization and metamorphic events in the two mines has been distinguished by cross-cutting relationships in both field mapping and microstructural analysis. The data obtained for the intermineral dyke in the Holloway mine, and the U-Pb zircon dates for volcanic and sedimentary rocks in the area, provide an absolute time reference

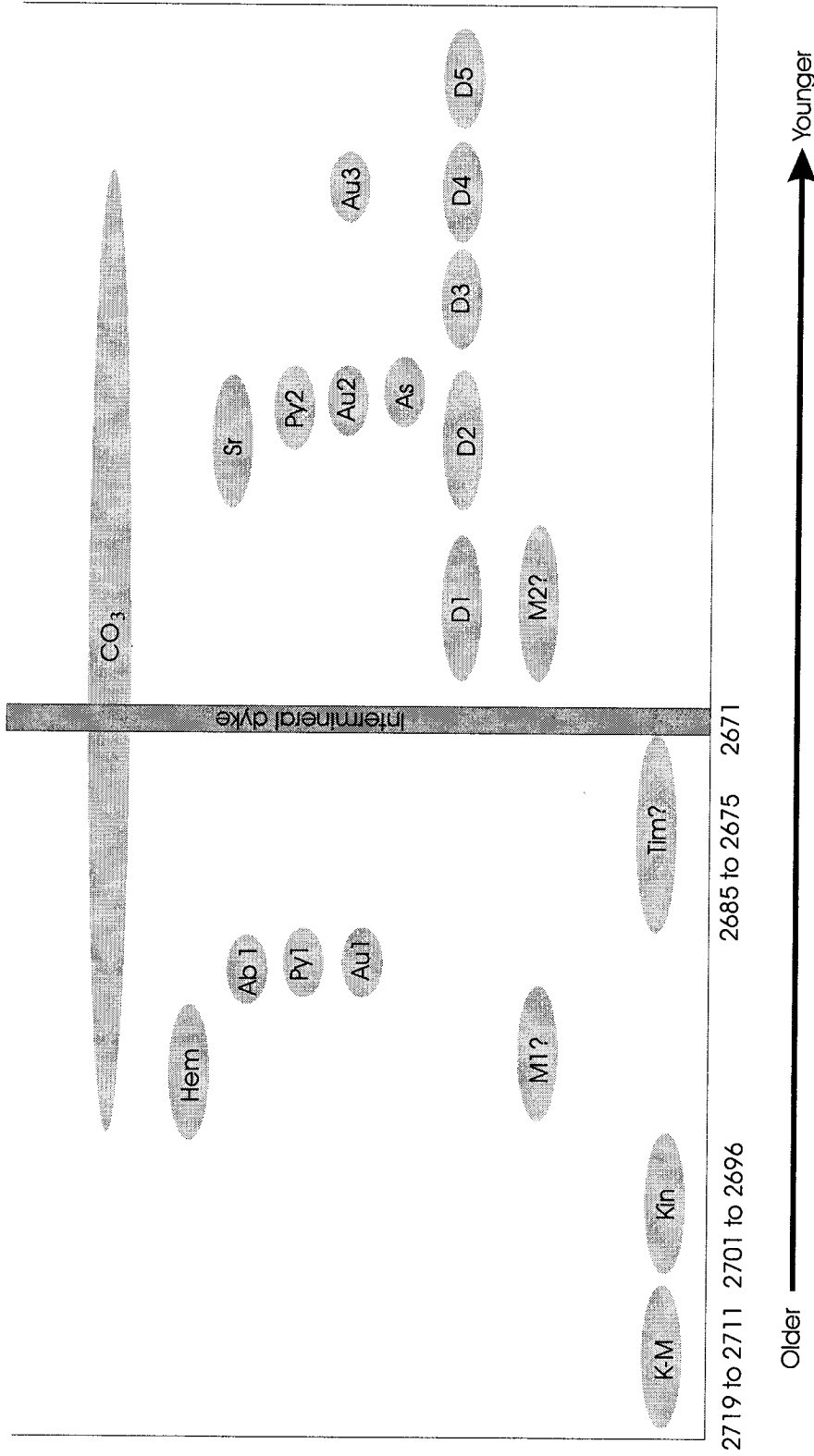


Figure 29. Relative and absolute timing of major deposition, metamorphism (M), deformation (D), alteration, and mineralization events. Abbreviations: K-M - Kidd Munro Assemblage; Kin - Kinjojevis assemblage; Tim - Timiskaming Assemblage; Hem - Hematite alteration; Ab - Albite alteration; CO_3 - Carbonate alteration; Sr - Sericitic alteration; Py - Pyrite mineralization; Au - Gold mineralization; As - Arsenian pyrite mineralization; ? - indicates that relative timing is poorly constrained; Ages listed in Ma.

scale. Figure 29 provides an overview of the relative timing of alteration, mineralization, metamorphism, sediment deposition and deformation in chronological order.

Deposition of volcanic rocks

Volcanic rocks of the Kidd-Munro and Kinojevis assemblages were deposited between 2719 to 2711 Ma and 2701 to 2696 Ma respectively (Ayer et al, 1999). The exact nature of the contact between the two assemblages has not yet been discerned, owing to the strong deformation concentrated at the assemblage boundary and to the presence of a band of Timiskaming sedimentary rocks between them. Evidence from the Timmins area suggests that these rocks were involved in at least one deformational event prior to deposition of Timiskaming rocks, based on an angular unconformity between the two structures (Brisbin, 1997; Ayer et al., 1999). Within this area, intense S_1 development at or near the lithological boundaries precludes any conclusive statement as to the exact nature of this relationship. In fact, at least one contact, seen in drill hole (housed at the OGS storage facility – Kirkland Lake) Kidd Munro and Timiskaming assemblage rocks appear to have a depositional contact. However, the prevalence of transposition in the area combined with the fact that this is an isolated observation cannot preclude the existence of an angular unconformity in the area.

Pre D₁ alteration, mineralization and metamorphism.

The earliest seen alteration event in this area is a hematite event, recorded in rocks from both deposits. Associated with this event is an oxidation of iron within the rocks, which has created a dark purple hue, accompanied by a modal increase in chlorite in volcanic rocks. This alteration is found exclusively in volcanic rocks. Interpreted to be coincident with this alteration is an early metamorphic event (M1 in figure 28), based on the prevalence of chlorite and carbonate alteration, which corresponds well to metamorphic mineral assemblages described by Powell et al. (1993). This mineral assemblage predates albite alteration, and therefore D₁, in the study area.

Albite alteration, accompanied by pyrite and Au mineralization cross-cuts hematized volcanic rocks in both deposits. The pyrite is iron rich, with low values of arsenic. It is represented by pyrite in the South zone (Holt-McDermott mine), and the cores of pyrites within the Lightning zone (Holloway mine).

Carbonate alteration has been found to predate, be synchronous with, and postdate D₁ deformation. Early carbonate veins are folded parallel to S₁ in both deposits; additional carbonate veining both cross-cuts and is folded into S₁. The timing of carbonate alteration is complicated by the fact that calcite is a constituent of the metamorphic mineral assemblage outlined by Powell et al. (1993).

Deposition of the Timiskaming Assemblage (2685 to 2675 Ma)

The relative timing of Timiskaming sedimentation predates D_1 in the study area, due to the fact that Timiskaming assemblage rocks have a well-developed S_1 foliation. Detrital U-Pb zircon dating of clasts provide oldest possible ages of 2685 to 2675 Ma for Timiskaming rocks for the Abitibi (Ayer et al., 1999), while a Timiskaming assemblage breccia from the Holloway mine produced a maximum age of 2686.6 ± 1.8 Ma (Ropchan et al., 2002).

Timiskaming rocks have undergone neither albite nor hematite alteration; rather, they contain clasts of previously albitized and hematized volcanic rocks. This suggests that if Timiskaming rocks have local provenance, they were deposited after the major albite alteration and gold mineralization.

Intermineral dyke intrusion (2672 Ma)

The dyke cross-cuts early albite alteration and the main gold mineralization, contains a well-developed S_1 foliation and is cross cut by later alteration events in the Holloway mine. An U-Pb zircon crystallization age of 2671.5 ± 1.9 Ma was obtained for this dyke bracketing mineralization in the deposit. Dykes of similar composition and with similar relative timing relationships were observed in the Holt-McDermott mine, but were not selected for geochronological analysis.

Post D₁ alteration, mineralization and deformation

Albitized and hematized volcanic rocks of the Kidd-Munro and Kinojevis assemblages, as well as Timiskaming sedimentary rocks all, show D₁ structures, including isoclinal folds, S₁ foliation and L₁ lineation.

A series of flat to gently south-dipping quartz and carbonate veins, with haloes of sericite and carbonate alteration (Sr on Figure 29) as well as pyrite mineralization (Py2, Figure 28) all cross-cut stratigraphy and D₁ fabrics. The second mineralization event is characterized by large anhedral, globular grains of pyrite which are arsenic rich. Within previously albitized zones, pyrite grains associated with this mineralization are typically zoned from ferroan centers to arsenian rims, suggesting that pyrite was precipitated on previously formed grains.

This later alteration and mineralization event is spatially associated with D₂ folding and lithological contacts near D₂ folds at the Holloway mine. Rather than representing an introduction of gold into the system, this mineralization event probably reflects a remobilization of gold within the deposits during D₂ structural development. Arsenic may have been leached from surrounding sedimentary rocks that had been juxtaposed to volcanic rocks during D₁ folding. Lithological contacts and D₂ structures provided conduits for the hydrothermal fluids that remobilized the gold.

The presence of the secondary mineralization event at the Holloway mine and, its absence at the Holt-McDermott deposit can be attributed to the difference in intensity of D_2 structures between the two mines.

A final mineralization event has been described in the area (Au3, Figure 29). Large (up to 1m) thick quartz veins have been documented on the Holloway mine property, the nearby Seagar's Hill claim, the historical Howey-Couchenour workings as well as numerous other deposits along the PDDZ, including the world-famous Croesus mine (Berger and Amelin, 1998). The veins strike north to north-east and have variable dips. Significant values of free gold are associated with the veins in the Harker-Holloway gold camp as well as other locations along the PDDZ (Berger and Amelin, 1998). The relative timing of these structures is unclear; however, they do cross cut both D_1 and D_2 features and have an orientation which suggests that they can easily be interpreted as D_4 features. It is interpreted herein that these veins likely reflect a second remobilization of gold in the area rather than a new introduction of gold into the area.

CHAPTER EIGHT: CONCLUSIONS

8.1 The Porcupine Destor Deformation Zone

One primary goal of this work was to describe the structures that define the PDDZ in the study area. The PDDZ can be defined as a sinuous, east-west striking zone of strong shearing and faulting, composed of many smaller, discrete zones of intense shear surrounding lithons of relatively undeformed rocks. These smaller shear zones range in thickness from 5 meters to more than 500 meters.

At least four distinct generations of structures have been identified within the PDDZ in this area. All four generations of structures have affected Timiskaming assemblage rocks, the youngest supracrustal rocks in the study area, therefore post-date deposition of Timiskaming sediments.

The dominant structure within the PDDZ is a well developed broadly east–west striking, steeply south dipping foliation (S_1). Associated with the S_1 foliation are isoclinal F_1 folds, which are often rootless and only identifiable by facing reversals. A steeply plunging L_1 lineation is also locally developed within the PDDZ. Where shear sense is determined, the kinematics of the D_1 deformation suggest a south over north displacement; however, caution must be used when interpreting the kinematics of the shear zone given the preponderance of isoclinal folding in the area

D_1 structures are reoriented locally by D_2 folding. D_2 folds range from open gentle folding of strata as seen in the Holt McDermott mine to intense, isoclinal folds with faulted limbs at the Holloway mine. Developed within the hinge zones of these folds, and axial planar to these folds, is a sub-horizontal crenulation cleavage, S_2 .

East-west striking, steeply south dipping D_3 faults, including the McKenna Fault, are subparallel to D_1 features, yet have not been affected by D_2 folding. These faults commonly form a boundary to competent ore zones and likely reflect a later reactivation of D_1 shear zones.

The final generation of structures identified within the PDDZ is a series of north to northeast trending faults, identified on magnetic maps, as well as by underground mapping. These linear faults strike N to NNE and have steep dips. Deflection of marker horizons within the Holt-McDermott Mine indicate only minor displacement, consistently in an east-side down sense of shear.

8.2 Tectonic implications for the PDDZ

Any tectonic model for the Abitibi must account for a few key observations made of the PDDZ. The first key observation is that all rocks of this region have been affected by all four generations of structures. This means that the tectonic events that formed these structures affected the entire sequence of rocks in the area.

Included in that sequence of rocks is an unconformity between Timiskaming sedimentary rocks and older volcanic rocks, indicating that at least one tectonic event precedes development of D_1 structures in this area. The exact nature of tectonic events prior to D_1 structure development is speculative. However, the linear geometries of Timiskaming sedimentary basins and their close spatial relationship to the PDDZ in this area suggests that the Timiskaming assemblage rocks may have been deposited in association with early displacements on the PDDZ. The PDDZ may have been active as an extensional basin boundary fault, as suggested by Dimroth et al. (1983a, 1983b) or as a transcurrent fault zone as suggested by Mueller and Donaldson (1992).

D_1 deformation within the PDDZ records regional, north-south oriented shortening of the Abitibi greenstone belt, which resulted in inversion of the Timiskaming sedimentary basins and strong partitioning of strain into the pre-existing PDDZ.

On a regional scale, orientation of D_1 structures is broadly parallel to the axes of major folds in the Abitibi, including the Blake River Syncline, located directly south of the PDDZ. This suggests that the PDDZ formed during the same north-south directed shortening event as the Blake River Syncline. D_1 structures in the PDDZ record a predominantly oblate finite strain ellipsoid, documented by pillows and varioles in volcanic rocks as well as by clasts in Timiskaming sedimentary rocks, consistent with deformation within the limbs of folds. Considering these observations, along with the parallel orientations of the PDDZ with large-scale folds, it seems possible that the D_1

deformation within the PDDZ records shortening along the limbs of the larger scale Blake River syncline, as documented by Benn et al. (2002).

8.3 Gold mineralization in the Harker-Holloway gold camp

A few key observations must be considered when formulating a synthesis emplacement of gold deposits in the area. Firstly, hydrothermally altered and gold bearing zones are spatially associated with D₁, D₂ and D₄ structures in the area. Secondly, primary gold mineralizing fluids were introduced into the area early in the tectonic history.

An U-Pb zircon crystallization age of 2671.5 ± 1.9 Ma was established for an intermineral dyke which cross cuts major albite associated gold mineralization in the area. The lack of albite alteration within Timiskaming-aged rocks, and the presence of albitized clasts within the Timiskaming conglomerates suggest that major albite-associated mineralization predates deposition of the Timiskaming assemblage, at a maximum age of 2686.6 ± 1.8 Ma (Ropchan et al., 2002).

Economically significant albite-associated gold mineralization is confined to specific stratigraphic units within both the Holloway and Holt-McDermott deposits. In the Holloway mine, gold mineralization is confined to a hyaloclastite unit while in the Holt-McDermott mine mineralization is confined to a trachytic unit. This relationship indicates that there was some form of lithological control on gold deposition. The exact nature of the lithological control is not well understood. It is clear that economically

significant gold mineralization is confined to specific lithological units. Ropchan et al. (2002) suggest that gold mineralization is related to high Fe/Mg ratios.

Although initial gold mineralization may have been confined to specific lithological units, the location, geometry and distribution of gold deposits in this area is predominantly controlled by the PDDZ. Since all rocks, including the Timiskaming assemblage rocks, have undergone all four generations of deformation identified in the PDDZ it seems that gold mineralization occurred prior development of the preserved structures. This means that all major deposits within the PDDZ have been affected by all four generations of structures, which have significantly modified the geometry and spatial distribution of ore zones in the area.

At least two minor gold mineralization events occurred after initial introduction of gold into the area during the first identified albite-associated mineralization event. The two later mineralization events appear to be spatially and temporally associated with D₂ and D₄ structures.

D₂ folds appear not only to have reworked the albite-associated ore bodies, but also to have provided a conduit (limbs) and a trap (hinge zones) for additional hydrothermal mineralizing fluids. Quartz-carbonate veins associated with this mineralization have similar orientations to S₂ crenulation cleavages, and tend to be concentrated within hinge zones of D₂ folds.

Broadly north-striking quartz veins with anomalously high Au values are parallel to D₄ faults. D₄ faults may have provided conduits for gold-bearing hydrothermal fluids from which the veins originated. Gold has been associated with these D₄ faults outside of the study area, at the formerly producing Croesus Mine, the Ludgate deposit and the Howey-Couchenour claim located in Harker Township (Berger and Amelin, 1998).

The lack of continuity within secondary and tertiary gold mineralized zones and their location on the peripheries of the first mineralization suggest that these mineralization events likely reflect a remobilization of gold in hydrothermal fluids associated with the development of D₂ and D₄ structures.

8.4 Recommendations for further study

This study has identified the major structures associated with the PDDZ in the Harker-Holloway gold camp, and their controls on the geometries and spatial distributions of gold deposits. Further work should expand to include deposits both east and west of the study area along the PDDZ. Additional investigations within areas that have good geological data coverage from both drill core and underground workings should be included to provide a more comprehensive gold mineralization model for the PDDZ.

At the deposit scale, a few questions remain which could provide useful exploration tools in the future. The provenance of mineralizing fluids could be determined using high precision isotope analysis. This study successfully separated different alteration facies

based on crosscutting relationships. Sampling in rocks affected by specific alteration events would allow for the determination of the source of gold bearing fluids, an essential component of models for gold mineralization in the Abitibi.

A few key observations require more explanation within the context of tectonic models for the Abitibi greenstone belt. Firstly, the spatial relationship between Timiskaming sediments and major deformation zones throughout the Abitibi suggests that these rocks are of local provenance (Hyde, 1978; Chown et al., 1992; Born, 1996; Mueller et al., 1997). However, the remarkable similarity in clast composition throughout the Abitibi points to a more regional sedimentary system. A comprehensive analysis of all Timiskaming sedimentary basins in the Abitibi would be beneficial in assessing this apparent juxtaposition as well as providing a useful tool for evaluating tectonic models applicable to the Abitibi region.

Finally, further Geochronological analyses of rocks, particularly within the Holt-McDermott mine, may provide some useful insights into the tectonic framework of the area. Trachytic rocks are not considered to be a key component of Kinojevis assemblage rocks. The REE patterns for these trachytic rocks are identical to those of the Timiskaming sedimentary rocks described by Ropchan et al. (2002). The exact age of the trachytic rocks could provide a additional insight into gold mineralization in the area.

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Appendices