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THE GEOLOGY AND ALTERATION ASSOCIATED WITH THE GENEX
VOLCANOGENIC CU MASSIVE SULPHIDE DEPOSIT, GODFREY TOWNSHIP,
TIMMINS, ONTARIO.

by

MARC HUBERT LEGAULT

A thesis submitted to the Faculty
of Graduate Studies and Research in conformity
with the requirements for the degree of
Master of Science

Carleton University
Ottawa, Ontario
April, 1985

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FRONTISPIECE: Genex Headframe, Concession 3, Lot 9, Godfrey Township. As it appeared in 1970 (Middleton, 1975).

ABSTRACT

The Genex volcanogenic Cu massive sulphide deposit is located within the Kamiskotia Volcanic Complex, on the southwestern margin of the Abitibi Subprovince, 15 km west of Timmins, Ontario. The Genex Mine area is underlain by three principal stratigraphic units: a lower felsic unit, made up of felsic flows and fragmentals; a middle, dominantly mafic unit at least 600 m in thickness, made up of two cycles of massive to pillowed flows which are separated by a thin felsic flow; and the overlying Mt-Jamieson Rhyolite formation. These are cut by synvolcanic felsic and mafic intrusions and by Early to Middle Precambrian diabase dykes. The ore zones developed by Genex Mines Ltd. in 1964-66 are located near the top of the first mafic volcanic cycle.

The mafic volcanics were affected by an early spilitic alteration and were locally silicified. Background felsic volcanics are affected by low-temperature potassic-feldspar alteration. Important sulphide mineralization is associated with three separate, linear, cross-stratal zones of hydrothermal alteration within the first mafic volcanic cycle and the intercycle felsic flow. These zones represent synvolcanic faults which also controlled extrusion of volcanics, and felsic and mafic intrusions. Each zone is characterized by three mineralogical facies in which a massive chlorite core zone grades outward into a quartz-sericite zone; peripheral quartz-chlorite alteration grades into less-altered mafic rocks. The alteration zones coalesce to form a quartz-sericite lower alteration zone within the footwall felsic strata which has been traced for over 700 m below the deposit.

Variably altered mafic and felsic rocks are characterized by consistent ratios of Ti, Al and Zr which reflect parental compositions and provide the basis for constraining volume changes during alteration. The volume changes range from -40% during chlorite alteration to >80% associated with quartz-sericite alteration. Chemical mass balance calculations indicate that alteration proceeded by a series of sequential steps: the overall alteration state is dominated by Mg and Fe addition and Si, Na, Ca, K, Rb and Sr depletion relative to least-altered rocks. K and Si are enriched adjacent to the chlorite core and Si, Mg and Fe have been added at the periphery of the zones. Nb and Y have been stripped from the most altered footwall rocks.

The mineralogical zoning is interpreted as due to the progressive reaction of a metal-rich fluid with rocks previously affected by high-temperature unreacted seawater-dominated alteration. Decreasing temperature along the margins of the fluid channelways is also thought to have enhanced the stability fields of quartz and sericite. Cooling near the seawater-rock interface precipitated the sulphides and caused a depletion in the Si content within the chlorite core zone. Geothermal activity continued after the extrusion of the intercycle felsic flow and resulted in silicification and carbonate alteration of the overlying volcanics and associated intrusions.

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CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION

The Genex Mine area is located in west-central Godfrey Township, about 16 km west of Timmins, Ontario (fig.1). The property consists of about ten contiguous mining claims covering an area of 1.5 km², near Lots 8, 9 and 10, Concession 2 and 3, Godfrey Township, Ontario.

The Early Precambrian (Archean) volcanic, sedimentary, and mafic to felsic intrusive rocks which make up the most of the bedrock in the area form part of the Kamiskotia volcanic belt located on the southwestern margin of the Abitibi Sub-province of the Canadian Shield (fig.2).

The Timmins area has been synonymous with gold; with over 56 million ounces produced since 1910, it ranks as one of the largest gold mining camps in North America. Following the discovery in 1964 of the Kidd Creek copper-zinc-silver massive sulphide orebody in Kidd Township, 27 km north of Timmins, this area also became an important base metal producer.

Base metals were encountered early in the search for gold as prospectors explored the Kamiskotia area west of the main Timmins gold camp; underground development by Hollinger Consolidated Gold Mines on the site of the Kam-kotia copper-zinc mine, in Robb Township, 20 km northwest of Timmins, began as early as 1927. The first base metal production came from that mine in 1944 under contract to the Wartime Metals Corporation. Since 1964, three additional mines in the Kamiskotia

Figure 1: Location map of the Genex Mine area.

area went into production as a direct result of the Texasgulf Ltd. Kidd Creek discovery. The Genex Mine, one of the four Kamiskotia deposits, began underground development in late 1964 and ceased operations in December 1966 after intermittent production.

The purpose of the thesis study is to outline the volcanic stratigraphy as well as zones of alteration and mineralization in the area surrounding the Genex Mine based on detailed field mapping, petrography and geochemistry.

1.2 ACCESS

The Genex Mine area is located about 16 km west of Timmins (fig.1). Central Godfrey Township is accessible from Timmins along Highway 101 west for 8 km, then 10 km northwest on Highway 576. The Feldman Timber road splays west from Highway 576 near Mt-Jamieson (the Kam-kotia ski hill) and provides a good light-truck route southward for about 3 km along Godfrey Township's Lot 8-9 boundary. The Genex Mine gravel road continues south for 2 km to Aconda Lake and the Genex minesite. A winter road, the Lally Trail, also provides access to Aconda Lake 3.5 km westward from Highway 576 at Waterhem Creek (Lot 4, Concession 3, Godfrey Township).

1.3 ACKNOWLEDGEMENTS

Much of this study was made possible through the cooperation and contribution of Campbell Resources Ltd., Kidd Creek Mines Ltd. and Samim Canada Ltd. who gave permission to

Figure 2: Simplified geology of the Abitibi Subprovince.

do field work on their properties in the Genex Mine area. Kidd Creek Mines Ltd.'s generous financial and material support over three field seasons were invaluable in the completion of this study. Samim Canada Ltd. graciously provided some geochemical analyses from their property in the area. Special thanks are due to C.D.A. Comba, R. Bula, Dr. T. Hamilton and Dr. J. Franklin whose help pushed the study into its final stages. D. Ritcey, J. Cecchetto, B. Cornell, R. Thompson, M. Cook, and B. Amsden were able assistants over the three summers of field work in the area. P. Degagne and R. Bula helped map certain sections of the map area. D. Last and M. Gaboury, Kidd Creek Mines Ltd., helped draft the base maps used in the study. Finally, special thanks go to J. Legault who helped complete the field work and to Dr. J.M. Moore and Dr. D.H. Watkinson who supervised the project.

1.4 PREVIOUS WORK

Much of the prospecting activity in the Kamiskotia area has been linked to major developments in the mining industry such as the Porcupine gold rush of 1909, the 1925 discovery of the large Horne and Amulet copper-zinc-gold deposits in Noranda, Quebec, and the Texasgulf Sulphur discovery in Kidd Township in 1964.

A geologist attached with A. Niven's Ontario Land Survey party, W.A. Parks, one of the first to note the occurrences of gold in the Porcupine area, first referred to the Kamiskotia area (Parks, 1900) when he described the canoe route into Kamiskotia Lake and briefly commented on the gabbroic intru-

of Godfrey and Turnbull Townships along Niven's 1899 baseline. Kerr (1906) described the lake in a sketch during his general exploration of the Mattagami Valley in 1905.

Some attention was paid to the Kamiskotia area following the great Timmins gold discoveries in 1909. Burrows (1911) attached a geological sketch of Jamieson and eastern Robb Townships and described some of the rocks exposed there in the first comprehensive geological report of the Timmins area; Godfrey Township was also included in the general map of the Porcupine area which accompanied his report.

Gold had been discovered since in several parts of Robb and Turnbull Townships and some of these gold occurrences were appended by Burrows and Hopkins (1915) to the third report on the Timmins area. They were the first to note the presence of a "Fahlband" (or gossanous outcrop), 2 km northeast of Kamiskotia Lake on the site which later became the Kam-kotia Mine.

As prospecting activity resumed following the First World War, the Ontario Department of Mines, in view of aiding exploration in the new "Kamiskotia Gold Area", dispatched F.L. Finley in 1924 to describe the geology and the numerous gold-bearing quartz veins. Finley (1925) produced the first comprehensive geological report as well as a 1 inch to 40 chains (1:47520) coloured map of Godfrey, Turnbull, Robb and Jamieson Townships. He was the first to mention the geology of the Aconda Lake-Genex Mine area when he referred to well-developed "ellipsoidal" and "amygdaloidal" structures which

characterized the mafic volcanics exposed in a large outcrop in Lot 9, Concession 3, Godfrey Township.

In 1927, in hope of finding counterparts to the important Horne and Amulet copper-gold discoveries of the Noranda region, the Ontario Department of Mines examined certain copper-gold discoveries in the "Kamiskotia Mining Camp". Base metal mineralization in the Aconda Lake area was first mentioned by Gledhill (1928) as one of two principal occurrences in the Kamiskotia region:

Copper is in chalcopyrite which occurs together with pyrite and zincblende in sheared acid and basic Keewatin lavas... The main sulphide find is on claim no. 12049.

The Genex Mine headframe was erected on this claim 37 years later. The other occurrence, on the site of the Kam-kotia Mine in Robb Township, was being developed by diamond drilling and underground work by Hollinger Consolidated Gold Mines.

In 1949, N. Hogg began an examination of the principal mineral occurrences in Godfrey and Turnbull Townships including the Mordey Copper (Genex Mine) showings. Hogg (1954) presented the first synthesis of the geology and mineralization in the Genex Mine area and in Godfrey Township.

Following the discovery of the Kidd Creek Mine in nearby Kidd Township, the lack of exposure in the Kamiskotia area (and consequently the inaccuracy of existing geological maps) spurred interest in alternate mapping methods involving geophysics. The most recent comprehensive geological-geophysical reports on the Kamiskotia area by the Ontario Department of Mines are by Middleton (1973, 1974, 1975). Pyke and

Middleton (1970,1971) reported on the sulphide occurrences in the Kamiskotia region (including the Genex^x deposit).

The stratigraphic setting of the Kamiskotia area rocks within the Abitibi Subprovince, as well as their geochemical characteristics have been described by Goodwin (1979) and Pyke (1978,1982). The most recent work sponsored by the Ontario Geological Survey deals with certain trace element abundances in the felsic rocks of the Kamiskotia belt (Thurston,1981; Campbell et al.,1981a,b; Leshner et al.,1983;Hart,1984).

1.5 HISTORY AND DEVELOPMENT IN THE GENEX MINE AREA

The study area covers several mineral claims that have been held by many different interests over the last 60 years. A diagram which shows the location of the claims referred to in this section is presented in Appendix D.

The history and development in the Genex Mine area between 1926 and 1949 has been described by Hogg (1954) and from 1949 to 1970 by Middleton (1975); these are briefly summarized in Table 1.

The discovery in April, 1964 of the Kidd Creek deposit by Texasgulf Sulphur Ltd. in Kidd Township north of Timmins sparked one of the largest staking rushes in the history of Ontario. It is not by coincidence that Genex Mines Ltd. acquired the 7 claim, Maple Bay Copper Mines Ltd. property on May 12, 1964; over 10 700 m of diamond drilling, carried out since 1927, had outlined significant Cu-Zn mineralization in three separate lenses (Middleton,1975). By December 1964, after 6610 m of diamond drilling had outlined over 470 000 t

of 1.95% Cu to the 90 m level, Genex Mines Ltd. made the decision to collar a 84 m deep, two-compartment, exploration shaft with levels to be established at 38 and 76 m depth.

In November of 1965, after underground exploration had returned encouraging results, a decision was made to bring the property into production; a 180 t per day mill, purchased by a private group from the Delnite gold mine in Timmins, was moved to the Genex claims. Although shipments of Cu-ore to the mill began in May, 1966, the surface plant did not reach its rated capacity until September, 1966. At that time, the company, in financial difficulty, was reorganized and arranged to purchase the mill in order to effect an economy in the operation. Four car-loads of Cu-concentrate totalling 218 t with grades ranging from 21.45 to 24.25 % Cu were shipped to New York in September, 1966; all the mill feed was from the C-zone lens on the 36 m level. The indicated reserves were recalculated and reduced to 122 000 t at 2.47 % Cu.

In early November, 1966, the company was again reorganized and renamed Irvington Mining Company Ltd.; subsequently an error was found in the estimate and the indicated reserves were cut to 38 000 t at 2.5 % Cu after dilution. Production was halted in late November due to financial difficulties and the shaft was capped in December, 1966. At that time, underground development consisted of over 11 000 m of drifting, crosscutting and raising, and the preparation of 3 stopes. By January, 1967, Irvington Mining Company Ltd. declared bankruptcy.

United Obalski Mining Company Ltd. purchased the 7-claim mining property and other assets from the trustee in bankruptcy in March, 1967. The indicated reserves above the 76 m level were then recalculated at 121 000 t of sulphides grading 2.22 % Cu (United Obalski Mining Company Ltd., 1966 Annual Report). The 7-claim Genex Mine property is presently owned by Campbell Resources Ltd..

Table 1: History of Development in the Genex Mine Area

Date	Claim #	Description
1926	P.27216 P.27215	staked by F. Steep and P. Sheehan
1927 -1928	P.27216 P.27215	optioned to Aconda Mines Ltd. surface-trenching, electrical survey, and 14 diamond drill holes (Ac-1,14). option dropped (Timmins File T-231)
1937	P.27215 P.27216 P.567635 P.567637	transferred to C. McGaughey and Alameda Mines Ltd. 6 diamond drill holes (Al-1,6) on P.27215-16. option dropped (Timmins File T-231)
1942	P.27215 P.27216 P.19290 P.19292	optioned to Sylvanite Gold Mines Ltd. surface trenching. option dropped (Timmins File T-231)
1944 -1954	P.27215 P.27216 P.19292 P.19290 P.27677 P.28252 P.28253	purchased by Mordey Copper Mines Ltd. 5 diamond drill holes (Mo-1,5) totalling 766 m in 1946. magnetometer survey in 1946. (Timmins File T-231)
1948	P.567635 P.567637	optioned to Millbren Copper Mines Ltd. 3 diamond drill holes (M-1,3) totalling 419 m in 1948. option dropped (Timmins File T-330)

1951	P.567635 P.567637	optioned to New Walcoro Porcupine Mines Ltd. 12 diamond drill holes (NW-1,12) totalling 1232 m in 1951. option dropped (Timmins File T-330)
1955	P.567635 P.567637 P.583996 P.27216	optioned to Broulan Reef Mines Ltd. electromagnetic survey, 3 diamond drill holes (S-3,6) totalling 439 m in 1955. option dropped (Timmins File T-570)
1956	P.27216 P.27215 P.19290 P.19292 P.27677 P.28252 P.28253	optioned to Kimberley Copper Mines Ltd. magnetic, electromagnetic, self-potential, 31 diamond drill holes (unknown series) totalling 2327 m in 1956. option dropped (Toronto File 63.1138)
1958	P.567635 P.567637	P.J. O'Neill surface trenching, 3 diamond drill holes totalling 16 m. (Timmins File T-330)
1959	P.19290 P.19292 P.27215 P.27216 P.27677 P.28252 P.28253	purchased by Maple Bay Copper Mines Ltd. electromagnetic survey, 17 diamond drill holes (H-5,21) totalling 1500 m in 1959. (Timmins File T-231)
1960		Maple Bay Copper Mines Ltd. 30 diamond drill holes (60-1,30) totalling 3148 m in 1960. (Timmins File T-231)
1961	P.567637 P.567635 P.585390 P.583993 (P.27216)	optioned to Maple Bay Copper Mines Ltd. electromagnetic survey, 5 diamond holes (61-1,4) totalling 456 m in 1960. (Timmins File T-330)
1962	P.19290 P.19292 P.27215 P.27216 P.27677 P.28252 P.28253	Maple Bay Copper Mines Ltd. down hole electromagnetic survey, 21 diamond drill holes (62-1,21) totalling 2985 m. (Timmins File T-231)

1964 P.567635 P.J. O'Neill
P.567637 5 diamond drill holes (75-78)
totalling 393 m in 1964.
(Timmins File T-330)

1964- P.19290 purchased by Genex Mines Ltd.
1967 P.19292 induced polarization survey,
P.27215 50 diamond drill holes (G-
P.27216 series) totalling 5568 m in
P.27677 1964. Shaft sunk to 84 m in
P.28252 claim P.27215 with levels at 38
P.28253 m and 76 m. Total of 807 m of
drifts, 211 m of raises, 95 m
of crosscuts and 82 underground
drill holes (1-,2-series) for
2831 m. Ore custom milled on
the property intermittently
during 1966 at 90-180 metric
t/day. Operations ceased Novem-
ber, 1966.

Genex Mines Ltd. changed names to Irvington Mines Ltd. in
September, 1966. Declared bankruptcy in February, 1967.
(Timmins File T-231)

1965 P.583997 Consolidated Sannorm Mines Ltd.
induced polarization survey, 1
drill hole (C-1) for 143 m.
(Timmins File T-1051)

1967 P.19290 purchased by United Obalski Mining
P.19292 Company Ltd.
P.27215 geological survey, surface sam-
P.27216 pling, ore reserved calculation
P.27677
P.28253
P.28252

1968- optioned to Kennco Explorations Cana-
1969 da Ltd.
15 diamond drill holes (unknown
series) totalling 3499 m in
1969.
option dropped

1978 Geophysical Engineering
Dighem II geophysical survey.
(Toronto File 2.2841)

1981 P.567635 Texasgulf Ltd.
P.567637 magnetic, electromagnetic, 2
diamond drill holes (G-51-
11,12) totalling 853 m.

*Note: G-51, A1-1, M-1 etc. refer to diamond drill holes
plotted on the Preliminary Geology Map attached.

CHAPTER 2: REGIONAL GEOLOGY

2.1 SUMMARY - TIMMINS AREA STRATIGRAPHY

All the bedrock within the Timmins area, with the exception of a few diabase dykes and minor Middle Precambrian sedimentary rocks is of Early Precambrian (Archean) age. These form the southwestern margin of the Abitibi Subprovince (fig.2), the largest granite-"greenstone" terrain in the Superior Province of the Canadian Shield.

Although the geological synthesis of the Timmins area geology and gold mineralization began with reports by Burrows (1924), Dunbar (1948), Carlson (1967), Ferguson et al. (1968) and others, stratigraphic correlation in the Timmins area was first initiated by Pyke (1974, and associated geological reports: 1975a, 1975b, 1978, 1982). The volcanic rocks in the Timmins area have been subdivided into the younger Deloro Group and the Tisdale Group. The Tisdale-Deloro subdivision, commonly used in any discussion of the Porcupine Gold Camp is best described by Pyke (1982).

However, in the context of the stratigraphic make-up of the whole Timmins-Kirkland Lake region including the Kamiskotia area, Pyke and Jensen (1976) subdivided the volcanic rocks into two supergroups, the Lower and Upper Supergroups. Within the Timmins area, the Lower Supergroup comprises all those formations previously assigned (Pyke, 1975b) to the Deloro Group; the Tisdale Group corresponds to the Upper Supergroup.

Recently MERQ-OGS (1983), in an attempt to correlate and

Figure 3a-Stratigraphy of the Timmins-Kirkland Lake Area showing location of stratigraphic columns shown in Figure 3b. Geology by Pyke (1978) and Jensen (1979) (Pyke, 1982)

Figure 3b-Generalized stratigraphic columns from east to west in the Timmins-Kirkland Lake Area. For locations of numbered columns see Figure 3a. (Pyke, 1982)

amalgamate several independent stratigraphic compilations done in the Abitibi Subprovince (Pyke, 1982; Jensen, 1982a,b; Dimroth et al., 1982; QMER, 1982) produced a large scale litho-stratigraphic map of the area. Although stratigraphic mapping of the Abitibi region is largely incomplete, based on chemostratigraphic units, the compilations tentatively identify at least four distinct volcanic cycles making up the Abitibi Subprovince. The oldest and youngest volcanic cycles, Cycle I and Cycle IV respectively (according to the MERQ-OGS (1983) designation) are only partially preserved in certain parts of the Abitibi region. The two major volcanic cycles which make up most of the Abitibi Subprovince, Cycles II and III, correspond to Pyke and Jensen's (1976) Lower Supergroup and Upper Supergroup respectively. For simplicity, in the general discussion that follows, the Lower-Upper Supergroups designation will be retained; the stratigraphic description of the Precambrian lithologies in the Timmins area is taken from Pyke (1982) and MERQ-OGS (1983).

In the Timmins area, the Lower Supergroup, at least 4500 to 5000 m in thickness, is largely a calc-alkaline succession (fig.3). The base of the supergroup consists of ultramafic and basaltic komatiite and tholeiitic mafic volcanics; these are overlain by calc-alkalic basalts and andesites. Felsic pyroclastics are abundant towards the top of the supergroup. Iron formation, dominantly oxide and sulphide facies, commonly form discontinuous and isolated lenses 6 to 30 m thick in the upper formations of the Lower Supergroup (Pyke, 1982).

The base of the Upper Supergroup in the Timmins area

consists of basaltic and peridotitic ~~basaltic~~ tiite and magnesium-rich tholeiitic basalt; these are often interbedded with the calc-alkaline felsic rocks near the Upper Supergroup-Lower Supergroup contact. Turbiditic sediments, part of the Porcupine Group (Lorsong, 1976) which mark the first infiltration of sediments in the area, are also commonly intercalated with the volcanics at the supergroup boundary. The overlying group consists of iron-rich and magnesium-rich tholeiitic basalt. The uppermost group consists of calc-alkalic rocks, basaltic to andesitic tuff and tuff-breccia. While the stratigraphic thickness of the Upper Supergroup may be only 4000 m in the Timmins area (where it is defined by the Tisdale Group; Pyke, 1982) the total thickness of the Upper Supergroup in the Timmins-Matachewan area is estimated to be approximately 12 000 m (Pyke and Jensen, 1976; Pyke, 1982).

The Lower Supergroup is not well exposed (fig.3); it is confined to domal-type structures such as the Shaw Dome south of Timmins, or to the margins of granitic plutons (the Kenogamissi Pluton) which have arched-up or domed the surrounding supracrustal rocks. Zircon U-Pb geochronology by Nunes and Pyke (1980) on felsic volcanics forming the upper part of the Lower Supergroup in the Timmins area returned a 2725 ± 2 Ma age.

The main structure within the Upper Supergroup is an east-trending east-plunging synclinorium (fig.3). The volcanic and sedimentary rocks in the Timmins area are interpreted to be located in the nose of this synclinorium. The Upper

Supergroup is also disrupted by batholithic intrusions; the Kenogamissi Batholith marks the westward termination of the Upper Supergroup and of the associated synclinorium (Pyke, 1982). Nunes and Pyke (1980) dated a calc-alkaline rhyodacite tuff from the uppermost formation of the Upper Supergroup and established an age of 2703 ± 2 Ma (U-Pb analyses of five zircons).

Stratigraphic correlation of the Kamiskotia volcanic succession with the rest of the Timmins-Kirkland Lake area has been hampered by the lack of exposure and detailed mapping in the area. Goodwin (1979) considered the Kamiskotia supracrustal rocks (which he designated as the Godfrey Group) to be pre Blake River Group and correlated the volcanic rocks with the Deloro and Tisdale Groups. His correlation in part was based on the presence of greywacke-shale-conglomerate sediments, similar to those found interbedded with the Deloro and Tisdale Groups in Timmins; overlying the upper part of the volcanic sequence in Godfrey Township.

Pyke (1978, 1982) tentatively included the Kamiskotia Volcanic Complex in the Lower Supergroup for three reasons:

Firstly, large gabbroic complexes like the Kamiskotia Gabbro are not known to occur in the Upper Supergroup whereas layered gabbroic bodies often intrude the Lower Supergroup.

Secondly, ultramafic volcanic rocks are only known to occur near the top of the main volcanic sequence in the Kamiskotia area (R.S. Middleton, pers. comm., 1977 in Pyke, 1978, 1982).

Thirdly, the Kamiskotia area is located on the western margin of a large granitic complex (the Groundhog Batholith; Goodwin, 1979). Similar batholiths (i.e., the Kenogamissi and Round Lake Batholiths) are bordered by Lower Supergroup formations in the Timmins-Kirkland Lake region; the same situation is postulated to exist in the Kamiskotia area.

The recognition of the general tholeiitic character of the main volcanic succession in the Kamiskotia area (and possibly the Kidd Creek Mine area) by Campbell et al. (1981a,b), Leshner et al. (1982) and Hart (1984) may be incompatible with Pyke's (1978,1982) correlation of the volcanic stratigraphy north and west of Timmins. The MERQ-OGS (1983) geologic interpretation of the Kamiskotia area appears to be substantially incorrect.

2.2 REGIONAL GEOLOGY: KAMISKOTIA AREA

2.2.1 Introduction

The Kamiskotia area, located 12 km west of Timmins, Ontario, is a region more or less defined by 8 townships (fig.4); from north to south these are: Loveland and MacDiamid, Robb and Jamieson, Turnbull and Godfrey, and Carleton Place and Bristol Townships. This area is underlain by a generally north- to northwest-trending, steeply-dipping, eastward-facing bimodal succession of felsic and mafic volcanic and minor sedimentary rocks which have been intruded by a large (22 x 25 km) multi-phased sill-like intrusion, the Kamiskotia Gabbroic Complex (fig.4). The Kamiskotia supracrustal succession occurs on the eastern margin of the Groundhog Batholith, a granitoid mass approximately 60 by 30 km in area, which appears to be related to doming or arching of the Kamiskotia rocks in their present configuration (Goodwin, 1979)(figs.3,4).

Early descriptions of the regional geology were presen-

FIGURE 4: SIMPLIFIED GEOLOGY MAP OF THE KAMISKOTIA AREA (after Hogg, 1954; Middleton, 1973, 1974, 1975; Pyke, 1978, 1982).

ted by Finley (1925), Berry (1944), Ferguson (1944) and Hogg (1954). More recently, large-scale regional geophysical, geological, and stratigraphic interpretation of the Kamiskotia region have been presented by Middleton (1973,1974,1975, 1976). Some geochemical aspects of the Kamiskotia area have been described by Wolfe (1970), Goodwin (1979), Campbell et al. (1981a,b,1982a,b), Thurston (1981), Leshner et al. (1983), and Hart (1984). Sommerville (1967), Bright (1972b), Goodwin et al. (1972), and Fisher and Ransom (1975) also describe the geology of the Kamiskotia area.

Because the relationship between the volcanic and sedimentary rocks exposed in Carscallen and Bristol Townships and those exposed in the rest of the Kamiskotia region is poorly documented, it will not be included in the stratigraphic discussion which follows.

2.2.2 Volcanic Stratigraphy

The volcanism and sedimentation in the Kamiskotia area have been tentatively divided into two cycles (Middleton, 1973,1974,1975)(fig.4): A lower tholeiitic succession (Cycle I), at least 10 km in thickness, which underlies most of the region; and an upper, possibly calc-alkaline succession (Cycle II) greater than 5 km in thickness which appears to be exposed only in the northeastern part of the region. In Bristol Township, Cycle II volcanics appear to be absent, their position being apparently occupied by Porcupine Group sedimentary rocks (Pyke,1978,1982).

The main part of the Kamiskotia volcanic succession(ie.

Cycle I) was previously interpreted to be calc-alkaline (Pyke and Middleton, 1970, 1971; Middleton, 1975). Hogg (1954) and Middleton (1973), based on petrographic, major element geochemical and field relationships, suggested that the Cycle I mafic and felsic volcanics were related to mafic and felsic phases of the Kamiskotia Intrusive Complex. Middleton (1975) showed that, while most of the mafic volcanics and mafic phases of the Kamiskotia Gabbro were clearly tholeiitic and showed distinct iron-enrichment trends, many of the Cycle I felsic volcanics and some of the mafic volcanics in the area, however, had calc-alkaline major element compositions. The main volcanic cycle in the Kamiskotia area was therefore defined as calc-alkaline (Thurston, 1981; Pyke, 1982; MERQ-OGS, 1983).

Recently, Campbell et al. (1981a,b) and Hart (1984) on the basis of rare earth, trace element and major element contents, showed that the felsic volcanics were extrusive equivalents of the granodioritic phase of the Kamiskotia Intrusive Complex and that this felsic phase may have been derived by partial melting of mafic volcanics by the Kamiskotia Gabbro: ie., the Kamiskotia volcanic succession was tholeiitic. MacGeehan and MacLean (1980a,b) argued that calc-alkaline rocks associated with massive sulphide deposits at Matagami, Quebec were altered tholeiitic volcanics which as a consequence of the alteration process developed a calc-alkaline signature; similarly, Gibson et al. (1983) made the same argument for the Amulet Rhyolite formation at Noranda, Quebec. The same situation is interpreted to exist (in part)

in the Kamiskotia area (Campbell et al., 1981a,b, 1983; Legault et al., 1985)

The lower part of the tholeiitic Cycle I is not well exposed; much of it was removed from the present erosion level by intrusion of the Kamiskotia Gabbro in the Robb-Jamieson Townships area. However, the geology and geochemistry of Cycle I rocks have been better documented because of greater accessibility and exposure, and because they host four base metal sulphide deposits. The contact between the two cycles is not well defined but appears to extend from southern Loveland Township southeasterly to northeastern Godfrey Township (Middleton, 1975) (figs. 3,4).

The upper volcanic cycle is bounded to the east by the Mattagami River Fault (figs. 3,4) and by a northwest-trending synform interpreted by Pyke (1978, 1982) to occur approximately in central MacDiarmid Township. This synform separates similar lithologies flanking another dome-like structure, the Pamour Dome, interpreted to occur north of the Kidd Creek Mine area by Pyke (1978, 1982).

A stratigraphic section for the Kamiskotia area is shown in Figure 5. It is compiled from Middleton's (1973, 1974, 1975) geological and geophysical interpretations of the area.

2.2.2a Cycle I

Cycle I, well exposed in the Turnbull-Godfrey area may be divided into four different volcanic formations totalling about 10 000 m in thickness (assuming that the stratigraphy in the area has not been repeated by faulting or folding).

The lowermost formations have been disrupted by numerous sill-like felsic and mafic intrusions satellitic to the Kamiskotia Gabbroic Complex which underlies most of the western and northwestern parts of the Turnbull-Godfrey region. The upper part of the first main volcanic cycle is often covered by extensive glacial deposits in eastern Godfrey and Jamieson Townships.

The lowermost Cycle I volcanic stratigraphy exposed in the area consists of north- to northwest-trending, dominantly quartz-phyric felsic fragmentals and lavas approximately 5 km in thickness. Interbedded mafic fragmentals, tuff and agglomerate, as well as massive to pillowed basalt (dominantly tholeiitic - Middleton, 1975) appear to make up as much as 15% of the lower felsic stratigraphy exposed in eastern Turnbull Township. The mafic volcanics interpreted to occupy most of north-central Turnbull Township resemble fine-grained gabbroic rocks exposed in Robb Township (Middleton, 1975; Wolfe, 1971). The lower felsic stratigraphy is not exposed in the Robb Township area; its stratigraphic position is apparently occupied by the main part of the Kamiskotia Gabbro (see Figure 4).

A more or less continuous north-trending, east-facing unit of dominantly mafic pillowed volcanics and minor quartz-phyric felsic flows and fragmentals overlies the dominantly felsic lower formation in Godfrey Township and forms the base of the exposed Cycle I stratigraphy in the Robb-Jamieson area. On the order of 500 m thick in the Genex Mine area,

this unit thickens progressively to the north until, in Robb and northwestern Jamieson Townships, mafic volcanics dominate the supracrustal succession. In northern Robb Township, where the absence of exposure is offset by diamond drill hole and geophysical information, mafic volcanics and abundant thin gabbroic sills make up most of the stratigraphy. Along strike to the southeast, felsic quartz-phyric flows and fragmentals become more common within the mafic horizon. Minor extensive chert (up to 0.5 m thick) and block lapilli ignimbrite/ash flow tuffs, massive sulphide deposits, and numerous fine-grained mafic dykes and sills also comprise the mafic stratigraphy in southeastern Jamieson and eastern Robb Townships.

Partially overlying the dominantly mafic horizon is a domal succession (up to 2.2 km thick in northern Godfrey Township) of felsic lava flows, breccia and minor tuff, the Mount Jamieson Rhyolite. This formation may be traced from southern Godfrey Township to as far north as central Jamieson Township where it appears to interfinger with the lower mafic volcanic formation which dominates the Upper Cycle I volcanic stratigraphy extending to the northwest (fig.4). This rhyolite formation has been described by Fisher and Ransom (1975), Goodwin et al. (1972), Goodwin (1979), and Middleton (1973, 1974, 1975).

The Mt-Jamieson Rhyolite formation is characterized by flows of great thickness (up to 500 m) and relatively short strike length, and by an unusually high potassium content (as high as 12 wt% K_2O ; R. Bula, pers.comm., 1983) probably attri-

butable to low-temperature hydrothermal alteration (Legault et al., 1985). Fisher and Ransom (1975) described three members of the formation in the Mt-Jamieson area near the Godfrey-Jamieson Township boundary: The Tower Road Rhyolite, the oldest member, 500 m in thickness; the Godfrey Ridge Rhyolite, also 500 m in thickness, characterized by an aphanitic flow-banded fragment-bearing basal zone, a coarsely flow-banded spherulitic core, and a rhyolite breccia carapace; and the North Ridge Rhyolite, the uppermost member, consisting of at least two 300 m thick flow-banded lava flows separated by a pyroclastic breccia.

Massive to quartz-phyric felsic volcanics with minor graphitic felsic tuff and mafic volcanics, up to 2.0 km in thickness, overlie the dominantly mafic volcanic formation exposed in northern Robb Township and the Mt-Jamieson Rhyolites in the Godfrey-Jamieson area. These felsic tuffs generally grade upward into metasediments (tuffaceous argillite and wacke) and mark the upper part of the first volcanic cycle. Minor beds of sulphide-facies banded iron formation also occur within the felsic tuff and sediment in southwestern Loveland Township (Berry, 1944; Middleton, 1974).

2.2.2b Cycle II

The upper succession (Cycle II) underlies a poorly exposed part of the region extending southeastward from eastern Loveland Township into eastern Jamieson and northeastern Godfrey Townships (fig. 4) and as such the character of the volcanics which underlie this area and the extent of the

upper cycle are not well known. However, limited geochemical data suggest that high-alumina basalt and andesite of calc-alkaline affinity dominate the upper volcanic cycle (Middleton, 1973, 1974, 1975). Ultramafic volcanics also apparently occur within this group (R. Middleton, pers. comm., 1977 - in Pyke, 1978, 1982).

Pillowed amygdaloidal basalt-andesite, massive porphyritic andesite, and minor breccia which form the large outcrops in central Loveland and western Macdiarmid Townships, make up the main Cycle II volcanic succession exposed there. These mafic to intermediate volcanics are interpreted to extend into east-central Godfrey Township. Felsic volcanics as well as intermediate to mafic pyroclastic rocks have been indicated by drilling to occur within these volcanics (especially in northeastern Jamieson Township).

Felsic tuff with associated graphitic tuff and tuffaceous argillite occur in northeastern Loveland and northwestern Macdiarmid Townships west of the Mattagami River Fault. These may represent folded equivalents of similar volcanics and sediments forming the top of Cycle I in southwestern Loveland Township; Cycle II stratigraphy therefore would form the core of Pyke's (1978, 1982) inferred northwest-trending syncline. Alternately, if Pyke's interpretation is incorrect, the felsic volcanics and sediments in northwestern Macdiarmid may be a different unit.

2.2.3 Kamiskotia Gabbroic Complex

The Kamiskotia Gabbroic Complex is a large composite,

generally mafic intrusion which occupies the western border of the Kamiskotia supracrustal succession (fig.4). Smaller intrusive bodies, probably related to main complex also occur at intervals throughout the volcanics and sediments that flank the Kamiskotia Complex. The intrusion has been described in detail by Berry (1944), Hogg (1954), Pyke and Middleton (1970,1971), Wolfe (1970,1971), and Middleton (1973,1974,1975).

Primary igneous layering and gravity data on the margin of the Kamiskotia Complex suggest that the contact between the Complex and the surrounding volcanics is nearly vertical and generally conformable or sill-like (especially in Robb Township)(Berry,1944;Middleton,1976).

The mafic phases which make up most of the Complex are gabbro, norite, anorthositic gabbro, and hornblende gabbro. They are characterized by large variations in texture and grain size and commonly contain irregular pegmatitic segregations of hornblende-plagioclase-magnetite.

Layered noritic gabbro and norite form prominent outcrops in the Kamiskotia Hill area in southeast Robb Township. Coarse-grained to pegmatitic gabbro and hornblende gabbro form important parts of the intrusion which extend into southwestern Jamieson Township, northwestern Godfrey Townships, and western and northern Turnbull Township.

Sill-like gabbroic intrusions are often intercalated with the Kamiskotia volcanic and sedimentary succession; the fine-grained intrusions are often difficult to distinguish

from flows. Middleton (1973,1974) noted a progressive change in the composition of the mafic sills from gabbroic, abundant in the Cycle I stratigraphy, to ultramafic in the Cycle II stratigraphy in northeastern Jamieson and Robb Townships and Macdiarmid Township. Ultramafic intrusions (serpentinized peridotite, dunite) form minor parts of the main Kamiskotia Complex in southwestern Turnbull Township and northwestern Carscallen Township (Middleton,1974;Wolfe,1970).

Intermediate intrusive rocks which occur only in the lower Cycle I stratigraphy in Godfrey and Turnbull Townships (fig.4), are informally termed "granophyres" and have been described in detail by Hogg (1954) and Middleton (1975). Middleton (1975) on the basis of chemical composition and texture, described them as microdiorite and porphyrite. They are generally dark, fine-grained to porphyritic (quartz-albite to albite porphyry) and commonly exhibit spherulitic textures and granophyric intergrowths. The microdiorites-granophyres are interpreted to be late-stage differentiates of the Kamiskotia Complex or high-level intrusions which may have fed andesitic volcanics higher in the stratigraphic pile (Middleton,1975).

The fine-grained felsic intrusions associated with the Kamiskotia Gabbroic Complex have been studied recently by Middleton (1973, 1975), Campbell et al. (1981a,b), and Hart (1984). These rocks are granodioritic and are composed of an equigranular granophyric intergrowth of mm-sized altered albite and quartz (Hogg,1954;Middleton,1975). Because the feldspars are strongly sericitized, the granodiorites were

readily foliated and the quartz grains form very prominent "eyes" so that these intrusive rocks are often called quartz porphyries (Pyke and Middleton, 1970, 1971; Middleton, 1973, 1975). The margins of the intrusions and most of the related dykes surrounding them are granular aplites which commonly display graphic quartz-albite intergrowths (Hogg, 1954). Because these felsic rocks often also contain miarolitic cavities and vesicles (in Robb and Jamieson Townships) and are sometimes spherulitic (in central Godfrey Township), the granodiorites are interpreted to be subvolcanic intrusions (Pyke and Middleton, 1970, 1971; Middleton, 1973, 1975) which likely fed felsic volcanics in the Kamiskotia area (Campbell et al., 1981a, b; Hart, 1984).

Rocks described as granophyric quartz diorites (1 to 400 m wide) always occur between, and generally are gradational to the Kamiskotia granodiorites and the enclosing mafic volcanics and intrusions; they are interpreted to be hybrid rocks formed on intrusion of the granodiorite (Hogg, 1954; Middleton, 1973, 1975).

2.2.4 Late Felsic Intrusions

Massive, medium- to coarse-grained granitic rocks (granodiorite, quartz-monzonite, tonalite) intruded the western part of the Kamiskotia area in Loveland, Robb, and Turnbull Townships (fig. 4). These intrusions are generally fresh looking, unfoliated and have chilled margins and agmatite zones against the Kamiskotia Gabbroic Complex. Migmatite zones in the Gabbro are often associated with similar granitic rocks

to the west in Cote and Massey Townships. These rocks are interpreted to be pre- to synkinematic felsic intrusive rocks, probably associated with the Groundhog Batholith to the west (Middleton, 1973, 1974, 1975; Pyke, 1982; MERQ-OGS, 1983).

2.2.4 Early to Middle Precambrian Diabase Dykes

North- to north-northwest-trending diabase dykes cut all the rocks in the Kamiskotia area. They are quite common, often occurring at intervals of 500 m or less. The dykes, generally 10 to 30 m in width, are fine- to medium-grained (rarely feldspar porphyritic) and have chilled margins. Although the Kamiskotia diabase dykes sometimes contain quartz grains when they cross felsic volcanics (Middleton, 1973), they are generally not quartz-bearing as reported by Berry (1944), Hogg (1954), and Legault (1982). Olivine diabase dykes are also reported in the area (Berry, 1944; Middleton, 1973, 1975).

The diabase dykes in the Kamiskotia area were previously assumed to form part of the Early Precambrian Matachewan dyke swarm (2690 ± 93 Ma; Gates and Hurley, 1973) which are also north-trending. However, potassium-argon ages of the Kamiskotia dykes in Bristol Township by Leech (1965) are Middle Precambrian ranging from 1.325 to 1.760 Ga. Middleton (1973) showed that the Kamiskotia diabase dykes have magnetic properties similar to those of Late Precambrian Abitibi dykes.

2.3 HISTORY OF DEVELOPMENT: KAMISKOTIA AREA

Four volcanogenic massive sulphide deposits occur in the Kamiskotia region: The Kam-kotia Mine in Robb Township, the Jameland Mine in Jamieson Township, the Canadian Jamieson and Genex Mines in Godfrey Township. This makes the Kamiskotia area the most important region, in terms of massive sulphide deposits, in the Ontario part of the Abitibi Subprovince.

Very little is known about the deposits in comparison to other mining camps such as the regions of Matagami and Noranda, Quebec and Sturgeon Lake and Uchi Lake, Ontario. Table 2 is a summary of published work on the deposits exposed in the Kamiskotia area; until recently, they were generally described as epigenetic replacement deposits.

The initial discovery of base metal mineralization in the region was made as early as 1915 (Burrows and Hopkins, 1915). Including a short period of production from the Kam-kotia Mine under the impetus of wartime demand from 1943 to 1944, the Kamiskotia area produced roughly 90 100 tonnes of copper, 100 000 tonnes of zinc, 236 000 g of gold, and 29.9 million g of silver from 7.30 million tonnes of ore during the period 1961 to 1972 when the Kam-kotia Mine finally shut down. A summary of production statistics for the area is given in Table 2.

The four deposits occur over a 13 km strike length within a dominantly mafic volcanic formation located roughly halfway up the exposed Kamiskotia volcanic succession (figs.4,5). The deposits generally share the following characteristics:

Table 2: Production Statistics and Previous Work on the Cu-Zn Deposits in the Kamiskotia Area.

Deposit	Date	Tonnage (10 ⁶ t)	Grade			
			Cu%	Zn%	Au(g/t)	Ag(g/t)
Kam-kotia	1941-43	0.171	2.03			
	1961-72	5.84	1.11	1.21	0.0299	3.53
Canadian Jamieson	1966-71	0.826	2.17	3.10	0.0686	11.0
Jameland	1969-72	0.462	0.99	0.88	0.0322	3.53
Genex	1966	218 t of concentrates @ 21.45-27.25 %Cu (0.121) (2.22)*				

*Known and approximate reserves (United Obalski Mining Ltd., 1966 Annual Report).

Sources: Middleton (1975) and Fisher and Ransom (1975).

References on Deposits:

Kam-kotia: Gledhill, 1928; Ferguson, 1944; Kalliokoski, 1965; Guimond, 1964; George, 1967; Pyke and Middleton, 1970, 1971; Bright, 1972a,b; Middleton, 1973.

Canadian Jamieson: Ferguson, 1944; Berry, 1944; Hogg, 1954; The Mine Staff, 1967, 1968; Pyke and Middleton, 1970, 1971; Bright, 1972a,b; Middleton, 1975.

Jameland: Paterson, 1957; Pyke and Middleton, 1970, 1971; Bright, 1970, 1972a,b; Middleton, 1973.

Genex: Gledhill, 1928; Hogg, 1954; Pyke and Middleton, 1970, 1971; Middleton, 1975.

- 1) They are made up of many small (less than 400 000 tonnes) pyritic massive sulphide lenses.
- 2) Mineable copper-rich stringer zones are usually associated with massive sulphide lenses.
- 3) Ore-bodies occur as stacked en-echelon lenses which sometimes follow extensive linear zones within a restricted stratigraphic level.
- 4) Individual lenses of massive sulphides typically display normal (Sangster, 1972) copper to zinc zonation. Copper-zinc zoning is sometimes observed on the scale of the deposit.
- 5) Felsic volcanics (ignimbrites, flows and tuffs) occur within each deposit although the sulphides are often hosted entirely by mafic volcanics.
- 6) Cherts are associated with some of the deposits; sulphide-rich exhalites are recognized only near the Genex deposit.
- 7) Chlorite alteration occurs immediately beneath most of the massive sulphide lenses. Strong sericite alteration envelopes all the deposits.
- 8) Silicification in the form of quartz-stockwork alteration is often associated with ore zones.

Clearly the deposits of the Kamiskotia area are similar in many respects to Precambrian volcanogenic massive sulphide deposits described in the Noranda-Matagami areas of Quebec (see Franklin et al., 1981; Hutchinson et al., 1982).

2.4 STRUCTURAL GEOLOGY

2.4.1 Introduction

The sparse exposure in the Kamiskotia area makes structural determinations difficult. However, deformation in the area is apparently simple; there is no identifiable large scale isoclinal folding in the steeply dipping, generally eastward-facing strata. The main event which affected the Kamiskotia succession west of the Mattagami River Fault (a

major northtrending structure;fig.4) is the emplacement of the Groundhog Batholith (Goodwin,1979), a pre- to synkinematic granitoid body which forms part of the westward margin of the Abitibi Belt (Pyke,1982;MERQOGS,1983).

In simple terms, the Kamiskotia area appears to have been arched or domed into its present configuration during emplacement of the Groundhog Batholith (Goodwin,1979); west of the Mattagami River Fault, in the region north of the Genex Mine area, the Kamiskotia succession (including the Kamiskotia Gabbroic Complex) appears to have been deformed into a simple, homoclinal east- to northeast-facing succession bordered to the north (according to Pyke,1978) by a southeast-trending synform in northeastern MacDiarmid Township (figs.3,4). This inferred synform separates the Kamiskotia volcanics from those forming the margin of the so-called Ramour Dome (see Pyke,1978;1982) located to the northeast of the Kamiskotia area.

The main structure which forms the border of the Kamiskotia Group south of the Genex Mine area is an east- to northeast-trending synform, the probable western extension of the Porcupine Syncline of the Timmins area, which crosses through southeastern Bristol Township.

2.4.2 Folding and Ductile Deformation

In Loveland, Macdiarmid, Robb, and Jamieson Townships, the trend of the Kamiskotia supracrustal succession is north-west to west-northwest, conformable with the underlying Gabbroic Complex (Berry,1944;Hogg,1954;Middleton,1973); the dip

is generally vertical to steep to the northeast.

Southward into Godfrey and Turnbull Townships and in the Genex Mine area, the strike gradually changes to approximately north-south; dips generally remain steep easterly to vertical. In northern Turnbull Township, there is some evidence (Middleton, 1975) for more easterly trending mafic rocks though these rocks have been interpreted as possible fine-grained gabbroic intrusions (Wolfe, 1971).

Magnetic trends in southwestern Godfrey Township and some flow contacts in southeastern Turnbull Township suggest that the metavolcanics in the area south of Forbes Lake strike more southeasterly and are possibly overturned (Middleton, 1975); this is confirmed by mapping some felsic fragmentals south of Forbes Lake.

It is unclear what type of structural feature may relate the southwest-trending volcanics and sediments mantling the Porcupine Syncline in southern Bristol Township to the southeast-trending volcanics in southern Godfrey Township.

While structure on a regional scale appears simple, in some areas local shallow attitudes and tight folding have been reported: in the Steep Lake area of Godfrey Township, detailed mapping and diamond drilling have outlined irregular dips approaching horizontal in an area cut by an abundance of intrusions (R. Bula, Kidd Creek Mines pers. comm., 1982). Tight to isoclinal horizontal- to shallow-plunging southeast-trending folds have been reported in the Canadian Jamieson Mine in northern Godfrey Township (The Mine Staff, Canadian Jamie-

son Mines, 1968; Pyke and Middleton, 1970; 1971; Bright, 1972a; Middleton, 1975).

There is generally no marked deformation-related flattening or stretching of spherulites, fragments, or pillows. Ductile deformation has been observed in a few areas, (see Photo 3. in Middleton, 1973) particularly in altered rocks (Legault, 1982). In the Genex Mine area, east-west stretching of fragments and pillows occurs along narrow east-trending shear zones. Often deformation is only exhibited by weak ptigmatic folding of quartz veinlets and sulphide veins or in thin-section by weak pressure shadows around amygdules and by schistosity.

2.4.3 Schistosity

All of the exposed rock in the area, with the exception of the Early to Middle Precambrian diabase dykes and the late felsic intrusions which cut the Kamiskotia Gabbroic Complex (Middleton, 1975) (i.e., the Groundhog Batholith) show the effects of regional dynamic metamorphism. A weak to moderate S-type tectonic fabric (i.e., primarily a planar fabric; Ramsay, 1967) or schistosity appears to be associated with the regional flexure of the volcanic pile.

The schistosity is defined in thin section by the parallel alignment or preferred orientation of groundmass chlorite-sericite-actinolite-epidote and by the trace of oxide trains and quartz blebs. Massive fine-grained rocks and relatively unaltered volcanics often only show a weak schistosity. Altered felsic volcanics have weak to moderate development of a

schistosity spaced 1 to 10 cm apart defined by anastomosing, 1 to 2 mm thin sericite veinlets. This spaced schistosity imparts a "curdy" texture to the outcrop (fig.10). Because the curdy texture appears to be best developed in more sericitic rhyolites, this texture may be used to infer the degree of alteration (or metamorphism) of the rock.

This prominent, nearly vertical schistosity has a variable trend ranging from northwest (parallel to the general strike and dip) in Laveland, Macdiarmid, Robb and Jamieson Townships (Middleton, 1973, 1974), to nearly east-west (perpendicular to the general strike and dip) in GodfreyTurnbull Townships area (Middleton, 1975). Some weak kinking of the S_1 fabric was observed only in a few outcrops of strongly altered rocks in the Genex Mine area; minor crenulations with horizontal axes (and in some cases, with vertical axes) have also been reported in schistose rocks in the Canadian Jamieson Mine (The Mine Staff, Canadian Jamieson Mines, 1968).

A second S-type tectonic fabric, northtrending and steeply dipping, has been recognized in only a few locations in the whole Kamiskotia area. Middleton (1974) mentions north-south shearing in rocks occurring on the east bank of the Mattagami River in southern Macdiarmid Township. A weak planar fabric resembling a spaced cleavage (2 to 4 mm spacing) trending 166° to 170° with a steep easterly to vertical dip is visible in a few outcrops near large north-northeast-trending diabase dykes in Jamieson Township (near Lot 10, Con 2 Legault, 1983) and in the Genex Mine area (Legault, 1982). Because the regional fracture system which channelled the

diabase dyke swarm in the Kamiskotia area parallels this second planar fabric (see Section 2.4.3), it is reasonable to relate the spaced cleavage fabric to movement along that fracture system (Middleton, 1974).

2.4.3 Faults in the Kamiskotia Area

Middleton (1973; 1974; 1975) inferred at least five fault systems in the Kamiskotia area from geological and ground magnetic data.

The first and possibly the oldest system, trends west-northwest to east-west, parallel to and probably associated with the regional schistosity. This fault system is of pre-dyke age since many of the dykes appear to be intruded along some of the faults (see Middleton, 1973; 1974; 1975). This system may have been active since dyke emplacement. In the Genex Mine area for example, a 15 m apparent rightlateral displacement of a diabase dyke has been recognized along a 115° fault (Legault, 1982).

A second fault system trending eastnortheast (070°), also apparently pre-dyke in age (Middleton, 1975) is most evident in the Mount Jamieson area (see Fisher and Ransom, 1975) displacing the thick massive rhyolite flows exposed there. Post-dyke fractures trending 060° to 070° reported by Middleton (1973) indicate that this fracture system may also have been active after the emplacement of the northnorthwest trending diabase dykes.

A third fault system, trending northeast in Godfrey and Robb Townships, may be of the same age as the second fault

system since it also does not displace the diabase dikes but often channels them along it (Middleton,1973;1975) .

The fourth and probably most evident fault system (Pyke et al.,1973;Pyke,1982) trends northnorthwest (160° to 180°) and localizes a swarm of diabase dykes. These faults and fractures (and diabase dykes) cut all rock types west of the Mattagami River Fault with a relatively high frequency compared to the rest of the Timmins area (Pyke,1982).

The Mattagami River Fault (figs.3,4) one of the major structural features in the Timmins area and a pronounced topographic lineament following Kenogamisis Lake to south and the Mattagami to the north, parallels the fourth fault system. Major apparent leftlateral movement along the Fault of up to 6 km has been documented by Middleton (1973). Middleton (1976), interpreted a major vertical displacement on the fault (west side up) on the basis of strong density contrasts across the Mattagami River Fault in Godfrey Township..

The fifth fault system trends northwest and is reflected by the trends of diabase dykes in Loveland Township (Middleton, 1974) and Turnbull Township (Middleton,1975).

2.5 METAMORPHISM

All the volcanic rocks and associated intrusive and sedimentary rocks (diabase dykes excepted) in the Kamiskotia area show the effects of greenschist facies metamorphism (Middleton,1973,1974,1975). Jolly (1974) outlined a weak aureole approaching amphibolite grade in the Kamiskotia Lake

area in Robb Township; Ferguson (1944) identified chlorite-amphibole-bearing mafic volcanics near the Kam-kotia deposit. The aureole however does not appear to surround the Kamiskotia Gabbroic Complex in the Godfrey-Jamieson Townships area (Jolly, 1974). The thermal effects of the Gabbroic Complex, itself generally showing greenschist facies metamorphism (Hogg, 1954; Walker, 1954), is not well documented.

An increasing grade of metamorphism, indicated by increasing degree of schistosity, developed in the supracrustal rocks and the Kamiskotia Gabbroic Complex, appears to be related to late-stage granitoid intrusions which cut the western part of the area (satellititic bodies of the Groundhog Batholith); Berry (1944) and Middleton (1973) note increasing grades of metamorphism in both western Loveland and Robb Townships in the vicinity of the late granitoid bodies. Zones of agmatite, migmatite and granitized gabbro surround these medium to coarse-grained rocks just west of the Kamiskotia region (Middleton, 1973).

In the Genex Mine area, the rocks generally show greenschist facies metamorphic assemblages of chlorite, epidote, actinolite, albite and sericite. In the area south of Forbes Lake, higher-grades of greenschist metamorphism are suggested by the presence of biotite and chlorite rimming ferroan dolomite porphyroblasts (fig. 22). Narrow zones of contact metamorphism are often associated with the diabase dykes which cut the area. In the Genex Mine area, the thermal effects associated with the thick diabase dykes results in the weak development of sericite and in the recrystallization

of quartz phenocrysts within 5 to 10 m of the intrusions. The effects are most noticeable in the mafic volcanics and fine-grained intrusions exposed within 5 to 10 m of the thickest diabases; these rocks are often altered to dense, siliceous trap material; quartz is common in fine veinlets and clots in these rocks. In thin section, contact metamorphism results in the development of fine-grained biotite which form at the expense of chlorite and sericite; often biotite-rich zones follow thin veinlets of quartz in the rocks (fig.59). This has the effect of giving these rocks a fine mottled brownish appearance in hand specimen.

Spotted pyroxene-hornfels facies metamorphism of chloritic pipe alteration within 10 to 15 m of the diabase dykes is also common in the area; mm-sized staurolite, generally showing retrograde alteration to sericite and chlorite is the only recognizable porphyroblastic mineral in these chlorite-rich rocks (fig.72). A different porphyroblast mineral phase now entirely replaced by chlorite, is suggested in the staurolite schists and in other spotted chlorite alteration zones in the area; these may be retrograded cordierite porphyroblasts (fig.73). Andalusite was identified in only one specimen of mafic volcanic altered to a biotite-chlorite-sericite-quartz schist within 15 m of 60 m thick diabase dyke; in this case sericite was misidentified as fibrous sillimanite by Legault (1982).

3.0 GEOLOGY OF THE GENEX MINE AREA

3.1 INTRODUCTION

The general geology of Godfrey Township is taken from Hogg (1954) who did much of the original mapping in the area, Middleton (1975), and unpublished detailed mapping by Texas-gulf Ltd.-Kidd Creek Mines Ltd.. The geology in the Genex Mine area is taken from Legault (1982;1983) and this study.

The north-trending, east-facing, dominantly mafic volcanic formation which hosts the Genex Mine overlies a thick succession of fragmental to massive felsic volcanics with minor mafic flows which make-up the lowest known formation of the Kamiskotia supracrustal succession. The mafic volcanics are overlain by the Mt-Jamieson Rhyolite formation. The upper part of the volcanic pile in Godfrey Township is made up of pillowed mafic volcanics, felsic volcaniclastics with associated graphitic tuffs which grade into wackes and argillites exposed in southeastern Godfrey Township.

The thin succession of mafic volcanics, dominantly amygdaloidal pillowed flows and breccias with minor felsic flows and fragmentals, which host the Canadian Jamieson and Genex deposits, extends from northern Godfrey Township to possibly as far south as Godfrey Lake near the Bristol-Godfrey Township boundary (fig.4). The whole volcanic succession is disrupted by:

- 1) Fine- to medium-grained mafic and felsic synvolcanic intrusions (spherulitic granophyric microdiorite and quartz-diorite with lesser granophyric granodiorite).
- 2) West-northwest trending faults (including a major fault which appears to roughly have a 1 km right-lateral

offset) located midway between Steep Lake and Aconda Lake, and traceable for over 5 km into Turnbull Township.

3) Discordant dyke-like bodies of quartz-phyric felsic volcanic which abruptly cut the pillowed flows extending south from the Canadian Jamieson Mine.

South of the Genex Mine area, in an area of no outcrop where geological information is provided by geophysical and sparse diamond drilling information, the dominantly mafic volcanic strata appear to extend to Godfrey Lake where they are cut off by another north-northwest trending fault (fig. 4).

The mapping completed in 1981 and 1983 for this thesis study covered the upper part of the lower felsic stratigraphy and almost the entire exposed predominantly mafic volcanic formation which contains the Genex orebodies. The first outcrop of the overlying Mt-Jamieson Rhyolite occurs approximately 200 m east of the map area. A simplified geology map of the Genex Mine area is presented in Figure 6; a coloured, detailed, 1:1000 scale geology map is provided in the map pocket.

3.2 STRATIGRAPHY OF THE GENEX MINE AREA

The area surrounding the Genex deposit is underlain by north-trending, east-facing, steeply-dipping, pillowed to massive mafic flows and fragmentals, by quartz-phyric massive to fragmental felsic volcanics as well as associated fine-grained synvolcanic intrusions. These rocks are cut by north-northwest-trending diabase dykes of Middle Precambrian age (fig.6).

FIGURE 6: SIMPLIFIED GEOLOGY MAP OF THE GENEX MINE AREA. PILLOWED FLOWS INDICATE A NORTH-NORTHWEST STRIKE AND DIP STEEP TO THE EAST AND OVERTURNED.

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The stratigraphically lowest formation mapped is made up of massive weakly quartz-phyric and flow-banded felsic flows and fine to coarse quartz-phyric felsic fragmentals. These felsic volcanics underlie the area extending from southwestern Aconda Lake to just south of Forbes Lake.

The lower felsic formation is overlain by a thick succession, at least 200 m thick, of pillowed to massive amygdaloidal mafic flows and breccias. The massive sulphide zones developed by Genex Mines/Irvington Mines in 1964-66 are located near the top of this first mafic volcanic cycle.

A thin unit, approximately 40 m thick, of quartz-phyric massive flow-banded to fragmental felsic volcanic partially overlies the first mafic volcanic cycle. This flow unit may be traced from south-central Aconda Lake to just southeast of the Genex shaft area.

The felsic volcanics are in turn overlain by a second, 250 to 300 m thick succession of massive to pillowed amygdaloidal mafic volcanics. These form the uppermost stratigraphic unit mapped in the area during 1983 and presumably the top of the dominantly mafic volcanic formation in this part of the Kamiskotia area.

The first mafic volcanic cycle in the Genex area is cut by four major east-trending felsic, weakly quartz-phyric to aphanitic dykes. Massive aphanitic to fine-grained mafic intrusions cut most of the volcanics west of the Genex shaft. The lower felsic strata in particular are broken up into large xenolithic bodies up to 100 m in size. Large sill-like bodies of very fine-grained mafic rock also occur throughout

the mafic volcanic succession, often dilating flow contacts between units and, in some cases, cutting off sulphide-rich zones and alteration developed in the mafic and felsic volcanics in the area.

3.2.1 Felsic Volcanics

The felsic volcanic rocks in the Genex Mine area comprise two main units:

- 1) Those massive to brecciated felsic flows and felsic fragmentals which make up the lower felsic formation on which the Genex area mafic volcanics rest.
- 2) A single felsic flow unit, the intercycle felsic unit, which partially overlies the first mafic volcanic cycle and forms the base of the second mafic volcanic cycle exposed to the area east of the Genex shaft zone.

3.2.1a Lower Felsic Formation: Genex Area

The lower felsic formation which is exposed in the Genex Mine area can be best described as a mixed succession of quartz-phyric massive to fragmental felsic rocks. Because of the degree of alteration, the general inherent lack of bedding in these rocks, and because they are quite often disrupted by mafic intrusive material forming up to 60 % of the rock exposed in the western part of the Genex Mine area, it is quite often impossible to trace units from one xenolith block to another; the result is that satisfactory interpretations as to the relationship of the felsic fragmentals with the massive rocks (ie. whether pyroclastic or autoclastic) are often not possible. In spite of these problems, mapping of the lower felsic strata appears to show the felsic rocks

north of Forbes Lake to be slightly different from those south of Forbes Lake and for this reason they will be discussed separately.

In general, the massive and fragmental felsic volcanics north of Forbes Lake share the following characteristics:

- 1) The fragmental phases are generally monolithic.
- 2) The fragmental rocks are poorly sorted, often coarse grained and generally show no evidence of bedding.
- 3) The fragments are generally angular and similar in composition to the matrix that surrounds them.
- 4) The fragmental rocks are cut by lobe-like felsic bodies similar in composition and texture to the rocks which surround them.
- 5) The massive felsic lobes generally have brecciated and flowbanded margins which sometimes grade into the fragmentals which surround them.

Typical surface exposures of the felsic fragmental rocks are shown in Figures 7, 8 and 9. These rocks generally consist of 30 to 50 % visible lapilli to block sized (up to 20 cm), quartz-phyric (up to 5 %, mm-sized quartz-eyes), weakly quartz-amygdaloidal, angular felsic fragments. These fragments, which weather low and are dark on a fresh surface, occur in a matrix similar in composition, which in thin section is seen to be made up of mm-sized chloritic, angular vitric granules in a siliceous microcrystalline mosaic of quartz and sericite (figs.11,12).

In some cases, the felsic fragmental rocks are fine-grained with up to 30 % 1 to 20 mm-sized felsic fragments or angular vitric granules, and occasionally some breccia-like exposures ; although these clastic rocks may essentially represent a weakly brecciated felsic lava, they are generally

grouped as fragmental on the base map. In a few cases, the rocks have a tuffaceous character; an example is the felsic rock exposed in the northwestern part of a large xenolith located in the region west of Baseline 3W, centred by Line 2160N. Here the rocks are quartz-porphyritic (up to 5 % or more) but also contain up to 15 % lithophysae with siliceous haloes 2 to 3 cm in diameter (fig.10), as well as 5 to 10 % chloritic, fiamme-like, angular vitric granules or lithic clasts, and up to 10 % lapilli-sized lithic fragments (figs.10,14). These rocks grade eastward into a very fine felsic fragmental to massive looking rock similar to those described above. In this case however, the rock is quite visibly recrystallized and altered; it consists dominantly of fine polycrystalline quartz with lesser interstitial sericite and chlorite (fig.15). The mm-sized quartz-eyes often consist of a core of inverted Beta-quartz (showing relict rhombohedral to hexagonal symmetry) which are thinly mantled by polycrystalline quartz (fig.15). Relict feldspar megacrysts are also visible in thin section (fig.16) but only appear to make up only a small proportion of the rock. The rough weathering texture and the presence of up to 30 % visible 1 to 20 mm-sized subangular felsic fragments (they are much more evident in the southwestern portion of the xenolithic block) suggest that these rocks are fragmental. In thin section some 1 to 3 mm-sized chloritic clots, mapped in the field as chloritic fragments, have irregular shapes with ragged edges and enclose up to 30% poikiloblastic quartz

COLOURED PICTURES
Images en couleur

Figure 7: Lower felsic formation, 2460 N, 30 m west of BL 3W (AA-23552, AA-2647). Hammer rests on a massive quartz-phyric felsic lobe with a weakly brecciated margin which grades into a coarse felsic fragmental volcanic. Note the silicified and sericitized matrix which weathers positively compared to the angular fragments (also note weak E-W fabric; handle points north).

Figure 8: Lower felsic formation, 2070 N, 170 m west of BL 3W (AA-23591, AA-23592). Coarse quartz-porphyrific felsic breccia-fragmental volcanic. Note unsorted, angular fragments up to 30 cm in size in a siliceous, sericitized matrix similar in composition. Hammer handle points north.

Figure 9: Lower felsic formation, 1980 N, 160 m west of BL 3W, (AA-23604). Coarse quartz-phyric felsic fragmental. Note generally rounded to subangular fragments set in a moderately silicified and sericitized matrix of similar composition. Hammer handle points north.

Figure 10: Lower felsic formation, 2210 N, 175 m west of BL 3W (AA-23568). Tuffaceous-looking, strongly sericitized fine quartz-phyric felsic fragmental volcanic. Finger pointing to 2 cm-sized lithophysae with siliceous haloes. Note strong E-W fabric-schistosity (hammer handle points north). Pits are due to chloritic fiamme-like clots (vitric granules?) which are oriented N-S.

Figure 11: Lower felsic formation, 2475 N, BL 3W (AA-2648). Photomicrograph of angular chloritic vitric granules (c) which partly enclose anhedral quartz grains (Q). Matrix is polycrystalline quartz, sericite and fine chlorite (plane-polarized).

Figure 12: Top of lower felsic formation, 1690 S, 160 m east of BL 3W (AA-2652) Photomicrograph of a quartz-phyric felsic hyaloclastite (part of the brecciated margin of felsic flow). Note the opaque-rich chloritic vitric granules (c) partly enclosing quartz grains (Q) in a recrystallized matrix of quartz, sericite and chlorite. Note the similarity with Figure 11 (plane-polarized).

Figure 13: Lower felsic formation, 2340 N, 130 m west of BL 3W, (AA-23558). Photomicrograph of a massive quartz-phyric felsic volcanic or synvolcanic intrusion. Single recrystallized quartz grain in a matrix of quartz (70%), sericite (10-15%) and chlorite. Note characteristic lack of igneous textures.

COLOURED PICTURES
Images en couleur

Figure 14: Lower felsic formation, 2210 N, 175 m west of BL 3W (AA-23568). Strongly sericitized, tuffaceous, quartz-phyric felsic fragmental volcanic. Note abundance of lapilli-sized siliceous lithic fragments and strong E-W schistosity (hammer handle points north).

Figure 15: Lower felsic formation, 2110 N, 95 m west of BL 3W (AA-23581). Photomicrograph of silicified, sericitized, quartz-phyric, massive to fine felsic fragmental volcanic. Inverted Beta-quartz (Q) mantled by granular quartz (note similar optic orientations). Note completely recrystallized matrix of mortar-textured quartz (80%), with veinlets of sericite (Ser)(5-7%) and fine interstitial chlorite (5-10%) (crossed polarizers).

Figure 16: Lower felsic formation, 2110 N, 95 m west of BL 3W (AA-23581). Photomicrograph of silicified, sericitized, quartz-phyric, massive to fine felsic fragmental volcanic. Relict feldspar megacryst (F) (possibly sanidine) completely replaced by quartz; polycrystalline quartz mantle has a similar optic orientation. Note the chlorite clot (C) with ragged edges and poikiloblastic anhedral quartz grains which could be mistaken as a fragment in hand sample (plane-polarized).

Figure 17: Lower felsic formation, 1980 N, 85 m west of BL 3W (AA-23598). Photomicrograph of chloritized and silicified, massive to weakly brecciated felsic volcanic lobe (probably marginal facies of flow). View of flow-banded fragment (quartz and chlorite after obsidian) which make up 20% of sample. Hyaloclastite fragment is partially surrounded by a matrix of fine chlorite with micropoikiloblastic quartz (plane-polarized).

Figure 18: Lower felsic formation, 1975 N, 100 m west of BL 3W (AA-23601). Strongly altered, quartz-porphyrific felsic hyaloclastite breccia. Note the chloritized angular fragments set in a strongly silicified matrix. Also note the abundance of curvilinear, cusped, edges indicating that these fragments were originally glassy. Strong E-W imbrication (hammer handle points north) is possibly tectonic.

Figure 19: Lower felsic formation, 1975 N, 100 m west of BL 3W (AA-23601). Chloritic, opaque-rich, angular felsic vitric granules or hyaloclastite (C) in matrix of polycrystalline quartz (70%) and fine chlorite (30%). Largest vitric granule contains relict plagioclase phenocryst (P) (replaced by quartz, chlorite and carbonate)(plane-polarized).

- Figure 20: Lower felsic formation, 1490 N, 160 m west of BL 3W (south of Forbes lake; AA-23768). Coarse felsic fragmental volcanic (tuff-breccia); crude sorting suggest SE-NW strike (hammer handle points north). Note subangular to rounded blocks and banding evident in some of the felsic fragments. (potassic-feldspar alteration).
- Figure 21: Lower felsic formation, 1525 N, 210 m west of BL 3W (south of Forbes Lake; AA-23767). Quartz-phyric felsic tuff to lapilli-tuff; note heterolithic angular fragments; abundant cm-sized resistant white siliceous fragments and carbonatized porous fragments (which weather low as pits in the outcrop). (potassic-feldspar, carbonate alteration).
- Figure 22: Lower felsic formation, 1495 N, 65 m west of BL 3W (south of Forbes Lake; AA-23771). Photomicrograph from a massive, sericitized, quartz- and weakly feldspar-phyric felsic volcanic. Phenocryst cluster of adularia (A) with minor poikiloblastic quartz (q) which is surrounded by 30 % ferroan dolomite (d). Some of the dolomites have chlorite rims (c). Matrix of fine quartz (60%) adularia (20%), chlorite (10), sericite (5%) and carbonate (plane polarized).
- Figure 23: Lower felsic formation, 1495 N, 65 m west of BL 3W (south of Forbes Lake; AA-23771). Photomicrograph of banded vitric granule whose delicate laminae are completely replaced by fine quartz and adularia (plane-polarized).
- Figure 24: Lower felsic formation, 1525 N, 210 m west of BL 3W (south of Forbes Lake; AA-23767). Photomicrograph of cluster of adularia (A), biotite (b), and ferroan dolomite (d). Note the inhomogeneous extinction of adularia. In a matrix of sericite of recrystallized quartz (crossed polarizers).
- Figure 25: Mt-Jamieson Rhyolite formation, Concession Line 4-5, Lot 8-9 boundary (PG-2). Photomicrograph from massive weakly quartz- and feldspar-phyric felsic volcanic. Altered phenocryst (possibly after anorthoclase or sanidine) made up of adularia (A; note the inhomogeneous extinction) with a core of poikiloblastic albite (P; weak albite twinning). Note the presence of carbonate (c) around margin and matrix of fine quartz, adularia, sericite (crossed polarizers).

grains (fig.16) and may be the result of alteration (see Section 4.3).

The fragmental felsic volcanics are often cut by lobe-like "intrusions" of massive felsic volcanic. The massive lobe-like felsic volcanic phases are commonly similar in composition and quartz-eye content to the fragmentals which surround them. For example, the large felsic volcanic xenolith exposed in the area west of Baseline 3W near Line 2040N, is made up of coarse felsic fragmental rocks which are cut by a sill- or lobe-like body of more massive-looking felsic volcanic; it is spherulitic and flowbanded in areas and contains 1 to 2 % quartz amygdules and up to 20 % fragments. The contact between the more massive felsic unit and the surrounding fragmental is generally sharp; in a few small outcrops, however, the contact appears to be gradational. In the area 80 m west of Baseline 3W and 60 m south of Line 2040N) the felsic lobe contains up to 20 %, 1 to 3 mm-sized angular flowbanded fragments (fig.17). Immediately adjacent to the lobate felsic volcanic body is an exposure of strongly altered, coarse felsic fragmental (fig.18). The fragmental shows some imbrication due to tectonic rotation during deformation. The fragments, 1mm to 20 cm in size, are quartz-phyric (2 to 3 % mm-quartz-eyes), strongly chloritized, angular with cusped edges and are nicely highlighted in a resistant siliceous quartz-phyric felsic matrix. Similar features and textures are seen in thin section; angular 1 to 5 mm-sized quartz-phyric shards (now altered to chlorite) occur in a quartz phyric matrix of microcrystalline quartz, chlorite

and minor sericite (fig.19). Some of the clasts appear to have been fragmented in situ and contain relict altered plagioclase feldspar megacrysts (less than 1%, altered to chlorite, quartz, carbonate and opaques). These textures suggest that this rock is an altered obsidian breccia or felsic hyaloclastite probably associated with a massive lobe immediately adjacent to the breccia.

In some cases, the relatively massive phases are more obviously cross-cutting; for example, the felsic rocks occurring between Line 2400N and Line 2280N west of Baseline 3W form part of a cork-shaped exposure which juts 15 to 20 m above the swamp which surrounds it on three sides. This outcrop is made up of siliceous, massive to flow-banded to very weakly brecciated felsic volcanic cut by 5 to 20 cm-thick barren quartz veins. The rock differs slightly in quartz phenocryst content from the adjacent felsic volcanics to the north; it is only weakly quartz-phyric (generally 1 to 2%). Chlorite-sericite alteration coupled with a granular texture gives this rock a brecciated appearance on a weathered surface and a mottled waxy yellow to dark green colour on a fresh surface. In thin section, the rock is recrystallized, consisting mainly of fine polycrystalline quartz with minor sericite and chlorite, as well as a few scattered mm-sized anhedral quartz phenocrysts (fig.13). Although this rock is interpreted to be a massive, possibly dome-like, felsic volcanic body it may also represent the dilated feeder zone to the dyke.

(1).

The felsic fragmental rocks in the area north of Forbes Lake could have been formed by two possible mechanisms:

- 1) They are proximal pyroclastic rocks or explosion breccias, formed by phreatomagmatic activity around a vent area, the massive rocks in part representing thin contemporaneous intrusions.

- 2) Alternately, the fragmentals could have been formed by autobrecciation and quenching of felsic flow lobes forming the top of the lower felsic formation.

While it could be argued that the apparently low proportion of massive lobe material to volcanoclastic rock (compared with the felsic flows described by de Rosen-Spence et al. (1980) in the Noranda region) favours a pyroclastic mode of formation for these rocks, some Icelandic subglacial felsic flows (ie. at Blahnukur - Furnes et al. (1980)) may only contain a minor amount of lobe material (13% of the outcrop - roughly the same as in the Genex area). However as discussed previously, in some cases, massive volcanics may have been incorrectly mapped as being fine-grained fragmental rocks because of the presence of some visible fragments.

An almost complete felsic flow succession is interpreted to occur at the top the lower felsic formation east of Baseline 3W and north of Tieline 1730S. This group of felsic rocks has been previously interpreted as a felsic dyke (Hogg, 1954) and a tuff (Legault, 1982). However, mapping further to the west and south suggest that this may not be the case. Although these rocks are quite strongly hydrothermally altered, some large scale and surprisingly small scale volcanic structures remain:

- 1) this rock is quite strongly flowbanded, particularly near its upper margin and in what remains of the core

zone (now dilated by a mafic intrusion).

2) a thin (up to 10 m thick) irregular mantle of coarse breccia made up of angular, dominantly felsic and minor mafic clasts (up to 30 cm in size) in a strongly chloritic and siliceous matrix forms the contact zone between the felsic formation and the overlying mafic volcanics.

3) the rock is similar in composition to the massive felsic volcanic lobes and coarse felsic fragmentals exposed to the west (the contact zone between the fragmentals and these "massive" volcanics has not been observed). A few block-sized quartz-phyric fragments, usually less than 1 %, are commonly present.

4) these rocks may contain up to 15 % 1 to 5 mm, angular vitric granules or possible lithic clasts (now altered to chlorite) which weather low in a resistant silicious quartz-phyric matrix which in thin section is strongly recrystallized and made up of microcrystalline quartz, minor sericite and chlorite (fig.12).

The rocks forming the top of the lower felsic formation exposed in this region east of Baseline 3W are clearly similar to those subaqueous rhyolite flows of Archean age exposed in the Noranda region, and well as Quaternary Icelandic subglacial equivalents described by de Rosen Spence et al. (1980) and Furnes et al. (1980).

The lower felsic formation is probably best exposed south of Forbes Lake; crude bedding in the fragmental sequence and field relationships in this area define an anomalous northwesterly trend (about 140°). Crude sorting in the part of the felsic fragmentals define a generally upward fining sequence; it begins with coarse heterolithic fragmental (fig.20) which progressively upward in the stratigraphy grades into a more fine-grained heterolithic fragmental (fig.21). This fragmental also changes compositionally; at the base, the rock is made up of subangular quartz-phyric

12.

amygdaloidal lithic fragments (fig.20), minor massive siliceous fragments and aphyric chalk-white felsic fragments in a quartz-phyric, finely fragmental, matrix (2 to 3 % quartz-eyes). Bands of coarse fragmental rocks contain spindle-shaped fragments as well fragments with chilled margins. These rocks grade upward into a "lapilli-tuff-breccia" sequence made up of a quartz-phyric matrix with lapilli- to tuff-sized fragments containing 1 to 2 % angular, weakly quartz-phyric, siliceous fragments up to 30 cm in size. The top of the fragmental sequence contains no siliceous felsic blocks but has a higher component of porous lapilli-sized felsic fragments (fig.22). In thin section, the angular lapilli-sized fragments consist almost entirely of sericite or carbonate occur in a strongly recrystallized matrix of fine polycrystalline quartz, fine sericite, carbonate and adularia. The quartz phenocrysts (2 to 3 %, 0.2 to 1.0 mm in size) are usually resorbed and embayed.

These fragmental rocks are correlated across Forbes Lake with similar tuff-breccias which form the top of the felsic formation near Lines 1894N and 1824N.

Intruding into, partially overlapping and overlying the fragmental unit is a generally massive quartz-phyric felsic flow unit similar in morphology to those subaqueous felsic flows described in Noranda, Quebec and Iceland by de Rosen Spence et al. (1980) and Furnes et al. (1980). It is generally sericitic and siliceous, quite often amygdaloidal, flow-banded and brecciated with coarse flow-banded blocks near its upper margin, and has a spherulitic to microbrec-

ciated flow top. Where the flow overlaps the sequence in a lobe-like protrusion, the contact is often obscure; this may be due to some local welding due to the proximity of the flow. In thin section, the massive felsic rock is quite visibly recrystallized, containing 1 to 2 % mm-sized quartz phenocrysts (with resorbed margins mantled by polycrystalline quartz) in a matrix of polycrystalline quartz with up to 20 % potassic feldspar with carbonate and sericite, as well as minor chlorite and biotite. This rock also contains relict feldspar megacrysts which have been replaced by adularia and carbonate as well as other alteration minerals (figs. 22 to 25).

The area south of Forbes Lake is interpreted to be underlain by a pyroclastic fall sequence which was deposited near a vent zone from which extruded a felsic lava flow which subsequently covered the tuffs.

3.2.1b Intercycle Felsic Unit

The band of felsic volcanics, informally called the Intercycle Felsic Unit which occurs east of the Genex shaft area, has been traced intermittently in outcrop and in diamond drilling from southern Aconda Lake to a point 30 m southeast of the Genex shaft area (fig. 6). For the most part the lower contact of the felsic unit has been disrupted and dilated from the underlying mafic volcanics by a fine-grained mafic sill and a 60 m thick diabase dyke; xenoliths of felsic volcanic occur throughout the mafic sill on both sides of the diabase dyke (these xenoliths are strongly recrystallized and

often display granophyric quartz-albite). In only one small exposure, 30 m southeast of the shaft zone, was the intercycle felsic unit observed overlying first-cycle mafic pillow-breccia.

Based on morphological characteristics, this felsic unit is interpreted to be a flow similar to those described in the Noranda region and in Iceland by de Rosen-Spence et al. (1980), Furnes et al. (1980) and Self (1982). It has a relatively thick stubby form and has steep margins characteristic of a viscous felsic lava flow. It is also made up of two distinct zones:

- 1) an internal zone made up of strongly flow-banded to massive siliceous and sericitic felsic volcanic characterized by locally abundant contorted flow banding and containing up to 3 % mm-sized quartz eyes and 20 %, 1 to 20 cm angular siliceous felsic fragments. This internal zone is exposed in at least two areas, namely north of Line 2227N and near Line 2111N.

- 2) an external zone gradational to the internal zone, representing an outer carapace which both partly underlies and overlies the flow, and is made up of a complex assortment of felsic breccias and fragmentals.

The volcanoclastics which surround the massive felsic flow lobes form a generally unsorted clastic mantle made up of fine to coarse (1 mm to 1 m sized) quartz-phyric, often flow banded and spherulitic felsic fragments and chloritized vitric granules. In one area along the eastern margin of the flow (between Lines 2179N and 2227N) the breccias themselves appear to contain fragments of breccia suggesting possible minor seafloor reworking of the talus breccias surrounding the massive flow lobes.

Owing to their strongly altered nature, the primary

character of those felsic rocks which form the segment of the flow exposed north of Tieline 1730S to the shores of Aconda Lake, is difficult to identify. The presence of what may be primary fragments as well as the lack of flow-banding suggests that these rocks are probably also the autobrecciated facies of the felsic flow.

3.2.2 Mafic Volcanics

The predominantly mafic volcanic formation exposed in the Genex Mine area can be conveniently divided into two cycles (fig.6); the contact of the two cycles is marked by a felsic flow, the intercycle felsic unit. The first and second cycles differ in many respects. The first cycle is cut by at least four synvolcanic felsic dykes whereas the second cycle is not cut by any. The first mafic cycle is cut by at least three zones of alteration, whereas the second cycle has not been affected by similar alteration systems. The third and most obvious difference is that all the known sulphide mineralization in this part of the Kamiskotia area is confined to the first mafic volcanic cycle.

The mafic volcanics in the Genex Mine area are generally fine-grained to aphanitic and non-porphyritic. Except in areas of strong alteration, the degree of preservation of large scale structures (pillows etc.) is good; original glass has been devitrified and generally all igneous crystals have been metamorphosed to greenschist facies assemblages (quartz-chlorite-actinolite-epidote-albite-sericite). In a few cases relict mineralogy and textures confirm that these are al-

- Figure 26: Dominantly mafic formation, Cycle 1, 1585 S, 215 m east of BL 3W (AA-2833). Photomicrograph of relict quench olivine megacryst preserved by opaques (or possible quench titaniferous magnetite grain). Remnant skeletal feldspar microlites (completely replaced by quartz) in a matrix of fine chlorite, quartz, opaques and minor sericite which suggests basaltic intersertal texture. (quartz-chlorite alteration)(plane-polarized).
- Figure 27: Dominantly mafic formation, Cycle 1, 1875 N, 375 m east of BL 3W (AA-23790). Photomicrograph of an altered feldspar megacryst (albite) in a matrix of limpid albite grains, fine chlorite (dark), epidote, carbonate and opaques. (spilite, weak carbonate alteration)(plane-polarized).
- Figure 28: Dominantly mafic formation, Cycle 1, 1590 S, 50 m west of BL 1200W (AA-2853). Strongly amygdaloidal pillowed mafic; over 40 %, 1-10 mm, carbonate-quartz-filled amygdules. Hammer handle points north (carbonatized, spilite).
- Figure 29: Dominantly mafic formation, Cycle 1, 1645 S, 50 m west of BL 1200W (AA-2849,-2852). Large mattress pillows with thick selvages and bleached pillow cores. Note the re-entrant pillow crust (B), the scattered large (3-5 cm) carbonate-filled amygdules (B) and the very weak concentric cooling cracks (spilite).
- Figure 30: Dominantly mafic formation, Cycle 1, 2260 N, 390 m east of BL 3W (AA-23675). Broken pillow crust or "ghost selvedge": pencil marks the trace of a partially remelted re-entrant pillow crust (spilite 10 m stratigraphically below C-zone).
- Figure 31: Dominantly mafic formation, Cycle 1, 2270 N, 380 m east of BL 3W (AA-23675,-23713). Quartz-filled gas cavities or lava levels; note the the convex-up and flat-bottomed shapes. Weak silica dumping in pillow selvedge (black specks are mm-sized euhedral titaniferous magnetite grains)(spilite).
- Figure 32: Dominantly mafic formation, Cycle 1, 2213 N, 380 m east of BL 3W (AA-23683). Large pillow fragment and weakly silicified hyaloclastite in a broken-pillow breccia. Note the selvedge and concentric cooling cracks as well as the bleached pillow-core (pencil points east)(spilite).
- Figure 33: Base of Cycle 1, dominantly mafic formation, 1835 N, 75 m east of BL 3W (AA-23779). Large blocks of chloritized felsic fragmental (F) mixed with pillow fragments (p) in a chloritized matrix.

tered basalts (figs.26,27). Generally, no measurable strain in the mafic volcanics has been observed. It is this high degree of preservation, which coupled with better than average outcrop exposure, has facilitated tracing mafic flow units across the property, in spite of the high degree of faulting, dyking and alteration.

Both cycles of mafic volcanics are made up of flows and associated breccias. As was observed in the Rouyn-Noranda area by Dimroth et al. (1978) and by Carlisle (1963), structural divisions within individual mafic flows in the Genex Mine area follow a more or less consistent sequence beginning with a basal massive division, followed by pillows and capped by pillow breccia (Dimroth et al.'s (1978) hyalotuff division is absent).

The mafic volcanics in the Genex Mine area are quite strongly vesicular; the degree of vesicularity, now represented by quartz-, carbonate-, chlorite- and sulphide-filled amygdules, increases toward the top of individual mafic flows (from 1 to 2 % (by volume) to over 40 % (fig.28)). Vesicularity can also vary laterally within the flows (figs.28,29). The amygdules are generally enriched in the periphery of the pillows and near their top, and amygdules are relatively large varying from 3 mm to over 8 cm in size ("Goose Egg" amygdules). Pipe vesicles are not found associated with the pillows in the area.

The pillows vary from almost circular, small, buns (30 cm in diameter) to elongate or mattress-shaped pillows

(fig.29) up to 2 m in length (the large pillows are usually flattened in the plane of the flow). Broken pillow selvages between adjacent pillows or re-entrant pillow crusts, evidence that pillows form by budding (Wells et al., 1979; Dimroth et al., 1978) are commonly found; also found are "ghost" type re-entrant selvages described by Wells et al. (1979) suggesting partial remelting of the glassy selvedge material by hot magma (fig.30). Lenticular, flat-bottomed quartz-filled gas cavities or lava-levels are observed at the top of some pillows (fig.31); similar drain-away cavities have also been described in the Rouyn-Noranda region by Wells et al. (1979).

Most of the pillows have concentric cooling cracks, defined by subtle differential weathering in outcrop (or enhanced by alteration (fig.29,32)); radial cooling cracks have also been preserved in some exposures of altered pillow basalt (Legault, 1982).

Southeast of the Genex shaft, the uppermost member of the first mafic cycle appears to be made up of welded megapillows (Dimroth et al., 1978), pillows that lack a quenched selvedge possibly due to slow cooling of the flow. The presence of the pillows is inferred by traces of cooling cracks and by recognizable pillows exposed laterally along the same flow.

3.2.2a First Mafic Volcanic Cycle

The first mafic volcanic cycle (fig.6) 250 to 270 m thick, is made up of at least four amygdaloidal mafic flows; these range in thickness from about 20 m to over 100 m. The

These three blocks are dissimilar in the morphology of the flows which make them up. The southern block (those mafic volcanics between Lines 1761N and 2028N) appears to have a greater proportion of massive lavas (roughly 40 %) than the other blocks. The central block of mafic volcanics (exposed in the area between Lines 2028N and 2380N) contains the highest proportion of pillow lavas (about 90 %). In the northern block (in the area between Line 2028N and Aconda Lake) the proportions of massive, pillowed and breccia divisions approach those of the whole first mafic cycle; ie., 35 %, 55 % and 10 % respectively. Individual flow units cannot be readily traced from one volcanic "block" to another.

One exception is a major breccia unit which has been traced intermittently from Aconda Lake to the Genex shaft area. This unit, a broken-pillow breccia (Dimroth et al., 1978), is made up of pillow fragments in a fine-grained matrix of hyaloclastite (altered angular vitric granules or shards of devitrified glass) which form a deposit up to 15 m in thickness. Pillow fragments often have concentric cooling cracks (fig.32) and chilled margins and lobes of underlying lava have been seen extending into the breccias. It has been suggested (Dimroth et al., 1978) that fragmental deposits of this type probably formed by in situ granulation (with only minor transport) of the glassy top of pillowed (and massive) flows during the final stages of an eruption when the rate of lava extrusion has decreased significantly, rather than by a friction fragmentation-autobrecciation mechanism.

Other mafic fragmental deposits often seen in the first cycle of volcanism are lenses of pillow-bearing hyaloclastite (or isolated-pillow breccia; Dimroth et al., 1978). These pod-shaped masses, generally 10 to 20 m in diameter, are made up of fine nonbedded mm-sized hyaloclastite (angular vitric granules/shards) with about 10 % isolated pillows and pillow fragments. The fragmental deposits are associated with the upper part of amygdaloidal, generally pillowed flows; similar deposits are thought to have formed by quenching and fragmentation (granulation) of the glassy crusts of hot lava in contact with seawater (Dimroth et al., 1978). The lens shape of the hyaloclastite deposits in the Genex area in particular suggests that they were formed by local accumulation, perhaps in a paleodepression, of glassy detritus spalling off the top of a mafic flow.

These breccia units are found at different levels in the stratigraphy, often located in areas associated with east-trending synvolcanic felsic and mafic dykes. Two lenses, in an almost stacked relationship, occur near the margin of a felsic dyke near Line 2087N. Another pair of pillow-bearing hyaloclastite deposits are symmetrically opposed; one unit overlies an amygdaloidal, pillowed volcanic flow adjacent to a zone of felsic and mafic dykes just south of Tie-line 1730S; the other lens of pillow-bearing hyaloclastite, located near Line 1680S, also overlies a massive to pillowed amygdaloidal flow sequence. The two massive-pillow-breccia sequences appear to be correlative. They are separated or dilated by a 60 m wide east-trending, dyke-like body of

weakly amygdaloidal massive mafic volcanic which appears to form part of the basal massive zone of a flow succession which overlying the breccias. The geometry of the mafic volcanics in this area suggests that the breccia zones define a volcanic vent zone. The breccia lenses may have been part of the same deposit now dilated by the feeder dyke.

3.2.2b Second Mafic Volcanic Cycle

The second mafic volcanic cycle (or hangingwall succession) forms the stratigraphically highest unit mapped in this study (exposure decreases dramatically immediately to the east; fig. 6). Mapping of this cycle is not as complete as that of the first cycle, but with the help of Mr. Paul Degagne, who mapped the southeast part of the second cycle, an adequate knowledge of the character of this unit has been obtained.

The second cycle, approximately 250 to 300 m thick, is made up of at least three separate mafic flow sequences totalling about 180 m in stratigraphic thickness in the map area. These mafic volcanics are in general quite similar in composition, degree of vesicularity, and flow morphology to those making up the first cycle. The percentages of massive, pillowed and brecciated facies are in the order of 60, 35 and 5 % respectively. The second cycle is intruded by a thick semi-conformable, massive mafic sill which extends from Aconda Lake to the east of the intercycle rhyolite unit (fig. 6).

The contact between the intercycle rhyolite unit and the second mafic volcanic cycle is not well preserved. Immediately east of the Genex Shaft zone however, incipiently pil-

lowed amygdaloidal volcanics conformably overlies a mixed, felsic-mafic fragment, flow-breccia forming the contact zone with the felsic flow. A screen-like lenticular mass of amygdaloidal, pillow volcanic (fig.6) also occurs within the massive, fine-grained mafic sill between Lines 2040N and 2227N. North of Tieline 1730S, immediately overlying the intercycle felsic unit is a thin (less than 20 cm thick) banded, sulphide-rich, siliceous to chloritic exhalite. This exhalite sometimes consists of two to three thin, finely laminated sulphide bands units separated by a chloritic laminated to massive mafic material (5 to 10 cm thick). This exhalite is generally north-trending, dips vertically to steeply to the east (80°) and has been traced intermittently on surface for over 70 m from Line 1620S to Tieline 1730S (Legault, 1982); diamond-drilling by Kidd Creek Mines Ltd. in 1982 shows that it apparently does not persist at depth (see Section 3.4). Immediately overlying the banded-sulphide zone in this area is a thin massive amygdaloidal mafic unit less than 5 m in thickness.

3.2.3 Synvolcanic Felsic Intrusions

Four major, generally east-trending, felsic dykes cut the lower cycle of mafic volcanism in the Genex Mine area (fig.6). Due to the intrusive/xenolithic nature of the basal strata exposed in the area, tracing the lower extent of these dykes is difficult; however, some of the dyke roots can apparently be traced into the lower felsic strata.

The width of the dykes ranges from 40 to 150 m and they

usually taper to the east; the largest dyke (centered near Line 2024N) is more plug- or dome-shaped than the rest. In outcrop and in thin section, the dykes are physically and texturally similar in appearance to massive felsic volcanic rocks. These intrusive rocks have the following characteristics:

- 1) spherulitic and flowbanded margins.
- 2) 1 and 5 % mm-sized quartz phenocrysts (fig.34); relict plagioclase feldspar phenocrysts also occur in minor amounts.
- 3) are often brecciated and contain flow-banded clasts up to 20 cm in size.
- 4) often contain xenoliths of mafic volcanic material.
- 5) occur in areas which also have been the loci of strong hydrothermal alteration; three of the four are altered and mineralized; one hosted some of the stringer ore zones developed by Genex Mines Ltd. in 1964-66.

The largest synvolcanic felsic intrusion, located roughly between Lines 1894N and 2087N, is generally well exposed and exhibits all of the characteristics described so far. Because it also hosts the Genex "H" zone orebody, it is also the most frequently referred to in mining reports (Hogg, 1954; Middleton, 1969, 1975; Pyke and Middleton, 1970, 1971). Because of its size and shape, this unit is interpreted to be a subvolcanic dome, similar to those endogenous submarine quartz-feldspar porphyry (QFP) rhyolite domes described by Knuckey et al. (1982) in the Noranda, Quebec region.

Deformation of the strongly sericitized, generally massive, quartz-phyric felsic dyke has imparted a curdy texture (see Section 2.4.3) to these rocks such that this body is often interpreted to be an intrusive breccia (see photo 6 -

Figure 34: Synvolcanic felsic intrusion, 2075 N, 275 m east of BL 3W (AA-23710). Photomicrograph showing inverted beta-quartz phenocryst (Q) and smaller prismatic quartz open-space filling; Matrix of fine quartz (75%), chlorite (15%), sericite (10%) and opaques (quartz-sericite alteration)(plane-polarized).

Figure 35: Synvolcanic felsic intrusion, 2075 N, 275 m east of BL 3W (AA-23710). Photomicrograph of relict fibroradial (spherulitic)(S) or radial fibroprismatic (after zeolite) open-space filling which are completely replaced by quartz (Q) and fine chlorite. Matrix of quartz, sericite, chlorite and anhedral quartz phenocrysts (QP) (quartz-sericite alteration)(plane-polarized).

Figure 36: Synvolcanic felsic intrusion, 2020 N, 360 m east of BL 3W (AA-23746). Siliceous and sericitized rounded pseudo-fragments separated thin sericite-, chlorite- and pyrite-rich veinlets. Note the strong schistosity (E-W-trending) developed in this curdy-textured rock located above projected H-zone in the 76 m Level (quartz-sericite alteration with progressive chlorite).

Figure 37: Synvolcanic felsic intrusion, 1990 N, 360 m east of BL 3W (AA-23747). Weakly flow-banded, silicified and sericitized felsic fragment within a strongly altered felsic intrusion (quartz-sericite alteration).

Middleton, 1975). Figure 36 shows a typical exposure of this "curdy rhyolite" with its round lenticular pseudo-fragments in a matrix of sericite, chlorite and minor disseminated pyrite. This felsic rock is generally massive to flow-banded, weakly quartz-amygdaloidal (up to 2 %) but does contain fragments (on average about 3 to 5 %) which are frequently flow-banded (fig.37). These flow-banded blocks are quite abundant (up to 15 %) along the upper margins of the intrusion near Line 2024N. These rocks may also contain significant amount of angular chloritic vitric granules (up to 20 % 1 to 5 mm-sized).

The contact zones, because of the strong alteration effect, are often difficult to define. The northern contact of the major dyke with a mafic pillow-bearing hyaloclastite near Line 2087N is typical of these contact areas. Near the contact, the felsic rock is significantly brecciated. At the contact the rock contains a large number of mafic fragments in a quartz-phyric matrix. The contact is marked by the sudden predominance of mafic clasts in a mafic hyaloclastite matrix devoid of quartz-eyes. Along the contact zone, the felsic rock often contains 50 cm-sized amygdaloidal mafic xenoliths. The pillow-bearing hyaloclastite zone is also cut by thin irregular quartz-phyric felsic dykes (up to 20 cm in thickness).

All of the major felsic dykes are cut by aphanitic mafic dykes; frequently, the mafic dykes are strongly amygdaloidal and invade the overlying mafic volcanics. This suggests that, in terms of relative timing, these synvolcanic dykes

were likely emplaced shortly after the first mafic cycle was deposited; this is consistent with the idea that at least one of the dykes fed the felsic volcanism marking the boundary between the first and second mafic volcanic cycles.

3.2.4 Mafic Intrusions

Mafic intrusive rocks, including the diabase dykes, make up approximately 50 % of the exposed rock in the Genex Mine area (fig.6). Prior to this study, much of the fine-grained mafic rock was mapped as volcanic although Hogg (1954) recognized that some of the mafic rocks were probably intrusive. As a result, the thickness of the mafic volcanic strata exposed in the area has been effectively halved (fig.4).

The mafic intrusions may be classed, on the basis of average grain size, degree of vesicularity, field relationships, and petrography into two broad groups:

- 1) synvolcanic mafic dykes likely related to the first and second cycles of mafic volcanism in the immediate Genex Mine area. This group would include those mafic intrusive rocks not directly related to volcanism in the area, but which were probably emplaced during or immediately after active mafic volcanism (ie. subvolcanic intrusive rocks).

2. mafic intrusions which post-date mafic volcanism in the area.

There is generally very little physical difference, such as grain size, degree of vesicularity or alteration, between those synvolcanic feeder dykes and the intrusive rocks less clearly related to active volcanism (the subvolcanic intrusions); they can be distinguished from each other on the basis of field relationships and some of the differences are

confirmed using trace element geochemistry. However, these rocks appear to make up a spectrum of intrusions from those dykes which likely fed overlying volcanism to the intrusive material which occupied the high level subvolcanic magma chamber after mafic volcanism ended at this level. The second group of mafic intrusive rocks are physically, texturally and geochemically quite distinct from the feeder dykes and the subvolcanic mafic intrusive rocks.

3.2.4a Synvolcanic Mafic Intrusions

Rocks which make up the first group of synvolcanic mafic intrusions include those massive aphanitic dykes which cut the mafic and felsic volcanics. These feeder dykes are often strongly amygdaloidal; one thin dyke which cuts the felsic flow near the base of the first mafic cycle near Line 1620S shows increasing vesicularity (from a trace to 1 % to 3 % or more) toward the top of the flow. Frequently mafic dykes cut through east-trending zones of strong hydrothermal alteration associated with sulphide mineralization and are themselves visibly altered. Another feature of these dykes is that they often follow prominent east-trending zones which also were the loci of felsic dyking (fig.6); synvolcanic mafic dykes cutting felsic dykes is consistent with the interpretation that the felsic dykes fed the intercycle felsic flow; it is reasonable to assume that conduits for the second cycle of mafic volcanism would follow zones of synvolcanic felsic dyking and alteration. Some of these dykes may also post-date volcanism.

A second group of fine-grained mafic rocks which make up the first broad grouping of synvolcanic to subvolcanic mafic intrusions are the large sill-like mafic bodies which intrude the upper part of the predominantly mafic volcanic formation east of the Genex Shaft (fig.6). Three apparently separate intrusive bodies make up this group, namely:

- 1) the small (60 to 80 m in diameter) plug-like fine-grained intrusion located near Lines 2270N and 2321N northwest of the Genex shaft.
- 2) the fine-grained mafic sill which dilates the intercycle felsic flow from the underlying mafic volcanics.
- 3) the fine-grained weakly amygdaloidal sill which dilates the intercycle felsic flow from the overlying mafic volcanics.

These rocks are physically and texturally similar to the mafic volcanics and the feeder dykes; they are fine-grained to aphanitic and are sometimes weakly amygdaloidal especially near their upper margins. Some of the intrusions, in particular the thick sill dilating the intercycle rhyolite from the underlying mafic volcanics and the small plug-like intrusion northwest of the Genex shaft, also cut off prominent east-trending zones of alteration and mineralization and are themselves not visibly altered or mineralized.

A third group of rocks which make up most of the synvolcanic intrusions are those fine-grained mafic rocks which underlie a greater part of the western Genex Mine area (figs.6,38). In outcrop, their intrusive nature is defined of course by their irregular contacts along the felsic volcanic xenoliths; the knife-like embayments in the xenoliths are amygdaloidal (1 to 2 %) and contain abundant finely abraded

felsic volcanic material and quartz-veins. Frequently these intrusions are quite pervasively carbonatized; they contain up to 20 % mm-sized euhedral porphyroblasts of rusty-coloured weathering ferroan dolomite/ankerite (fig.39). Carbonate (and minor quartz) filled fractures give the intrusions a strongly jointed appearance on a weathered surface (fig.38). Rarely polygonal jointing can be observed (fig.40).

This intrusive material is generally fine-grained (fig.41) and resembles the volcanic rocks; in fact, some outcrops contain up to 5 %, 1 to 2 mm-sized subhedral mafic clots which resemble perlitic fragments (fig.41). The most significant feature of these fine-grained rocks is that they have been affected (geochemically and texturally) along the east-trending alteration zones which have affected the volcanics to the east.

The mafic intrusive rocks which occur in the area between Lines 1761N and 1824N, 140 m east of Baseline 3W, form a fourth group of synvolcanic intrusions in the Genex Mine area. These intrusive rocks, in spite of strong carbonate alteration, still retain, in thin section, a relict microgabroic texture (fig.42); they are also weakly feldspar porphyritic, containing 1 to 5 %, 1 to 2 mm-sized subhedral to euhedral saussuritized albite phenocrysts and glomerocrysts (fig.43). The presence of minor amygdules is consistent with a synvolcanic character. The intrusions are also different from the rest of the mafic intrusions in that they contain minor amounts (less than 1 %) of what appears to be primary potassic-feldspar with poikilitic albite grains (T. Hamilton,

Figure 49. Section of the C-zone, view looking north (for section line see Figure 46). Compiled from mine plans, Genex Mines Ltd. and geology projected from surface.

- Figure 38: Subvolcanic mafic intrusion, TL 1730 S, BL 3W (AA-2646). Photomicrograph of ferroan dolomite to ankerite porphyroblasts (D) in matrix of chlorite (c) with minor quartz (q), and sericite. Note the lack of igneous textures (strong carbonate alteration)(plane-polarized).
- Figure 39: Subvolcanic mafic intrusion, 2435 N, 40 m west of BL 3W (AA-2646,-23554). Oblique view of fine-grained mafic intrusion; note carbonate-filled joints which weather low. Hammer handle points north (carbonate alteration).
- Figure 40: Subvolcanic mafic intrusion, 2190 N, 70 m west of BL 3W. Well developed polygonal cooling cracks which are silicified; alteration probably due to contamination from nearby large felsic xenolith (carbonate alteration, silicification).
- Figure 41: Subvolcanic mafic intrusion, 2280N, 70 m west of BL 3W (AA-23564). Photomicrograph of angular chloritic fragment with relict perlitic cracks filled with quartz. Matrix of ferroan dolomite (d)(20%), chlorite (60%), quartz (15-20%), albite and minor opaques. Note the lack of igneous textures (carbonate alteration)(plane-polarized).
- Figure 42: Feldspar-porphyrific mafic intrusion, 1720 N, 85 m east of BL 3W (AA-23774). Photomicrograph showing 40% relict interlocking feldspars (albite;A) as well as 20% carbonate (d), 20% chlorite, epidote (E) with minor fine interstitial quartz grains and sericite. Note the large yellowish epidote grain which is being replaced by chlorite and carbonate (carbonate alteration)(plane-polarized).
- Figure 43: Feldspar-porphyrific mafic intrusion, 1720 N, 85 m east of BL 3W (AA-23774). Photomicrograph showing large altered feldspar glomerocryst of albite, sericite, carbonate and epidote, in a matrix of interlocking albite with carbonate, chlorite and minor epidote and sericite (carbonate alteration) (crossed polarizers).
- Figure 44: Medium-grained gabbroic intrusion, northeast Forbes Lake (AA-23606). Photomicrograph showing some large altered albite phenocrysts (A) in a matrix of 40% carbonate (d), 40% fine chlorite, with minor muscovite and quartz. Note lack of igneous textures (carbonate alteration)(plane-polarized).
- Figure 45: Diabase dyke. Large saussuritized calcic plagioclase glomerocrysts in a matrix of subophitic labradorite, with hypersthene, and clinopyroxene.

pers. comm., 1984). The primary character of the potassic-feldspar is difficult to confirm in this case because of the general high degree of alteration developed in the rocks (see Section 4.3). However, the porphyritic nature as well as the presence of possible primary potassic feldspar clearly distinguishes these intrusive rocks from the rest and suggests a different origin. They may possibly represent a hybrid phase between the felsic volcanics and the mafic melt which intruded into them (T. Hamilton, pers. comm., 1984). The porphyritic intrusive rocks grade rapidly and without visible contact into apparently normal fine-grained mafic intrusive rocks.

The character of the mafic intrusions exposed in the western part of the region suggest that this mass of intrusive material is synvolcanic and was probably emplaced sequentially into subvolcanic magma chamber.

3.2.4b Post-volcanic Mafic Intrusions

This group of mafic intrusions, distinct from the diabase dykes, is only exposed on the northeastern shore of Forbes Lake. These rocks differ from the intrusions described above in many respects: firstly they are medium- to coarse-grained and are porphyritic (fig. 44). Secondly they lack chilled margins against the felsic volcanic xenoliths. Thirdly, although they are very strongly carbonatized, their composition, in general, is different from the surrounding intrusions and volcanics.

Hogg (1954) mapped these rocks as possible andesitic

equivalents to the spherulitic granophyre and quartz-albite porphyries which are exposed to the southwest and to the north near Keeley Lake; these rocks are equivalent to Middleton's (1975) microdiorites-porphyrites (late-stage intermediate intrusions derived from the Kamiskotia Gabbroic Complex).

3.2.5 Diabase Dykes

Three major, generally north-northwest-trending, steeply-dipping diabase dykes neatly cut the Genex map area into four areas (fig.6). These form part of a group of Middle to Late Precambrian dykes commonly referred to as the Kamiskotia swarm (Middleton, 1973, 1974, 1975; Pyke, 1982).

Weathering of the diabase gives a tan to orange-brown, rough surface exposure; they form rounded blocky outcrops which are hard and moderately jointed. Fine-grained chilled contact zones are normally 30 cm to 2 m wide; minor slickensides are commonly observed near the contact zones indicating minor recurring movement along the north-northwest-trending faults which controlled the emplacement of the dykes. Thin, very fine grained, irregular dykelets of diabase are often found in the volcanics a few metres from the contact.

The grain size in the centre of the thickest dykes may reach 5mm; more commonly, the dykes are medium-grained with a 2 to 3 mm average grain size. The dykes display typical diabasic textures, with hypersthene and clinopyroxene subophitically enclosing labradorite phenocrysts (fig.45). The dykes are sometimes weakly feldspar-porphyritic to glomero-

porphyritic.

The westernmost dyke, which varies in width from 30 m to 60 m, has been traced for more than 6 km from northern Bristol Township (Ferguson, 1957) to the southern shore of Aconda Lake where it abruptly forms two smaller dykes which extend, according to diamond drilling and geophysical evidence, roughly perpendicularly for short distances. This suggests the presence of an east-trending fault coincident with the southern shore of the lake (fig. 4). Another splayed dyke, which is quite glomeroporphyritic, can be traced from the north-central part of the area (fig. 6) on surface and in the Genex Mine workings, to the southern edge of the map area where it is subparallel to the western dyke.

The central diabase dyke has been traced for 30 km from northern Bristol Township (Ferguson, 1957) to northern Loveland Township (Middleton, 1974). This dyke, 50 to 70 m in width, forms steep cliff faces in the northern part of the property and the centre of the prominent hill east of the Genex headframe. Weak mineral banding oriented north-northwest was observed near the margins of the dyke just east of the Genex headframe and in the road near TL 1730S, 1230E.

The easternmost dyke, 10 m in thickness, has also been traced from northern Bristol Township to western Jamieson Township, a distance of over 16 km. It is generally fine-grained.

3.3 MINERALIZATION IN THE GENEX MINE AREA

The Genex Mine area has been explored extensively both on surface and in diamond drill core since 1925. This section is an overall summary of the copper-zinc-gold occurrences and, in particular, a description of the sulphide zones which were developed by Genex Mines over 1964-66. The information has been drawn extensively from Hogg (1954), Middleton (1975), Toronto Assessment Work Library, Timmins Assessment Files, Ontario Division of Mines Source Mineral Development Records, Energy Mines and Resources Mineral Resources Branch Reports, Canadian Mines Handbooks and press clippings.

Important mineralization occurs in five separate areas associated with three well-developed footwall hydrothermal alteration zones. These zones, which have also been the locus of synvolcanic mafic and felsic intrusions, are confined to the strata below the second mafic volcanic cycle; in addition, in all cases, synvolcanic mafic sills and subvolcanic mafic intrusions crosscut mineralization.

The northernmost showings are associated with alteration which cuts the first mafic cycle generally along Line 1560S on the southcentral shore of Aconda Lake (fig.6). On surface, the showings largely consist of up to 30% disseminated pyrite in sheared, chloritic pillows. Chalcopyrite-rich disseminated-pyrite zones are found with chloritic sheared mafic volcanics in the long trench along Line 1560S, 300 m east of BL 3W and in the synvolcanic felsic intrusion which also cuts through these rocks. Diamond drilling immediately below this trench intersected short widths of minor gold and zinc mine-

ralization associated with disseminated sulphides along the felsic intrusive-mafic volcanic contact. This east-trending mineralized zone is cut off by a major diabase dyke and a fine-grained mafic sill.

To the east of the diabase dyke and the sill, chalcopyrite- and sphalerite-rich stringers and disseminated pyrite occur on surface along narrow, chlorite-rich, zones within the intercycle felsic unit and for a short distance into the overlying mafic volcanics near 1620 S, 100 m east of BL 1200 W. The sulphide-rich exhalite and thin chloritic mafic tuff unit overlying the intercycle rhyolite has been traced intermittently for over 100 m in a north-trending series of trenches between Lines 1620 S and 1730 S. Chalcopyrite, pyrite and minor magnetite may occur in zones up to 30 cm-thick within the exhalite. North-south-trending shallow diamond drill holes in this area intersected important disseminated and stringer pyrite-chalcopyrite zones in silicified and chloritized sections of felsic and mafic volcanics. The exhalite and stringer mineralization apparently do not extend below 75 m.

The third mineralized area which was the site of early extensive surface trenching and diamond drilling occurs in the northeastern corner of claim P.27216. Narrow zones of disseminated to stringer pyrite and chalcopyrite occur within altered pillowed volcanics at the top of the first mafic cycle from TL 1730 S south to Line 2321 N. Stringer sphalerite and chalcopyrite cut strongly sericitized and chlo-

ritized volcanics in a 20 m wide zone within trenches north of Line 2380 N. The sulphide-mineralization in this area appears to stop at the base of an overlying, weakly-altered, amygdaloidal mafic flow (this contact zone is poorly exposed due to the intrusion of a fine-grained mafic sill; fig.6). The northernmost extent of this sulphide zone, consists of minor disseminated chalcopryite and sphalerite within a short section of silicified mafic breccia apparently also marking the basal contact of the upper Cycle 1 mafic flow near TL 1730S, 15 m west of BL 1200 E. The intercyle felsic unit which stratigraphically overlies this sulphide zone (fig.6) is strongly altered but carries only minor disseminated pyrite.

The most important zone of mineralization occurs along an east-trending area roughly centered by the large synvolcanic felsic intrusion within the first mafic cycle near Line 2028 N. Sulphide mineralization generally occurs throughout the area between the two major diabase dykes from Line 1894 N to Line 2213 N where Genex Mines Ltd. in 1964-66 delineated and developed two chalcopryite and sphalerite-rich stringer sulphide orebodies, the H-zone and the A-zone (fig.46).

The H-zone consists mainly of disseminated- to stringer-pyrite with chalcopryite which form irregularly-shaped east to northeast-trending bodies cutting through the synvolcanic felsic intrusion and the mafic volcanics (fig.46). Often the sulphides comprise over 95% of the material and contain fragments of altered felsic and mafic wallrock so that references to this ore zone describe it as a rhyolite breccia-

Figure 46: Geology of the Genex Mine, 38 m level, showing the section lines presented in Figures 47, 48 and 49. Compiled from mine plans, Genex Mines Ltd. and geology projected from surface.

Figure 47: Section of the H- and A-zones (view looking northeast). Compiled from nine plans, Genex Mines Ltd., lithium assessment records and geology projected from surface.

Figure 48 Section of the H-zone (view looking northeast). Compiled from mine plans, Genex Mines Ltd. and geology projected from surface.

Figure 49: Section of the C-zone, view looking north (for section line see Figure 46). Compiled from mine plans, Genex Mines Ltd. and geology projected from surface.

47.

pipe (Pyke and Middleton, 1970, 1971). Figures 47 and 48 illustrate the irregular nature of both the ore zone and the synvolcanic felsic intrusion. The H-zone was followed on the 38 m and 76 m levels and in diamond drilling (fig. 46) over a total length (in plan) of 120 m. The ore body projected vertically to surface extends roughly from a point 30 m south of Line 2028N, 330 m east of BL 3W, to within 20 m of the shaft zone.

The A-zone is also an east-trending, irregularly-shaped, disseminated- to stringer-sulphide zone; however, it is largely hosted within mafic volcanics (figs. 46, 47). It also differs from the H-zone (and C-zone) in that it is a sphalerite-rich, pyrite-chalcopyrite body. The A orebody has been traced on the 38 m level and in diamond drilling, for approximately 75 m; the sulphides and associated alteration are cut-off to the east by a fault (fig. 46) and an unaltered massive mafic rock. On surface, alteration and mineralization were also observed east of the Genex shaft to be abruptly cut-off by fine-grained mafic intrusion; this relation is interpreted to also exist on the 38 m level (fig. 46).

The C-zone orebody is the only sulphide occurrence which does not have an extensive footwall hydrothermal alteration zone associated with it. It is a lens-shaped massive pyrite-chalcopyrite body approximately 60 m in plan length (on the 38 m level; fig. 46), at least 80 m in depth, and no more than 8 m in true thickness; it conformably overlies a pillowed mafic flow which is strongly chloritized and rich in dissemi-

nated and stringer-pyrite only within 5 to 10 m of the massive sulphide lens (fig.49). The ore body appears to plunge steeply to the east suggesting that the rocks are overturned (fig.49). However, because the C-zone is in fault contact with a mafic intrusion to the east, and due to the lack of drill-core data, the dip of the strata cannot reasonably be determined.

In 1964, Genex Mines Ltd. chose to mill the ore through a copper-circuit only; because of this, zinc-rich zones (such as the A orebody) were ignored. The tenure of the deposit reported by Genex Mines Ltd. and in subsequent valuation reports by United Obalski Ltd., and Allied Mining Ltd. therefore did not include zinc and gold. Similar omissions have been documented by Knuckey et al. (1982) in the Noranda, Quebec region. In 1967, proven and probable ore reserves above the 76 m level were estimated at:

	Zone	Tonnes	% Cu
	H	36 000	2.14
	A	24 000	1.50
	C	43 000	2.92

	Total	103 000	2.31
possible reserves	H	14 000	1.82
	A	3 800	1.50

	Grand Total	121 000	2.22

CHAPTER 4: ALTERATION IN THE GENEX MINE AREA

4.1 INTRODUCTION

Abundances of major element oxides together with selected trace elements of 354 rock samples collected in the Genex Mine area are reported in Appendix A; the locations of the samples are given on the Preliminary Geology Map.

The study of alteration zones which underlie volcanic-associated massive sulphide deposits in Canada began with petrographic descriptions of the pipe-shaped, copper-bearing, stringer zones which formed important parts of Precambrian orebodies in the Noranda, Quebec region. More recently, the focus of research on Precambrian deposits has been on the chemical attributes of these alteration pipes underlying the massive sulphide lenses as well as the petrochemical aspects of broader, regional, lower conformable alteration zones (Franklin et al., 1977; MacGeehan, 1978; MacGeehan and MacLean, 1980a,b; Gibson, 1979; Gibson et al., 1983; Walford and Franklin, 1982). Alteration studies such as these are important because they invariably lead to the discovery of other deposits. The descriptive and genetic aspects of volcanic-associated stratabound massive sulphide deposits as a group have been reviewed by Goldie and Bottrill (1981), Franklin et al. (1981), Sangster (1972) and Hutchinson et al. (1982).

Evidence of chemical exchanges in volcanic rocks such as feldspar destruction and progressive chloritization and sericitization suggestive of alteration by hydrothermal solutions often found in Precambrian-greenstone belt terranes, has

also been observed in modern mid-ocean ridge basalts. Heat-flow modelling over ocean ridges (Lister, 1972), geochemical ocean mass-balance predictions (Wolery and Sleep, 1976), isotopic evidence (Muehlenbachs and Clayton, 1972) and studies of dredged metamorphosed sea floor (Humphries and Thompson, 1978) which showed mineralogical and geochemical evidence of hydrothermal alteration (including mobility of SiO_2 , CaO , MgO , K_2O and Na_2O), are evidence that high-temperature, convectively driven, sea-water hydrothermal systems are active along zones of ocean-floor spreading centres. In addition, experimental data on sea-water reacting with mid-ocean-ridge basalt which duplicated the geochemical transfers seen in actual oceanic volcanics (Bischoff and Dickson, 1975; Mottl, 1983) predicted the physical conditions under which the geochemical transfers were occurring on the seafloor. The discovery of seafloor hotspots, the zones of active discharge of metal-rich sea water-derived brines for the interpreted hydrothermal systems (Edmond et al., 1979) are generally regarded as genuine proof of sea-water hydrothermal alteration of present day submarine volcanics. A simple model of sea-water convection through the ocean crust as proposed by Spooner and Fyfe (1973) and Heaton and Sheppard (1977) who applied these ideas to examples of seafloor alteration, would envisage sea-water infiltrating the upper layers of the ocean floor through broad recharge areas, becoming heated during its descent, reacting with the volcanic rocks and finally returning in its modified form to the water-rock interface at points of discharge (black smokers; Edmond et al., 1979) probably localized by

fractures.

Isotopic as well as fluid inclusion studies around volcanogenic massive sulphide deposits in the Rouyn-Noranda region (Beaty and Taylor, 1982), suggest that the hydrothermal systems were also essentially composed of sea water which controlled the alteration of the volcanic pile as a whole (Gelinas et al., 1982; 1984). The petrochemical evidence that chemical exchanges between sea water and basalts (as well as andesites, dacites etc.) in the Archean (Baragar et al., 1979; Dimroth and Lichtblau, 1979; Gelinas et al., 1982) are identical to those of the modern sea floor (basalts only) reproduced in the laboratory (Mottl, 1983) is also consistent with sea water being the medium of chemical transfer seen in altered volcanic rocks surrounding volcanogenic massive sulphide deposits.

In the discussion of alteration associated with a particular volcanogenic massive sulphide deposit and in the application of geochemical methods to find similar deposits elsewhere in the area, some of the more important topics to be addressed include:

1. The recognition of the original geochemistry or that of the least altered host rock.
2. The identification of the alteration mineralogy and the textural pattern associated with the alteration process(es).
3. The distinction between alteration associated with the ore-forming process and that which is the result of normal events within a submarine volcanic or metamorphic regime.

These three topics will be discussed in the following

sections.

4.2 PRIMARY GEOCHEMISTRY OF THE VOLCANICS AND INTRUSIONS

4.2.1 Introduction

Strictly speaking, a common volcanic rock name (basalt, andesite, etc.) describes specific mineralogical and petrographical characteristics of a rock which distinguish it from other rocks. Petrographic evidence (albeit meagre and based on relict remnant textures) suggests that the rocks mapped in the Genex Mine area as mafic volcanics were originally basalts (probably tholeiitic) and that rocks mapped as felsic volcanics and intrusions are altered quartz- and weakly feldspar-phyric rhyolites. The purpose of this section is to determine the primary geochemistry of the volcanic rocks so that the effects of hydrothermal alteration can be properly assessed.

Chemical classification systems have been developed for metamorphosed volcanic rocks (Irvine and Baragar, 1971; Middlemost, 1972). There are constraints in applying such classification systems:

1. Although they categorize many of the major rock divisions common in Canada, these classification schemes do not allow for komatiitic volcanics which are quite abundant and form a petrogenetic series in the Abitibi Subprovince of the Canadian Shield.

2. Because the main criteria for final rock-type recognition in these systems is normative colour index and plagioclase composition (Irvine and Baragar, 1971) or alkali content (Middlemost, 1972), by definition, rocks which have been subjected to low-grade chemical alteration should be rejected.

3. Geochemical characteristics have been used to deduce the tectonic environment of formation of present day

Table 3: Petrographic and chemical rejection criteria used to determine the suitability of analyses for rock classification

A: Petrographic

- destruction of primary igneous textures (possibly indicating volume change during alteration).
- presence of limpid albite in mafic rocks (suggestive of calcium depletion).

B: Chemical

- alkali contents outside limits of igneous spectrum set by Hughes (1973) and Stauffer et al. (1975).
- volatile content (H_2O and CO_2) greater than 4 wt%.
- totals below 99.0 wt% or greater than 101 wt%.
- total Fe_2O_3 greater than 15 wt% in mafic rocks and 5 wt% in felsic rocks.
- Na_2O below 2 wt% (depletion)
- Abnormal normative mineralogy:
 - Corundum (alkali depletion)
 - Nepheline (addition of Si and Na)
 - Wollastonite (addition of Ca and Fe)

Sources: Hughes (1973), Stauffer et al. (1975), Wallford and Franklin (1982), Gelinas et al. (1979).

rocks (Pearce and Cann, 1973; Floyd and Winchester, 1975); although the use of such terms as calc-alkaline and tholeiitic in characterizing Archean rocks is widespread, because the tectonic processes in the Archean are poorly understood, their application does not imply an interpretation of tectonic environment; rather, the terms are used for purposes of comparison with present-day rocks.

Jensen (1976), recognizing some of the limitations of the Irvine and Baragar (1971) classification scheme (especially in the Canadian Shield), developed a cation plot for classifying rocks (including komatiitic volcanics) which used elements (Al_2O_3 , MgO and $\text{FeO-Fe}_2\text{O}_3\text{-TiO}_2$) considered less susceptible to chemical migration than SiO_2 , CaO , K_2O and Na_2O .

In order to determine the original composition of volcanic rocks, it is common to use a combination of chemical and petrographic rejection criteria (Gelinas et al., 1984; Costa et al., 1983; Hughes, 1973; Stauffer et al., 1975; Walford and Franklin, 1982) in order to weed out rocks which have been affected by hydrothermal alteration processes (Table 3). Care was taken not to sample rocks with excessive sulphides, or with veins of carbonate or quartz. On textural grounds, however, all of the rocks examined from the Genex Mine area, with the exception of a hypersthene-labradorite diabase, would be rejected; no primary igneous minerals or textures were completely preserved and in many cases, evidence of chemical mobility was often present. Chemically, all of the mafic intrusive rocks and the majority of the mafic volcanic rocks have volatile contents in excess of 4.0 % because of the presence of abundant carbonate, water, sulphides and

FIGURE 50: Alkali variation diagram (after Hughes (1973) and Stauffer et al. (1975)). Data from samples of dominantly mafic volcanic formation (O), synvolcanic mafic intrusion (■), intercycle felsic unit (Δ), lower felsic formation (Δ), and felsic intrusion (▲). Na-Field = spilite-keratophyre field; K-Field = potassium-keratophyre and K-rich spilite field; A-Field = field of pipe alteration.

other unknown elements, and would also be rejected following the criteria suggested in Table 3. As a further screen, data were plotted on an alkali-variation or "igneous spectrum" diagram proposed by Hughes (1973) and modified by Stauffer et al. (1975) as a means of testing for alkali metasomatism in igneous rocks as well as identifying spilites and keratophyres (fig.50). This screen is also convenient because all rock groups identified in field mapping can be tested using one simple diagram. While the specifics of the alteration types will be discussed below (see Sections 4.3 and 4.4), Figure 50 indicates that most of the rocks have undergone at least some alkali metasomatism and that many of them are spilites and keratophyres. In fact, only 10% of the samples from the Genex Mine area lie within the "igneous spectrum" or have alkali-contents typical of normal volcanic rocks.

Problems with identifying the original chemistry in volcanic rocks are not uncommon in studies of volcanogenic massive sulphide deposits (Stauffer et al., 1975; Thurston et al., 1978); usually it is necessary to recognize that no completely unaltered rock exists and use the chemistry of a sample which is petrographically and chemically interpreted to be least altered (Costa et al., 1983). The choice of least altered parent rocks for use in determining both the effects of alteration (such as mass balance calculations) and the petrogenesis of the rock units in the Genex Mine area was made based on the following criteria taking into consideration some of the points discussed above: remoteness from deposit; relatively low volatile content; visual lack of

chlorite and sericite alteration.

In order to minimize problems resulting from chemically mobile major and minor elements, appropriate diagnostic trace elements such as Ti, Zr, Y and Nb (and the rare earth elements) are often used to deduce or to confirm (Gelinas et al., 1984) the petrochemistry in Precambrian greenstone terrains; these elements have been shown to be both immobile under conditions of low-grade seawater weathering (Pearce and Cann, 1973; Floyd and Winchester, 1975) and relatively immobile in high-grade hydrothermal alteration systems associated with massive sulphide deposits (Campbell et al., 1982a,b; Costa et al., 1983).

Data for the least altered volcanic rocks in the Genex area are plotted on a Zr/TiO₂-Nb/Y diagram according to Floyd and Winchester (1977) (fig.51). In addition, data for the least altered mafic volcanic rocks only are plotted on Zr-Ti-Y and Ti-Zr diagrams (figs.52,53) according to the method described by Pearce and Cann (1973).

4.2.2 Felsic Volcanics

The major and trace element composition of the least-altered felsic volcanic rocks, each representing the major rock groups mapped in the Genex Mine area are given in Table 4. On Figure 51, data for some less-altered felsic volcanics form a reasonably tight cluster within the rhyolite field confirming the relict and remnant mineralogy and textures described in the felsic rocks in Section 3.2.2.

The Zr content of the felsic rocks in the Genex Mine

area are similar to those in the rest of the Kamiskotia area (Table 4). In contrast, as shown by Legault et al. (1985), the Y content of felsic volcanics within the dominantly mafic formation is significantly lower (less than 100 ppm) than those felsic volcanics making up the Lower Felsic formation and the stratigraphically higher Mt-Jamieson Rhyolite formation (generally 300 to 400; Table 4) suggesting that the felsic volcanics intercalated within the dominantly mafic volcanic formation in the Godfrey Township area have a different petrogenetic history. Rare earth and trace element data does show however that the felsic volcanics intercalated in the dominantly mafic formation and the Mt-Jamieson Rhyolite formation have a tholeiitic affinity (Campbell et al., 1981a, b; Hart, 1984).

The major element composition of the least-altered felsic volcanics is different in certain respects from that of an average rhyolite (Nockolds, 1954); namely higher SiO_2 , Fe_2O_3 and MgO contents, and consistently lower Al_2O_3 , CaO and total alkali content. None of the samples chosen as least-altered felsic volcanics from the Genex Mine area resemble (except in general SiO_2 , Al_2O_3 and total alkali content) tholeiitic rhyolites described by Goodwin (1979) for the Timmins-Kirkland Lake-Noranda region; the only samples which plot within the igneous spectrum for felsic rocks (fig. 50) chemically resemble Goodwin's (1979) calc-alkaline rhyolite. The least-altered sample of synvolcanic intrusion (Table 4) has a significantly higher Na_2O and lower K_2O content com-

TABLE 4: ANALYSES OF LEAST ALTERED FELSIC VOLCANICS FROM THE
GENEX AREA

Sample#	2651	23777	2865	28962	28965	23583	G-1	70718	CaRhy	ThRhy
SiO ₂	78.6	82.8	75.4	75.1	74.5	79.7	77.1	76.7	75.4	70.1
Al ₂ O ₃	8.85	8.99	10.1	12.0	11.8	10.1	12.1	10.9	13.0	14.0
CaO	0.02	0.85	0.07	1.52	0.29	0.49	0.32	0.49	0.80	0.90
MgO	3.50	0.31	2.09	1.85	2.87	1.24	0.71	0.32	0.80	0.90
Na ₂ O	<0.01	4.26	<0.01	1.13	1.66	3.92	3.43	0.73	3.80	3.40
K ₂ O	1.65	0.79	2.65	2.91	2.15	1.49	2.70	7.19	2.30	1.60
Fe ₂ O ₃	4.14	1.01	5.47	3.30	3.04	1.53	1.70	1.60	0.70	1.50
FeO	-	-	-	-	-	-	-	-	1.90	3.80
MnO	0.02	0.02	0.11	0.04	0.02	0.02	0.02	0.26	0.06	0.08
TiO ₂	0.21	0.21	0.28	0.29	0.26	0.11	0.28	0.30	0.21	0.41
P ₂ O ₅	0.01	0.03	0.02	0.05	0.04	0.02	0.05	-	0.07	0.15
Cr ₂ O ₃	-	0.02	-	0.01	<0.01	<0.01	-	-	-	-
L.O.I.	2.47	1.16	2.62	1.77	2.47	1.16	1.47	-	1.51	3.16

Total	99.5	100.5	98.8	100.0	99.2	99.8	99.9	98.49	100.0	100.0
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Cr ₂ O ₃	170	-	180	-	-	-	200	200	13	10
Y	70	-	90	-	-	-	-	300	-	-
Nb	10	-	40	-	-	-	-	-	-	-
Rb	30	20	60	80	80	40	110	-	-	-
Sr	<10	20	<10	40	40	10	30	<10	105	128
Zr	270	280	370	330	410	190	330	400	210	208
Cu	24.	15.	14.	37.	13.	10.	-	-	-	-
Zn	110	20.	440.	70.	90.	82.	-	-	-	-
S.G.	-	-	-	2.72	2.69	-	-	-	-	-

AA-2651 fragmental, quartz-porphyritic felsic volcanic, lower felsic unit (quartz-sericite alteration).

AA-23777 massive, quartz-porphyritic synvolcanic felsic intrusion (keratophyre).

AA-2865 fragmental, quartz-porphyritic felsic volcanic, intercycle felsic unit (quartz-sericite alteration).

AA-28962 fragmental, quartz-feldspar porphyritic felsic volcanic, intercycle felsic unit (potassium-keratophyre).

AA-28965 massive to brecciated, quartz-feldspar porphyritic felsic volcanic, xenolith of intercycle felsic unit (potassium-keratophyre).

AA-23583 massive, quartz-porphyritic felsic volcanic, lower felsic unit (weakly sericitized).

G-1 felsic volcanic, lower felsic unit south of Forbes Lake.

70-718 massive, grey rhyolite, Mt-Jamieson Rhyolite formation, Con. 5, Lot 8, Godfrey Township (potassium-keratophyre) (Middleton, 1975).

CaRhy average calc-alkaline rhyolite, Timmins-Kirkland Lake-Noranda region (Goodwin, 1979).

ThRhy average tholeiitic rhyolite, Timmins-Kirkland Lake-Noranda region (Goodwin, 1979).

FIGURE: 51

FIGURE: 52

FIGURE 51: Immobile element ratio diagram (after Floyd and Winchester, 1977). Least-altered samples of lower felsic formation (Δ), synvolcanic felsic intrusion (∇), high- TiO_2 mafic volcanic ($\circ$), low- TiO_2 mafic volcanic ($\bullet$) and mafic intrusion ($\square$).

FIGURE 52: Ti-Zr-Y ternary discrimination diagram (after Pearce and Cann, 1973). Least-altered samples of high- TiO_2 mafic volcanic ($\bullet$), low- TiO_2 mafic volcanic (∇), and mafic intrusion ($\square$). **A** - field of low-K tholeiites; **B** - field of ocean-floor basalts; **B** and **C** - fields of calc-alkali basalts; **D** - field of ocean island or continental basalts.

Figure 53: Ti-Zr discriminant diagram (after Pearce and Cann, 1973). See figure 52 caption for symbols. Also indicated are least-altered samples used in mass balance calculations.

pared to Goodwin's (1979) rhyolites (it plots as a keratophyre). In contrast, samples of the intercycle felsic unit have consistently higher K_2O contents (they plot as potassium-keratophyres; fig. 50). The chemistry of the felsic volcanics in the Genex Mine area suggests that these "least altered" rocks have also been altered by some of the hydrothermal processes described above. Clearly, these chemical changes will have to be taken into account during the interpretation of chemical mass transfer described in Section 4.4.

4.2.3 Mafic Volcanics

The major and minor element chemistry of some representative least-altered mafic volcanic rocks from the Genex Mine area (from the first and second mafic volcanic cycles) is listed in Table 5. On Figure 51, it is clear that the mafic volcanics are made up of at least two trace element-distinct rock groups which plot within Floyd and Winchester's (1977) alkaline to subalkaline basalt and basalt-andesite fields respectively. The slight alkaline affinity suggested for some of the mafic rocks in Figure 51, is due to very low Nb and Y contents and is possibly related to alteration (Section 4.4). Data from the least-altered mafic volcanics when plotted on Pearce and Cann's (1973) trace element discrimination diagrams show, in addition to their subalkaline character, that the mafic volcanics have trace element contents similar to modern tholeiitic volcanics. In Figure 52 for example, the Y-Zr-Ti inter-element ratios of these rocks are similar to those of modern calc-alkalic and tholeiitic basalts; the Zr-

TABLE 5: ANALYSES OF LEAST ALTERED MAFIC VOLCANICS IN THE GENEX MINE AREA

Sample#	2837	2851	23683	23790	23637	28958	2871	28998
SiO ₂	65.8	65.8	57.3	59.4	57.2	58.3	63.8	59.7
Al ₂ O ₃	12.2	12.1	16.0	14.3	15.6	12.1	14.3	14.8
CaO	4.58	3.54	4.30	5.02	3.62	6.29	2.06	3.58
MgO	4.24	4.87	5.73	2.57	5.50	3.04	2.59	2.80
Na ₂ O	4.62	4.00	5.13	5.56	5.33	2.32	5.00	4.71
K ₂ O	0.29	0.34	0.10	0.11	0.20	0.67	0.09	0.37
Fe ₂ O ₃	6.26*	7.49*	13.5*	10.5*	10.9*	14.7*	10.5*	12.4*
FeO	-	-	-	-	-	-	-	-
MnO	0.24	0.18	0.21	0.21	0.09	0.49	0.09	0.21
TiO ₂	1.50	0.96	2.47	1.91	1.20	1.49	1.21	1.10
P ₂ O ₅	0.50	0.18	0.28	0.45	0.24	0.48	0.23	0.24
Cr ₂ O ₃	-	-	<0.01	<0.01	<0.01	<0.01	-	<0.01
(L.O.I.)	5.77	1.54	3.16	4.62	6.54	2.23	3.47	4.54
(Total)	100.3	99.5	99.4	99.8	99.7	100.3	98.8	100.0
Cr ₂ O ₃	120	190	-	-	-	-	130	-
Y	30	50	-	-	-	-	40	-
Nb	20	20	-	-	-	-	30	-
Rb	10	10	<10	10	20	30	10	20
Sr	80	50	30	210	100	90	20	110
Zr	190	230	240	240	290	180	270	280
Cu	22.	45.	59.	32.	35.	36.	11.	57.
Zn	95.	52.	150.	140.	130.	190.	140.	150.
S.G.	-	-	2.71	2.76	2.75	-	-	-

Note, all major elements normalized to 100 wt%, volatile-free. *Total iron reported as Fe₂O₃.

AA-2837 massive, Cycle 1, high-TiO₂ mafic volcanic (silicified and spilitized).

AA-2851 massive, Cycle 1, low-TiO₂ mafic volcanic (silicified and spilitized).

AA-23683 pillowed, Cycle 1, high-TiO₂ mafic volcanic (spilitized).

AA-23790 pillowed, Cycle 1, high-TiO₂ mafic volcanic (spilitized and weakly silicified).

AA-23637 pillowed, Cycle 1, low-TiO₂ mafic volcanic (spilitized).

AA-28958 pillowed, Cycle 2, high-TiO₂ mafic volcanic (weakly silicified).

AA-2871 pillowed, Cycle 2, low-TiO₂ mafic volcanic (silicified and spilitized).

AA-28998 pillowed, Cycle 2, high-TiO₂ mafic volcanic (spilitized and weakly silicified).

TABLE 5 continued:

Sample#	FTh11	FTh12	ArchT	ArchCA
SiO ₂	55.0	51.8	51.4	49.7
Al ₂ O ₃	11.9	15.9	14.8	14.9
CaO	5.62	8.57	10.7	9.40
MgO	2.50	6.17	6.70	6.30
Na ₂ O	3.80	2.60	2.70	2.10
K ₂ O	0.19	0.25	0.18	0.32
Fe ₂ O ₃	5.06	13.3*	2.10	2.60
FeO	9.22	-	8.30	8.80
MnO	0.21	0.24	-	-
TiO ₂	2.45	1.10	1.92	1.0
P ₂ O ₅	0.43	-	-	-
Cr ₂ O ₃	-	-	-	-
L.O.I.	2.89	-	-	-

Total	99.37	97.80	-	-
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Cr	-	-	350	175
Y	-	-	10	15
Nb	-	-	-	-
Rb	-	-	4	10
Sr	-	-	100	165
Zr	-	-	55	100
Cu	-	-	110	110
Zn	-	-	115	100
La/Yb	-	-	1.5	5

FTh11 fine-grained, pillowed, high-iron tholeiitic basalt, Kinojevis Group, sample no.41 (Jensen,1976).

FTh12 1 to 2 mm grained, massive, high-iron tholeiitic basalt, Kinojevis Group, sample no. 25 (Jensen,1976).

ArchT average composition of 32 Archean tholeiitic basalts (D.A.T. Tholeiite) Condie (1976).

ArchC average composition of 18 Archean calc-alkaline basalts (E.A.T. Tholeiite) Condie (1976).

content of the mafic rocks in the area is enriched relative to other Archean and modern mafic rocks (Table 5). The tholeiitic character as opposed to calc-alkalic character is suggested by the generally high Ti content (5 800 to 14 000 ppm, volatile free) of these mafic volcanics (fig.53). This is consistent with the tholeiitic rare-earth element pattern of similar mafic volcanics sampled in the Kamiskotia area (Campbell et al.,1981a,b).

As shown in Table 5 and in Figures 52 and 53, two groups of mafic volcanics may be clearly distinguished apparently only on the basis of TiO_2 content, namely low- TiO_2 mafic volcanics (TiO_2 of about 1 %) and high- TiO_2 mafic volcanics (TiO_2 contents of approximately 1.8 %). In contrast, the Zr, Nb and Y contents of the two types of mafic volcanics are not demonstrably different from each other.

As mentioned in Section 2.2.2, the mafic volcanics in the Kamiskotia area have been shown, on the basis of textural evidence (Hogg,1954) and major element (Middleton,1973,1974, 1975) and trace element content (Campbell et al.,1981a,1981b; Hart,1984) and textural evidence (Walker,1955,1957), to be the extrusive equivalents of the tholeiitic Kamiskotia Gabbro. The Kamiskotia Gabbro and its volcanic equivalents are chemically quite similar to Jensen's (1976) high-iron tholeiitic basalts from the Timmins-Kirkland Lake area. It is clear (Table 4) that both the high- TiO_2 - and low- TiO_2 -mafic volcanics from the Genex Mine area in general have significantly higher SiO_2 and Na_2O contents and generally lower total FeO, Al_2O_3 , K_2O , MnO , CaO and MgO contents than some

representative samples high-iron tholeiitic basalts from the Abitibi Subprovince. The recognition of both the altered composition of the mafic volcanics chosen as least altered and the relict primary magmatic chemical composition (ie. the TiO_2 content) is important in assessing the magnitude of chemical transfer involved in the hydrothermal alteration in the Genex Mine area (Section 4.4). Also significant is the fact that two chemically distinct mafic volcanics make up the first and second cycles of mafic volcanism mapped in the Genex area.

Given the demonstrably highly inert behaviour of Ti and Zr (and Al) during all but the most intense hydrothermal alteration in the Genex Mine area, on the basis of TiO_2 and Zr content, Figure 55 was constructed using the available geochemical analyses. Certain conclusions may be drawn from the spatial distribution of the mafic flows in the Genex Mine area:

1. High- TiO_2 mafic lavas were erupting (at least initially) simultaneously with low- TiO_2 mafic lavas; this is indicated by the presence of juxtaposed high- TiO_2 - and low- TiO_2 -mafic volcanics in different volcanic blocks within the first mafic volcanic cycle.
2. Chemically distinct flow units within the first mafic cycle appear to abruptly end along east-trending zones marked by major felsic dykes. This suggests that these zones may have been actual physical barriers impeding flow movement.
3. The presence of high- TiO_2 and low- TiO_2 mafic volcanics throughout the first and second mafic volcanic cycles suggests that the mafic magma was not evolving stratigraphically upward.

4.2.3 Mafic Intrusions

Least-altered samples of mafic intrusion, generally representative of the four rock groups described in Section 3.2.5, are listed in Table 6. Trace element data from some less-altered mafic intrusions suggest that these rocks in general have a trace element content similar to modern subalkaline basalts and andesites (fig.51).

As expected, mafic intrusive rocks interpreted as synvolcanic feeder dykes have immobile trace element contents (Table 6, figs.52,53) similar to the high-TiO₂- and low-TiO₂-mafic volcanics described above.

In contrast, some of the mafic intrusive rock groups have immobile trace element contents which are significantly different from the mafic volcanics which surround them. For example, representative samples of the fine-grained sill which dilates the intercycle rhyolite unit from the top of the first mafic volcanic cycle (samples AA-2864, AA-28967; Table 6) have significantly lower Zr contents than both types of mafic volcanics (Table 5). Data from some less-altered mafic intrusions plot below the mafic volcanics in the subalkaline basalt and alkali-basalt fields in Floyd and Winchester's (1979) discriminant diagram (fig.51); according to discriminant analyses of Pearce and Cann (1975) these rocks may be classified as tholeiitic basalts (figs.52,53).

The subvolcanic intrusions cutting the lower felsic unit, for example sample AA-23564 (fig.53), have trace element compositions similar to the synvolcanic sill described above suggesting a common source. The major and trace element contents of the subvolcanic mafic intrusive rocks in the

TABLE 6: ANALYSES OF LEAST ALTERED MAFIC INTRUSIONS FROM THE GENEX MINE AREA

Sample#	2864	28967	2657	23685	2860	23640	26564	23776	23608
SiO ₂	55.4	53.9	64.0	62.7	60.4	57.7	52.7	60.6	50.5
Al ₂ O ₃	14.2	12.9	12.8	13.2	12.4	13.7	13.8	14.5	19.1
CaO	6.60	8.13	0.31	4.14	5.96	6.12	5.71	5.10	6.99
MgO	4.43	6.30	4.63	5.26	2.66	3.25	8.12	2.78	6.95
Na ₂ O	0.02	2.75	<0.01	3.31	3.04	4.34	2.06	3.35	3.09
K ₂ O	3.10	0.14	1.53	0.87	1.26	0.43	0.10	1.43	2.76
Fe ₂ O ₃	13.8	14.2	14.1	9.30	12.2	12.0	15.9	10.8	9.77
MnO	0.80	0.16	0.08	0.20	0.36	0.22	0.09	0.13	0.12
TiO ₂	1.51	1.26	1.16	0.92	1.83	2.01	1.40	0.98	0.61
P ₂ O ₅	0.12	0.11	0.22	0.19	0.36	0.22	0.12	0.21	0.05
Cr ₂ O ₃	-	0.01	-	<0.01	-	<0.01	<0.01	<0.01	0.01
(L.O.I.)	9.47	5.85	4.23	1.70	6.54	3.85	7.85	8.00	11.5
(Total)	100.8	100.1	99.0	100.3	100.1	99.0	99.8	100.3	99.9
Cr ₂ O ₃	150	-	250	-	110	-	-	-	-
Y	10	-	50	-	40	-	-	-	-
Nb	10	-	40	-	20	-	-	-	-
Rb	50	<10	20	10	20	<10	<10	40	70
Sr	30	140	<10	70	70	130	50	60	50
Zr	80	80	250	240	170	170	80	260	40
Cu	150.	100.	33.	24.	37.	39.	5.	23.	89.
Zn	200.	95.	250	87.	160.	120	57.	130.	77.
S.G.	-	-	2.81	-	-	2.84	2.71	-	-

AA-2864 massive, fine-grained, low-Zr, mafic intrusion, dilating the intercycle felsic unit from the first mafic volcanic cycle (carbonate alteration).

AA-28967 massive, fine-grained, low-Zr, mafic intrusion, dilating the intercycle felsic unit from the first mafic volcanic cycle (carbonate alteration).

AA-2657 massive, amygdaloidal, low-TiO₂ mafic dyke cutting top of lower felsic stratigraphy (quartz-chlorite with fracture-controlled quartz-sericite alterations).

AA-23685 massive, low-TiO₂, mafic intrusion at the base of first mafic volcanic cycle (silicification and volatiliziation associated with diabase dyke).

AA-2860 massive, high-TiO₂, mafic intrusion, dilating second mafic volcanic cycle from intercycle felsic unit (carbonate alteration).

AA-23640 massive, fine-grained, high-TiO₂, mafic intrusion within the first mafic volcanic cycle (spilitization).

AA-23564 massive, fine-grained, low-Zr, subvolcanic mafic intrusion west of Baseline 3W (carbonate alteration).

AA-23778 feldspar porphyritic, fine-grained, low-TiO₂ mafic (hybrid?) intrusion (carbonate alteration).

AA-23608 medium-grained, late-stage, gabbroic intrusion (microdiorite?) northeast shore of Forbes Lake (strong carbonate alteration).

Genex Mine area are similar in many respect to samples of the Kamiskotia Gabbro (Table 6; see Table 6 in Middleton, 1975) except for lower CaO , and K_2O shown by the rocks in the Genex Mine area.

The feldspar-porphyrific fine-grained intrusions, shown to be petrographically distinct from the rest of the intrusive and volcanic rocks have in contrast, trace element compositions similar to the low- TiO_2 -mafic volcanics (Table 6); the Zr- TiO_2 compositions are, however, approximately midway between the felsic volcanics and the low-Zr subvolcanic intrusions suggesting that these anomalous rocks may be hybrid.

The medium-grained strongly carbonatized gabbroic rocks which occur on the northeastern shore of Forbes Lake have significantly different trace element and major element contents to all of the volcanics described so far; although pervasive carbonate alteration has affected all the rocks sampled, the Zr, TiO_2 and Al_2O_3 contents are relatively consistent (Table 6). These rocks in fact, have trace element, Al_2O_3 and SiO_2 contents similar to medium-grained porphyritic gabbro and gabbro-anorthosites reported elsewhere in the Kamiskotia area by Middleton (1973, 1975).

Using a discriminant diagram similar to Figure 53, a map of the Genex area, was constructed (fig. 54). This map in part confirms the field mapping, especially the contacts of the sill-like intrusions within the mafic volcanics).

FIGURE 54 : SIMPLIFIED GEOLOGY MAP SHOWING THE DISTRIBUTION OF THE DIFFERENT TRACE-ELEMENT GROUPS IDENTIFIED IN THE GINEX MINI AREA.

4.3 PETROLOGY OF ALTERATION IN THE GENEX MINE AREA

This section deals with the physical effects of hydrothermal alteration seen both in outcrop scale and in thin section. At least eight types of alteration have been recognized in the Genex Mine area:

Low-Grade Alteration

1. Spilitization
2. Potassic-Feldspar alteration
3. Carbonatization
4. Silicification and volatilization adjacent to diabase dykes
5. Silicification

Pipe Alteration

6. Quartz-chlorite
7. Silica-Sericite
8. Chlorite

The first five types may be considered as low-grade or background alteration which are not directly related to the mineralization process. The last three are in general directly associated the sulphide mineralization in the Genex Mine area. Although eight distinct types are distinguished, there is overlap and they often occur together even within a thin section. Petrographic descriptions are given in Appendix B.

4.3.1 Spilitization

Spilitization has affected rocks in both the first and second cycles of mafic volcanism (as well as the fine-grained mafic intrusions) in the Genex Mine area. The progressive nature of the alteration is based on evidence of mineralogical zoning seen in thin section and to a lesser extent in outcrop.

In what appears to be its simplest form, spilitization is represented by the mineral assemblages:

1. chlorite + albite + epidote + quartz (+ actinolite + carbonate)

2. chlorite + albite + epidote + sericite + quartz (+ carbonate + potassic-feldspar)

The first assemblage, more common of the two, in fact is the mineralogy of the "least-altered" mafic volcanics in the area. The albite is in the form of limpid microlites and anhedral grains (fig.27). Epidote-group minerals generally occur as fine grains and clusters interstitial to the albite; they are also found as larger (up to 0.1 mm) subhedral to euhedral grains within the groundmass constituents (fig.42). Often carbonate occurs as a calcium bearing mineral phase instead of epidote. Actinolite is rare. Chlorite is by far the most abundant mafic constituent within the least altered volcanics and intrusions (generally in excess of 50%) and occurs as very fine grains interstitial to the albite or in coarse mm-sized polycrystalline sheets. Feldspar megacrysts, the only relict primary igneous minerals, though rare are often dusty and altered-looking and are albitic (fig.27).

The second assemblage has a more restricted paragenesis; in fact, potassic-feldspar was identified as a single potassium-bearing phase occurring with albite on only one occasion (AA-2850; Appendix B). Albite and sericite more commonly occur together with chlorite and minor carbonate or epidote in this type of alteration (fig.55). The presence of sericite in these mafic rocks is anomalous since the development of sericite is usually associated with feldspar-destructive pipe alterations (Franklin et al., 1981). The sericite asso-

ciated with some of the spilites may, alternately, be due to a superimposed alteration; for example, carbonate alteration is also common in these rocks.

In general, because these spilitic assemblages are dominated by chlorite, the rocks in outcrop are green and aphanitic and generally do not appear as altered as the petrography and chemistry show (see Section 4.4).

It is well established, based on textural evidence in modern and older mafic rocks (Hughes, 1973) and isotopic evidence (Munha and Kerrich, 1980), that spilites are the products of the interaction of sea water with basalts and are the natural consequence of cooling hot basaltic liquids in a submarine environment. In simple terms, the normal spilitization process is characterized by the formation of low-albite at the expense of primary calcic plagioclase; similarly the alteration of primary pyroxenes results in epidote or actinolite in a mass of chlorite and other minor constituents. Experimental evidence suggests that the above mineralogical changes observed in modern rocks had to occur at temperatures above at least 150°C and under conditions of low water/rock ratios (Mottl, 1983). In contrast, in some cases low-grade ocean-floor hydrothermal alteration of the rock result in the formation of potassium-rich phases such as K-rich smectites and zeolites which have been found in modern ocean floor basalts (Scarfe and Smith, 1977; Andrews, 1978); this situation has been shown to be common in lower temperature sea-water/basalt reactions, below 150°C.

It is evident that the spilitic mineralogy exhibited by

the "least altered" mafic volcanics in the Genex Mine area are nearly identical to those seen in modern rocks (and described in many other older rocks) which have been shown experimentally and isotopically to be natural products of progressive basalt/sea-water interaction.

Textural evidence which illustrates the progressive nature of hydrothermal alteration in the Genex Mine area are visible in the pillowed High-TiO₂ mafic volcanics forming the top of the first mafic volcanic cycle. These pillows often show a weakly bleached rim surrounding a normal greenish-grey core zone, and a thick chloritized margin and selvage (figs.29,30). Handsamples cut along the rim zone also shows the contrasting bleached rim and outer chloritized zones. In thin section, the bleached area of the pillow (the outer microlitic zone III; Dimroth and Lichtblau,1979) is dominated by limpid albite microlites and grains with lesser interstitial fine-grained chlorite and epidote and a trace of quartz (fig.27); near the chloritized margin, albite content decreases, relatively coarse (0.01 mm-sized) euhedral clinzoisite grains also appear to be generally less abundant (fig.56). Quartz is the next important phase in this domain, forming up to 5% or more in the chlorite-rich zone. While the albite-rich section is characteristic of strong spilitic alteration (Type 1 alteration), the mineralogy of the chlorite-rich margin seen in this section (fig.57) approaches the character of quartz-chlorite alteration (Type 6 alteration).

While most of the discussion has been on spilitization

COLOURED PICTURES
Images en couleur

lot 10 | 9

lot 9 | 8

ACONDA LAKE

intercycle exhalite

FORBIS LAKE

con 3

con 2

0 100 200 300m

Chlorite

Quartz-Sericite

Quartz-Chlorite

geological contact

- Figure 55: Synvolcanic mafic intrusion, 2155 N, 245 m east of BL 3W (AA-23687). Photomicrograph showing recrystallized albite grains (A) in a matrix of sericite (S), chlorite, carbonate and quartz (K-rich spilite, carbonate alteration)(crossed polarizers).
- Figure 56: Dominantly mafic formation, Cycle 1, 2120 N, 390 m east of BL 3W (AA-23683). Photomicrograph of incipient quartz-chlorite alteration near pillow-selvage zone; high-relief yellowish clinozoisite grains (5%), and rare albite in a matrix of 80% chlorite, 10% opaques and 5-10% fine quartz (plane-polarized).
- Figure 57: Dominantly mafic formation, Cycle 1, 2120 N, 390 m east of BL 3W (AA-23683). Photomicrograph of boundary between albite-epidote-rich zone (A,E) and chlorite-rich zone (C) reflecting alteration at progressively higher water/rock ratios (crossed-polarizers).
- Figure 58: Dominantly mafic formation, Cycle 1, 2239 N, 245 m east of BL 3W (AA-23637). Photomicrograph of ferroan dolomite (D) porphyroblasts and albite megacrysts in a matrix of albite and chlorite with minor epidote (spilite, carbonate alteration)(plane-polarized).
- Figure 59: Dominantly mafic formation, Cycle 1, 1590 S, 40 m west of BL 1200W (AA-2855). Photomicrograph showing fine biotite-sericite (brown) mantling a fracture in hornfelsed mafic volcanic. Matrix made-up of sericite, chlorite and quartz (quartz-sericite alteration with superimposed pyroxene-facies hornfels)(plane polarized).
- Figure 60: Fine-grained mafic sill, 2040 N, 315 m east of BL 2W (AA-28956). Photomicrograph of altered ferroan dolomite porphyroblasts; chlorite rim (C), epidote inner mantle (E), and chlorite-epidote-carbonate core. Note poikiloblastic opaques and quartz (q) surrounding porphyroblasts (plane-polarized).
- Figure 61: Dominantly mafic formation, Cycle 1, 2170 N, 225 m east of BL 3W (AA-23686). Photomicrograph of silicified albite (A), spherulites (S) replaced by radiating quartz-biotite overgrowths, and altered ferroan dolomite porphyroblasts (D) in matrix of quartz, sericite, biotite and chlorite (silicification and volatilization)(plane-polarized).
- Figure 62: Dominantly mafic formation, Cycle 2, 2175 N, 200 m W of BL 2W (AA-28970). Photomicrograph of quartz-chlorite pressure shadow in matrix of chlorite, quartz and carbonate (silicification)(plane-polar)

of mafic volcanic rocks, the same sea water interactions, resulting in a sodium-rich, potassium-poor rock (keratophyre) have been documented submarine felsic volcanic rocks (Hughes, 1973, Battey, 1955; Munha et al., 1980). Keratophyre is rare in the Genex Mine area; in fact, there is only one (AA-23777, Table 4; fig. 50) and it has been used as an example of a least-altered felsic synvolcanic intrusion.

4.3.2 Potassic Feldspar Alteration

Potassic alteration is interpreted to be a low-grade alteration primarily seen in felsic volcanic rocks which are not directly related to massive sulphide mineralization; it results in the progressive replacement of groundmass primary igneous feldspars by low-temperature K-feldspar or adularia and it is therefore distinct from the potassic alteration interpreted to be associated with quartz-sericite "pipe" alteration (Type 7).

Evidence of potassic alteration to form adularia and sericite within the Genex Mine area, is found only in the felsic fragmentals and flows south of Forbes Lake. However this type of alteration may have affected most of the felsic rocks in the Kamiskotia area, and is common in the Godfrey-Turnbull Townships region in particular, especially the Mt-Jamieson Rhyolite formation (Legault et al., in prep).

Massive to brecciated quartz-feldspar phyric felsic rocks as well as fragmental felsic volcanics south of Forbes Lake are characterized by the mineral assemblage

quartz + adularia + sericite with lesser chlorite, carbonate, biotite and albite.

Adularia, is a variety of potassium feldspar (general composition $\text{Or}_{90}\text{Ab}_{9}\text{An}_1$; Deer et al., 1966) which is characterized by its pseudo-orthorhombic habit, its inhomogeneous optical and structural parameters and its restricted paragenesis (usually found in Alpine-type veins with other low-temperature minerals; Deer et al., 1966). K-feldspar, although found mixed with the groundmass quartz and minor carbonate, chlorite and sericite, is most often recognized as polycrystalline grains replacing feldspar phenocrysts with poikiloblastic quartz and other alteration minerals (sericite, carbonate, biotite; figs. 22, 23). In other rocks, adularia is often observed either partially or totally replacing primary igneous anorthoclase phenocrysts which sometimes have cores of albite (fig. 25) (Légault et al., in prep). It is also found with poikiloblastic quartz visibly replacing delicately-textured relict flow-banded hyaloclastite granules (fig. 23). Sericite is also abundant in these volcanic rocks (forming up to 10%), occurring as fine-grained oriented vein-like masses or replacing fragments. The sericitization is the most visible effect in outcrop that these rocks have been altered (Section 3.2.2). Carbonate is also abundant in these rocks, surrounding phenocryst clusters (fig. 24) or in thin veinlets in the rock. The distribution of potassic-feldspar alteration is shown Figure 63.

Alteration of primary igneous feldspars resulting in the formation of low-temperature potassic-feldspar in felsic volcanics (potassium-keratophyres) is not common, but has

been documented in Mesozoic subaqueous rhyolites in New Zealand (Battey, 1955), and in upper Devonian to lower Carboniferous felsic tuffs in the Iberian Pyrite Belt of southern Portugal (Munha et al., 1980); in these areas adularia is found progressively replacing primary igneous plagioclase resulting in a virtual total substitution of K for Na; potassium-keratophyres also occur interbedded with keratophyres in some cases (Battey, 1955). However, no occurrences of adularia-tization have so far been reported in the Archean (Legault et al., in prep). Potassium enrichment resulting in the formation of potassium-rich smectites and zeolites affects Oligocene to Miocene hydrated subaerial glassy to devitrified ash-flows and rhyolite obsidian in Nevada (Scott, 1971; Noble, 1967); there is apparently only one case of regional potassic alteration of subaerial ash-flows reported in the Archean (Thurston et al., 1978; Savory, 1976).

Experiments reacting basalt with sea water and isotopic studies on both modern submarine basalts containing secondary potassic-feldspar and older subaqueous adularia-bearing felsic volcanics suggest that the alteration took place below 150°C and possibly with low water/rock ratios.

Clearly, the potassium-feldspar alteration affecting the felsic rocks in the Genex Mine area and in the Kamiskotia area in general is similar in many respects to the regional potassium alteration described in subaqueous and subaerial felsic volcanics elsewhere. However potassium alteration has also been directly associated with ore-forming systems documented in volcanogenic massive sulphide deposits and in

FIGURE 63 : DISTRIBUTION OF ALTERATION FACIES IN THE GENEX MINE AREA. (spilites and keratophyres not shown). ALSO SHOWN ARE SURFACE PROJECTIONS OF SULPHIDE ORE-ZONES DEVELOPED BY GENEX MINES LTD. IN 1964-66.

Archean lode-gold deposits; as has been summarized by Franklin et al. (1981) and Kerrich (1983), it is generally associated with feldspar destruction and the formation of a sericite-rich halo (the exclusive potassium-bearing mineral phase) around the underlying stockwork alteration zone. Potassium-feldspar alteration of intrusive rocks is common in porphyry copper-molybdenum ore systems and is also reported in Archean age porphyritic subvolcanic intrusions associated with lode-gold deposits in the Malartic area of Quebec (Kerrich, 1983).

While characteristic sericitic "pipe" alteration occurs in the Genex Mine area (Type 7 alteration), the presence of adularia (as well as sericite), the lack of sulphide and gold mineralization in the area south of Forbes Lake, the demonstrated regional nature of this alteration in the Kamiskotia area and the difference in geochemistry of these rocks, suggests that this alteration is distinct and more likely associated with regional low-grade hydrothermal alteration than with alteration proximal to metal deposits.

4.3.3 Carbonate Alteration

This alteration type is possibly the most widespread in the Genex Mine area and has affected all the rock units described so far (except for diabase dykes). Carbonate in the rest of the volcanic rocks is generally in the form of fine mm-sized subhedral to euhedral rhombohedral porphyroblasts which occur pervasively throughout the rocks (figs. 38, 41) or less commonly as fine mm-thick veinlets. Carbonate is also a

common amygdule filling

Ferrodolomite-ankerite (by far the most common) was distinguished from calcite based on its typical limonite-red weathering colour. Ferroan ankerite or ankerite ($\text{Ca(Fe,Mg,Mn)(CO}_3)_2$), was distinguished from ferroan dolomite by the absence of pronounced glide twinning parallel to the short diagonal of the rhombic section of these minerals. Siderite was not identified in the Genex Mine area. There does not appear to be any pronounced mineralogical zoning of carbonate species in the Genex Mine area (except that calcite is more common both in amygdules and in the groundmass of the second mafic volcanic cycle).

In the mafic intrusive rocks west of Baseline 3W and in the fine-grained sills within the mafic volcanics, carbonate (ferroan dolomite to ankerite) is ubiquitous, and generally forms between 5 to 20 volume percent of the rock (fig.38); all igneous textures are obliterated in them. Carbonate is often found (in some cases with albite or quartz) replacing feldspar megacrysts. The medium-grained gabbroic to gabbro-porphyrific intrusive rocks which occur along Forbes Lake are the most highly affected by carbonate alteration which makes up to 30 volume percent of the rocks (fig.44). In some cases, carbonate with chlorite is also found replacing secondary minerals such as epidote grains (fig.42). Mafic intrusive rocks which characteristically show the least effects of carbonate alteration are the intrusions and thin feeder dykes exposed east of Baseline 3W which have been affected by

"pipe" alteration.

Mafic volcanic rocks are, in general, less affected by carbonate alteration; the carbonate in these rocks is usually found in the selvages of pillows, in amygdules, in veinlets (with quartz) but is also a common groundmass constituent. Some mafic volcanic rocks are quite strongly carbonatized, especially the pillowed volcanics making up the lower part of the first mafic volcanic cycle between Lines 2158N and 2321N; some of these rocks contain up to 30 volume percent ferroan dolomite (fig.58) concentrated as mm-sized porphyroblasts in the pillow selvages and in the amygdule-rich pillow rims; these rocks also characteristically lack remnant igneous textures. Breccias are also particularly affected by carbonate alteration in the form of veins and replacements of both matrix and fragments. However, many of the mafic volcanics do not contain appreciable carbonate; especially the pillowed flows forming the top of the first mafic volcanic cycle and those rocks affected by "pipe" alteration.

Felsic volcanics are the least affected by carbonate alteration of all the rock units described so far (except the diabase dykes). The carbonate is generally in the form of fine disseminations along schistosity planes or in fine veinlets or replacing the cores of altered plagioclase megacrysts (fig.22). The strongest carbonatization seen in felsic volcanic rocks is found along the contacts with mafic intrusive rocks or in felsic volcanic xenoliths especially in the lower felsic unit. The felsic volcanics south of Forbes Lake are also quite strongly carbonatized (up to 5 or 10 volume per-

cent), especially the fragmental rocks where carbonate and sericite replace porous-looking fragments (fig.21); it also occurs in the groundmass surrounding phenocryst clusters. In the more massive rocks, minor carbonate usually occur along fracture-planes. These rocks also occur along the margin of a large mafic to intermediate microdiorite intrusion. Felsic rocks which show the least carbonate alteration are those strongly altered synvolcanic felsic dykes which cut the first mafic volcanic cycle. The distribution of strong carbonate alteration is shown in Figure 63.

From the observations described above, a few conclusions regarding carbonate alteration in the Genex area may be made:

1. It affects all the volcanic and intrusive rocks in the Genex Mine area; in particular, it affects intrusive rocks which clearly postdate the mineralization and alteration in the immediate vicinity of the Genex shaft.
2. There is no relation or pattern observed between carbonate alteration and mineralization except that it appears to be associated with later mafic intrusive activity.
3. The degree of carbonate alteration is primarily controlled by primary porosity as well as rock type (as well as proximity to the intrusion); ie. breccias and fragmentals are usually most strongly affected, felsic rocks show the least effects.

Carbonate alteration is interpreted to be a regional destructive alteration not directly related to the formation of massive sulphides in the Genex Mine area. While it might be argued that carbonate alteration affecting the "hanging wall" volcanics and intrusions might be related to an as yet undiscovered sulphide deposit higher in the stratigraphy, the fact that carbonate alteration is pervasive throughout the

Kamiskotia region including rocks which are stratigraphically above all the known massive-sulphide mineralization as well as the lack of zonation obscures the relationship between the alteration and the ore-forming processes.

Because of the significant carbonate content exhibited by many of the rocks selected for routine geochemical analysis, the high L.O.I. has the effect of diluting the other oxides and thereby affecting calculations of the "primary" magmatic or alteration chemistry of some of these rocks. Following the procedure of Irvine and Baragar (1971) and others, all the analyses taken in the Genex Mine area have been recalculated volatile free and normalized to 100 percent in order that for purposes of comparison, all the rocks have a common basis. The L.O.I. and totals are however reported for convenience (and as a measure of relative carbonate content).

4.3.4 Silicification and Volatilization around Diabase Dykes

The rocks surrounding the large diabase dykes are visibly altered; this is not unexpected, thermal aureoles surrounding intrusions (such as diabasic sills and dykes) controlling metamorphic assemblages and isotopic signatures are well documented in the Abitibi Subprovince (Harrigan and MacLean, 1976; MacGeehan, 1979).

The thermal effects are usually visible within 10 to 15 m of the widest diabase dykes; the mafic rocks surrounding the dykes are altered to a dense siliceous-looking brittle trap-like rock; felsic rocks, on the other hand, appear less

affected (except that they lose their quartz-eyes (Legault, 1982)). The mineralogical changes due to thermal metamorphism around the diabase dykes are described in Section 2.5 (ie., the development of biotite (and andalusite) at the expense of chlorite and sericite (fig.59); and staurolite-chlorite(-cordierite?) spotted hornfels development in the chlorite alteration).

Mafic rocks (and to a lesser extent felsic rocks) surrounding the dykes often develop a porphyroblastic texture, visible to the naked eye and in a handlens (2 to 5% mm-sized subhedral light coloured feldspar-shaped blebs which were originally mistaken for primary igneous "phenocrysts" of saussuritized feldspars). In thin section however, the "phenocrysts" do not resemble relict feldspar; rather, they are generally euhedral and subequant to rhombohedral (fig.60). They have a rim of fine-grained chlorite, an inner margin of fine granular epidote and chlorite, and a core of epidote, chlorite and carbonate. Quartz and opaques are also poikiloblastically enclosed within the chlorite-epidote-carbonate clots in approximately the same distribution as in the groundmass (fig.60). When compared to similar rocks which occur more than 15 m from the diabase (fig.38), it is evident that the "phenocrysts" are actually relict carbonate porphyroblasts. Similar relict carbonates showing progressive replacement by chlorite and epidote are visible in all the rocks (volcanic and intrusive) bordering the diabase dykes; in felsic rocks, the porphyroblasts were frequently mistaken

for chloritic fragments in handspecimen. Clearly one of the effects of the diabase dykes intruding into the supracrustal rocks was to destroy carbonate; a simple reaction is suggested by these textures seen in both the felsic and mafic rocks in the Genex Mine area:

This process is controlled by the thermal halo around the diabasic intrusion; it released carbon dioxide from the carbonate in these rocks.

Another of the effects of the diabase is silicification as pervasive replacement of the groundmass constituents by quartz or as fracture-controlled silicic veinlets. In the area surrounding the western diabase and central diabase dykes, alteration related to the dykes is difficult to distinguish from "pipe" alteration related to the massive sulphide mineralization. It is sometimes possible to compare similar rocks both hornfelsed and "less-altered". Figure 61 is taken from a massive amygdaloidal mafic volcanic within 5 m of the diabase dyke; it has visible relict ferroan dolomite porphyroblasts (chlorite, epidote, biotite and a trace of carbonate) in a matrix of quartz with chlorite, biotite, albite and sericite. The quartz occurs as fine groundmass quartz and in irregular barren veinlets (fig. 61), replacing feldspar megacrysts, and mixed with biotite and chlorite in 0.1 mm-sized fibro-radial structures, possibly relict spherulites.

In the same general area but 25 m from the diabase dyke, is a "normal looking" chloritic amygdaloidal mafic rock; in thin section similar textures are observed as in the last rock (fig.55); ferroan dolomite occurs with chlorite, sericite, albite, quartz. Biotite is conspicuously absent as are the abundant quartz veinlets and clots. Chlorite in contrast is more abundant.

Silicic veinlet swarms and alteration associated with gabbroic sills has also been reported in the Matagami area (MacGeehan,1978). These altered zones (quartz-epidote-albite-chlorite "spilitic" patches mantling quartz-epidote-filled fractures, and thin "destructive" quartz-albite selvages mantling silicic veinlets) were interpreted to have developed because the basalts were highly permeable, water-saturated rocks at the time the gabbroic sills were emplaced. The sills subsequently cooled by hydrothermal convection with the fluid present in the basalt; the basalt reacted with the fluids through structures in the rock now preserved as silicic veinlets (MacGeehan,1978). It has been shown that convective hydrothermal heat-transfer is a natural consequence of intruding hot magma into a water-rich cool country rock (Cathles,1981).

A similar situation, in part, is interpreted to have occurred in the Genex Mine area; the diabase dykes intruded into water-saturated and carbonate-rich volcanic rocks. During convective heat transfer, carbonate was driven off, quartz was mobilized, and biotite formed at the expense of groundmass sericite and chlorite along fractures now preser-

ved as silicic veinlets.

4.3.5 Silicification

This is probably the most difficult alteration to describe in the Genex Mine area; it is distinct from the silica-sericite "pipe" alteration (Type 8) associated with feldspar destruction in the first mafic volcanic cycle. It is more often associated with spilitic rocks although not all spilites are silicified. It is a subtle alteration type, which although generally not noticeable in outcrop, is evident in the abundance of fine-grained quartz (up to 20 volume percent) in the groundmass of mafic volcanic rocks (fig.62). Typically, because most of the rocks have been affected by carbonate alteration and have a spilitic mineralogy, clearcut replacement textures are lacking. Rather the high modal silica, confirmed by SiO_2 values for these rocks varying from typical spilitized basalts to dacite, is difficult to reconcile from rocks which contain relict quench olivine megacrysts and have relict skeletal feldspar textures of basalts.

Silicified basalts and andesites have been documented in the Rouyn-Noranda and Matagami areas of northwestern Quebec (Gibson, 1979; Gibson et al., 1983; MacGeehan, 1978; MacGeehan et al., 1981) where they have been interpreted to be the product of extensive lateral or medial regional synvolcanic subseafloor geothermal alteration. In these areas, there is a close relationship between silicified rocks and volcanogenic massive sulphide deposits. In the central Noranda volcanic complex, intense pervasive silicification of andesite-basalts

involves the selective replacement by fine-grained quartz with minor epidote and calcite of groundmass chlorite-actinolite (albite megacrysts and microlites are generally preserved). This alteration is permeability controlled; the most intense halos, patches and envelopes are adjacent to amygdules and fractures (Gibson et al., 1983). A variation of the silicification alteration process, quartz-epidote alteration (involving the gradual total destructive replacement of groundmass constituents by fine-grained quartz and epidote) results in the formation of amoeboid patches up to 3 m in diameter. In the Matagami area, similar quartz-epidote patches as well as "spilitic" (quartz-albite-actinolite-epidote) alteration patches seen in the volcanic and synvolcanic intrusive rocks are also interpreted to be "silicification" features related to geothermal alteration (Harrigan and MacLean, 1976; MacGeehan, 1978).

The silicification described in the Rouyn-Noranda and Matagami areas is similar in many respects to the silicification in the Genex Mine area; the "silicification" of pillowed basalts described by MacGeehan et al. (1981) associated with the Norita deposit near Matagami, appear to be more similar to silica-sericite "pipe" alteration in the Genex Mine area. It differs somewhat in intensity in that no patches or halos are noticeable. The distribution of silicified mafic volcanics is given in Figure 63; the construction of this map relies on the chemical signature of silicification described in detail in Section 4.4). Clearly silicification in the

Genex Mine area is more regional and widespread, affecting what were considered "least-altered" and spilitized first and second cycle mafic volcanic rocks as well as intrusive rocks. This alteration is apparently not directly involved in ore-forming processes; this is suggested by the fact that chlorite and silica sericite "pipe" alteration associated with the massive sulphide zones at the Genex Mine crosscut rocks which have been spilitized and silicified. Another important difference is that it is recognized, at least chemically, in volcanic and fine-grained intrusive rocks which were emplaced later than the known mineralization. The relative timing of silicification and spilitization is unclear; the field relationships suggest that they are penecontemporaneous and proceeded immediately following extrusion.

4.3.6 Quartz-Chlorite Pipe Alteration

Quartz-chlorite alteration represents the outermost or weakest facies of "pipe" alteration directly associated with massive sulphide mineralization.

Mafic volcanic and some synvolcanic intrusive rocks which have been affected by quartz-chlorite alteration have the following characteristics:

1. Quartz-chlorite alteration is penecontemporaneous with volcanism, as indicated by the lack of such alteration in associated synvolcanic mafic dykes and sills.
2. Extensive quartz-chlorite alteration is not stratigraphically controlled but rather follows east-trending zones of more intense hydrothermal alteration and sulphide mineralization. It does not occur in the second mafic volcanic cycle.
3. Rocks which have been affected by this alteration generally retain large scale features such as pillows

and amygdules. In thin section, this alteration is reflected by a total replacement of the groundmass constituents by chlorite (with some minor sericite; figs. 26, 64) and minor fine-grained quartz (in roughly a 60/40 proportion); the fine feldspar microlites are always replaced by fine-grained quartz so that the basaltic texture is generally preserved.

4. Near zones of stronger alteration, fracture-controlled quartz-sericite or chlorite pipe alteration always crosscuts quartz-chlorite altered mafic volcanics and not spilitic or carbonatized rocks (figs. 63, 65, 68). However spilitic alteration has been observed in a few cases grading into quartz-chlorite alteration (fig. 57; Section 4.3.2).

The distribution of quartz-chlorite alteration is shown on Figure 63. Quartz-chlorite alteration is not definable in felsic volcanic rocks in the Genex Mine area; most of these have been altered to quartz-sericite rich rocks. In a few areas, felsic volcanic rocks have been altered to quartz and chlorite almost to the exclusion of sericite (fig. 19); however, the alteration seen in these rocks is not interpreted to be as low-grade as the quartz-chlorite alteration seen in mafic volcanic rocks; rather it is associated with strong alteration and mineralization.

Sea floor basalts which have been altered to a quartz-chlorite-rich rock (which retain their original igneous textures) have been dredged from modern ocean ridges (Humphries and Thompson, 1978) and reproduced in sea water/basalt experiments (Mottl, 1983). These rocks have been shown to be the result of high temperature (above 150°C) seawater dominated conditions (ie. high water/rock ratios). Mottl (1983) interprets quartz-chlorite alteration in modern ocean-ridge basalts to be the result of high-temperature unreacted seawater-based metasomatism occurring either at deep levels within

a downwelling limb of a hydrothermal convection cell or possibly within a discharge zone of a shallow-level convection cell more likely associated with fast-spreading ridges.

Quartz-chlorite-rich alteration assemblages have been recognized in Archean pillow basalts proximal to the Amulet and Delbridge volcanogenic massive sulphide deposits near Noranda, Quebec (Gelinas et al., 1982; Gelinas and Trudel, 1983). In most cases however, where pipe alteration associated with Precambrian sulphide deposits is documented cutting mafic volcanic rocks, the outermost alteration facies (Riverin and Hodgson, 1980; Watkins, 1980; Larson, 1984) is generally sericitic and is superimposed upon rocks with a spilitic alteration assemblage. The quartz-chlorite pipe alteration observed in the Genex Mine area and possibly near the Amulet and Delbridge deposits is therefore distinct from other volcanogenic alteration systems. This alteration type is important in that it marks the boundary condition from a rock-dominated regional alteration (such as spilitization) to seawater-dominated conditions proximal to hydrothermal channelways.

4.3.7 Quartz-sericite Pipe Alteration

Quartz-sericite alteration is recognized both in mafic and felsic rocks in the Genex Mine area and appears to define two domains of alteration: an upper domain within the first mafic volcanic cycle (including the intercycle felsic unit), which is characterized by three separate narrow east-tren-

ding zones of intense "pipe" alteration associated with copper-zinc mineralization; these coalesce to form a broad, pervasive alteration zone in the underlying lower felsic formation which has been traced over 750 m west of the Genex shaft, from southwestern Aconda Lake south to Forbes Lake (fig.63).

Quartz-sericite alteration involves the progressive replacement of groundmass constituents by fine-grained quartz and sericite and is, therefore, not silica "dumping" or infilling of fractures and amygdules by quartz. This alteration is, of course, dramatic in the mafic volcanic rocks because it has the effect of bleaching-silicifying the rock); in felsic rocks, sericitization could be mistaken as a natural effect of thermal metamorphism. Quartz-sericite alteration has the following characteristics which clearly distinguish it from regional metamorphic effects:

1. it is characteristically feldspar- and igneous texture-destructive.
2. it is a progressive permeability-controlled alteration which occurs along three, narrow, east-trending zones and is associated with Cu-Zn mineralization.
3. it generally surrounds higher-intensity chlorite "pipe"-alteration zones and grades out into a larger quartz-chlorite alteration halo.

Both in the east-trending "pipe"-like zones cutting the mafic and felsic rocks and in the lower alteration zone, no feldspar megacrysts are preserved in the lower felsic unit (fig.16), the synvolcanic felsic dykes (fig.35), the mafic rocks (fig.70) or the intercycle felsic unit.

In massive mafic volcanic rocks, incipient quartz-seri-

cite alteration occurs along fractures (fracture-controlled alteration; fig. 68) now filled with fine quartz and is superimposed on quartz-chlorite alteration; progressive alteration results in wider fine-grained quartz-sericite selvages around the fractures until it totally engulfs the rock (fig. 70). Complex fracture-controlled alteration coupled with differential weathering of the more resistant quartz-sericite alteration selvages against less-resistant chlorite-quartz matrix constituents, often results in a pseudo-brecciated appearance in outcrop (fig. 66). Quartz-sericite alteration along radial and concentric cooling-cracks and in pillow hyaloclastite is also quite dramatic (fig. 67). This has been referred to as spider-web-textured alteration (Legault, 1982). Vague pillow shapes are preserved even in the most extreme cases of quartz-sericite alteration (fig. 69); strong quartz-sericite alteration around concentric zones of quartz-filled amygdules often preserves the pillow shapes under conditions of stronger chlorite "pipe" alteration.

Quartz-sericite alteration in felsic volcanic rocks involves initial feldspar destruction (distinct from potassic feldspar-sericite alteration) and the development of sericite and quartz at the expense of chlorite. This results in a quartz-sericite rich rock (fig. 15) with 70 to 80 volume% fine-grained quartz, 5 to 20% sericite and minor chlorite (up to 20 %) and accessories; figs. 11, 16, 35). In strongly altered rocks, quartz and sericite often thinly mantle complex

- Figure 64: Dominantly mafic formation, Cycle 1, 2075 N, 465 m east of BL 3W (AA-28957). Photomicrograph of relict plagioclase megacryst altered to quartz and chlorite. Matrix of quartz (40%) and chlorite (60%) with nearby quartz-chlorite-filled amygdules (quartz-chlorite alteration)(plane-polarized).
- Figure 65: Dominantly mafic formation, Cycle 1, 1685 S, 210 m east of BL 3W (AA-2835). Photomicrograph of fracture-controlled chlorite alteration (C) cutting quartz-chlorite alteration; note distinct lack of quartz in chlorite zone (crossed-polarizers).
- Figure 66: Dominantly mafic formation, Cycle 1, 1670 S, 210 m east of BL 3W. Fracture-controlled quartz-sericite alteration of massive mafic volcanic; note the E-W trend of fracture pattern (view looking east).
- Figure 67: Dominantly mafic formation, Cycle 1, 1610 S, 210 m east of BL 3W (AA-2665). Fracture-controlled quartz-sericite alteration of pillowed mafic flow; note the tendency for alteration to follow selvages and cooling cracks (view looking east).
- Figure 68: Dominantly mafic formation, Cycle 1, 1585 S, 210 m east of BL 3W (AA-2833). Photomicrograph of sericite-quartz alteration mantling fractures now filled with quartz-pyrite; superimposed on quartz-chlorite alteration (dark)(plane-polarized).
- Figure 69: Dominantly mafic formation, Cycle 1, 2410 N, 270 m east of BL 3W (AA-23619). Pervasive quartz-sericite pipe alteration of pillowed mafic volcanic. Pillows indicate east-facing (view looking east).
- Figure 70: Dominantly mafic formation, Cycle 1, 25 m south of TL 1730 S, 30 m east of BL 1200 E (AA-23625). Photomicrograph of strong quartz-sericite alteration of mafic volcanic; 95% microcrystalline quartz with 5-10% interstitial sericite (plane-polarized).
- Figure 71: Synvolcanic felsic intrusion, 2065 N, 310 m east of BL 3W (AA-23732). Photomicrograph of fracture-controlled quartz-sericite alteration (QS) cutting a quartz-sericite-chlorite felsic volcanic. Core of the fracture is chlorite (C) and opaques (plane polarized).
- Figure 72: Synvolcanic felsic intrusion, 2020 N, 285 m east of BL 3W (AA-23743). Spotted staurolite-chlorite pipe alteration near H-zone; note the chistolite-shaped staurolites and ovoid chlorite spots (possibly cordierite) in matrix of chlorite and opaques. (plane-polarized).

Figure 73: Synvolcanic felsic intrusion, 2020 N, 285 m east of BL 3W (AA-23743). Replacement of staurolite chiasolites by sericite and chlorite (plane-polarized).

Figure 74: Dominantly mafic formation, Cycle 1, 1690 S, 175 m east of BL 3W (AA-2655). Fracture controlled chlorite alteration cutting mafic flow; note the resistant rims of quartz-sericite alteration in wall rocks (view looking southwest).

Figure 75: Lower felsic formation, Cycle 1, 1590 S, 170 m east of BL 3W (AA-2659,-2660). Progressive chlorite pipe alteration cutting felsic flow. Note the presence of abraded felsic material and vague shapes of relict breccia fragments in strongly silicified and sericitized wallrock (view looking south).

the intercycle felsic unit from the underlying first cycle mafic volcanics dilates cross-stratal zones of chlorite and quartz-sericite pipe alteration which can be followed from the mafic volcanics into the intercycle felsic unit.

3. Strong chlorite alteration with associated copper and zinc rich stringer mineralization which crosscut the intercycle felsic unit near Line 1620S abruptly stops and does not continue into the overlying mafic volcanics.

Clearly this evidence with similarities in other volcanogenic massive sulphide deposits suggests that the chlorite and quartz-sericite alteration zones and associated sulphide mineralization are penecontemporaneous with volcanism or synvolcanic and not metamorphic or epigenetic as they were described previously.

4.4 PETROCHEMISTRY OF ALTERATION IN THE GENEX MINE AREA

4.4.1 Introduction

In the last section, alteration types were described and divided into two major groups, "pipe"-alteration directly related to the ore-forming process distinct from "low-grade" alteration. In addition, petrographic and immobile trace element evidence show that the eight alteration types are superimposed upon a complex assemblage of rock types each with characteristic parental chemical signatures. The petrochemistry of low-grade alteration will be discussed separately from the pipe-alteration.

4.4.2 Low-Grade Alteration

Clearly, in order to systematically address the chemical variations predicted by the petrography of the low-grade

Genex Mine area (including the pipe and lower zones) is given in Figure 63. Several features of quartz-sericite alteration are displayed, namely:

1. The east-trending nature of the pipe alteration which abruptly ends at the intercycle felsic unit (dilated from the lower mafic cycle by an unaltered synvolcanic mafic sill).
2. The alteration halo not only affects the synvolcanic felsic dykes but also envelopes mafic volcanics and synvolcanic feeder dykes surrounding them.
3. Not all the felsic dykes are affected by quartz-sericite alteration.
4. The lower felsic unit is affected by quartz-sericite alteration while the subvolcanic mafic intrusions which surround them are not significantly altered.

Quartz-sericite-rich alteration halos in felsic volcanic rocks commonly surround copper-rich sulphide stringer mineralization and associated chlorite alteration zones underlying many Precambrian volcanogenic massive sulphide deposits (Sangster, 1972; Franklin et al., 1981; Hutchinson et al., 1982). Less commonly quartz-sericite-rich alteration has been documented affecting the underlying mafic volcanics (MacGeehan et al., 1981; Knuckey et al., 1982; Knuckey and Watkins, 1982; Larson, 1984)). Andalusite is a common alteration mineral underlying the Mattabi and Sturgeon Lake deposits, northwestern Ontario (Franklin et al., 1975, 1977). Fracture-controlled quartz-sericite alteration and insitu-brecciation similar to that described in the Genex Mine area (Legault, 1982) have been documented in felsic volcanic rocks underlying the Four Corners Cu-Zn prospect in the West Noranda region of Quebec (Parry and Hutchinson, 1981); similarly the white-pillow mar-

ker unit described by MacGeehan et al. (1981) associated with the massive sulphide zones at the Norita Mine near Matagami, Quebec resembles the strongly altered pillows described in the Genex Mine area.

The lower quartz-sericite alteration zone described in the Genex Mine area is similar in many respects to the lower conformable alteration zones documented by Franklin et al. (1977) in the Sturgeon Lake area, Ontario and by Walford and Franklin (1982) in the Anderson Lake area, Manitoba, and the vertically extensive alteration zones described in the Rouyn-Noranda area, Quebec by Spence (1975) and Knuckey et al. (1982).

4.3.8 Chlorite Pipe Alteration

Chloritic alteration in the Genex Mine area is characteristically the least commonly developed alteration in the area; it is generally directly associated with copper- and zinc-rich stringer mineralization developed in the area. As will be shown below, as an alteration type, it is usually associated with peripheral quartz-sericite and chlorite-quartz alteration and is therefore distinct from the chloritization associated with thin shear zones common in the area (Section 3.4; Legault, 1982). This alteration has the following characteristics:

1. It may occur along stratiform, laterally restricted zones of high primary permeability such as flow horizons, breccias) within felsic and mafic volcanic rocks.
2. It typically occurs along irregular fractures (up to 1 m thick) in the volcanics (fracture controlled alteration)(fig.74) or as narrow cross-stratal east-trending zones (fig.75). Primary igneous textures are destroyed

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by the chlorite-rich alteration.

3. It has been identified in all of the rocks stratigraphically below and including the intercycle felsic unit. Synvolcanic mafic sills and dykes which post-date the intercycle felsic unit generally cut-off chlorite alteration and mineralization.

Fracture-controlled chlorite alteration results in destructive replacement of the groundmass constituents by chlorite (fig.72,73) and is therefore distinct from lower grade quartz-chlorite alteration (fig.65). Generally the chloritic zones have symmetrical margins of quartz-sericite alteration (fig.71) which grade into a quartz-chlorite groundmass; this results in a differential weathering pattern; ie., a negative weathering core zone with more resistant margins and a lower weathering matrix (fig.72). Fracture-controlled chlorite alteration generally grades into fracture controlled quartz-sericite alteration (for example fig. 74 was taken 10 m from fig.66). Sometimes, however, fracture-controlled chlorite alteration cuts chlorite-quartz alteration zones with apparently no intermediate quartz-sericite alteration (fig.65).

East-trending zones of cross-stratal chlorite alteration were observed in a few areas within the felsic volcanics (see Legault, 1982). These zones are generally continuous, 2 to 3 m wide, and are distinguished from mafic intrusions using several criteria:

1. The chloritic alteration at the core of these "pipes" gradually gives way outward to a zone of strong quartz-sericite alteration; the margins of the chloritic zones are the locus of strong chlorite in situ brecciation and fracture controlled alteration; these grade into strong sericitic alteration zones in the felsic rocks (fig.75).

2. The alteration zones lack igneous textures in thin section though they often contain abraded wallrock material as well as fine quartz-veinlets; the fragments within the chloritic zones often show zoning indicating strong interaction with the groundmass (fig.75).

Synvolcanic intrusive dykes on the other hand have sharp contacts, commonly show relict igneous textures and are commonly amygdaloidal. Although the dykes are often altered (fig.63) they generally reflect lower grade alteration and often cut chlorite alteration zones.

While this intense pipe alteration is called chlorite alteration, in many cases these zones show the effects of contact metamorphism from the diabase dykes (see Section 3.5) so that they often contain up to 10 % mm-sized euhedral to subhedral porphyroblasts in a matrix of chlorite. Figures 72 and 73, show staurolite porphyroblasts (some showing the effects of retrograde alteration to chlorite and sericite) along with another unidentified (cordierite?) retrograded-chlorite porphyroblast in a matrix of chlorite. Many other samples of chloritic alteration display a spotted chloritic texture suggesting retrograde metamorphic alteration of porphyroblasts.

Several features suggest that chlorite alteration (and quartz-sericite and chlorite-quartz alterations) is synvolcanic and occurred before the deposition of the second cycle of mafic volcanism, namely:

1. In several areas such as the felsic flow forming the top of the lower felsic unit near Line 1620S, thin, amygdaloidal mafic dykes, themselves strongly affected by quartz-sericite alteration cut through zones of chlorite alteration in the felsic volcanics (fig.63).

2. The extensive fine-grained mafic sill which dilates

the intercycle felsic unit from the underlying first cycle mafic volcanics dilates cross-stratal zones of chlorite and quartz-sericite pipe alteration which can be followed from the mafic volcanics into the intercycle felsic unit.

3. Strong chlorite alteration with associated copper and zinc rich stringer mineralization which crosscut the intercycle felsic unit near Line 1620S abruptly stops and does not continue into the overlying mafic volcanics.

Clearly this evidence with similarities in other volcanogenic massive sulphide deposits suggests that the chlorite and quartz-sericite alteration zones and associated sulphide mineralization are penecontemporaneous with volcanism or synvolcanic and not metamorphic or epigenetic as they were described previously.

4.4 PETROCHEMISTRY OF ALTERATION IN THE GENEX MINE AREA

4.4.1 Introduction

In the last section, alteration types were described and divided into two major groups, "pipe"-alteration directly related to the ore-forming process distinct from "low-grade" alteration. In addition, petrographic and immobile trace element evidence show that the eight alteration types are superimposed upon a complex assemblage of rock types each with characteristic parental chemical signatures. The petrochemistry of low-grade alteration will be discussed separately from the pipe-alteration.

4.4.2 Low-Grade Alteration

Clearly, in order to systematically address the chemical variations predicted by the petrography of the low-grade

alteration types, it is necessary to make some initial assumptions:

1. For low-grade alteration such as spilitization or potassium feldspar alteration, that these processes occurred under constant volume conditions.
2. Because the magnitude of the chemical transfers involved in spilitization and K-feldspar alteration is generally minor and the behaviour of individual components are assumed to be independent of the others.

The above assumptions appear to be valid in the following discussion of spilitization and potassium-feldspar alteration for at least two reasons; namely, the preservation of igneous textures suggests constant volume metasomatism, and experimental evidence in other studies as well as petrographic descriptions predict the chemical mobility in these common alteration processes and support the case for immobile elements. In addition, because the deductions of chemical transfers during spilitization and potassic-feldspar alteration describe gross chemical variations only and generally do not deal with specifics, then any minor deviation from the ideal case (constant volume) may be overlooked.

The mineralogy of the least-altered mafic volcanic rocks, as discussed in the previous section suggests that they were spilitized (Hughes, 1973). The most dramatic effect of spilitization, as shown on an alkali-variation diagram (fig. 50), is the enrichment in Na_2O at the expense of K_2O . Isotopic studies on modern and older spilitized mafic rocks (Munha and Kerrich, 1980; Muehlenbachs and Clayton, 1972), studies on K/Na partitioning in feldspar-fluid systems (Orville, 1963; Munha et al., 1981), as well experiments reac-

ting seawater with basalt (Mottl, 1983) suggest that if the hydrothermal alteration or spilitization of a mafic rock proceeds in the presence of seawater, that Na is scavenged from seawater and fixed as albite (in exchange for K and Ca) under high temperature (above 150°C), rock-dominated conditions (water/rock ratios less than 5 to 10). The Ca released is partly fixed in epidote-group minerals (Humphries and Thompson, 1978) or scavenged by the fluid (Mottl, 1983). At water/rock ratios greater than 5 to 10, Na and Ca are leached from the rock (Mottl, 1983). Another important characteristic of spilitization is Mg-enrichment which results in the development of chlorite and actinolite; complete Mg-scavenging from sea water occurs under conditions above 70 to 150°C and at water/rock ratios below 50; at higher water/rock ratios, Mg-scavenging is not as complete (Mottl, 1983).

The petrochemistry observed in spilitized mafic rocks in the Genex Mine area (ie. higher MgO, Na₂O, and lower CaO and K₂O) compared to less altered rocks in the Kamiskotia area (Section 4.2) is identical to hydrothermal basalt-seawater chemical interactions observed in modern rocks (and generally duplicated in experiments).

The concept that spilitization is part of a spectrum of hydrothermal alteration is consistent with observations made on modern and older rocks as well as experiments. Taking into account the mineralogy of altered ocean-floor basalts as well as the chemical indicators of water/rock ratios observed in high-temperature experiments (above at least 150°C), Mottl

(1983) recognized normative mineral assemblages observed in seafloor basalts (assuming constant Al_2O_3) which he correlated with increasing water/rock ratios:

1. Quartz-chlorite-albite-epidote
-actinolite	water/rock ratio: 2-32
2. Quartz-chlorite-albite-epidote	water/rock ratio: 32-39
3. Quartz-chlorite-albite	water/rock ratio: 39-55
4. Quartz-chlorite	water/rock ratio: >55

These mineral assemblages are based on the steadily increasing fixation of seawater-derived Mg in the rock at successively higher water/rock ratios (and increasing alteration) observed in the modern seafloor and reproduced in the laboratory. Balancing this high-temperature Mg-scavenging is an observed progressive decrease in Na, K and Ca (and Sr) resulting in the successive disappearance of actinolite, epidote and albite at correspondingly higher water/rock ratios. The presence of quartz is a function of quartz-saturation observed in the high-temperature fluid systems (MacGeehan, 1978; Gibson et al., 1983). Fe and Mn enrichment observed in strongly altered modern rocks and in older greenstones, though not predicted in experiments, is thought to be due to diffusion or local redistribution to form chlorite (Mottl, 1983).

The paucity of actinolite and abundance of quartz and chlorite in the spilitic alteration assemblages observed in the Genex Mine area suggest that these rocks were altered at temperatures greater than 150°C but within the greenschist stability range and water/rock ratios greater than 30. Compa-

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nable petrochemical results of Archean age alteration of basalts with modern seafloor basalts and experiments are also reported by Gelinas et al. (1982) and Gelinas and Trudel (1984) in the Rouyn-Noranda region, Quebec.

Some relatively less-altered mafic rocks associated with spilitized volcanics in the Genex Mine area contain potassic-feldspar and sericite in addition to albite-epidote-chlorite-quartz (and carbonate); data from these potassium-rich "spilitites" plot to the right of the igneous spectrum on an alkali-variation diagram (fig.50). These rocks are important as K_2O -enrichment in rocks surrounding volcanogenic massive sulphide deposits is commonly associated with feldspar-destructive pipe alteration and not the low-grade alteration observed in these rocks. Potassium enrichment associated with the formation of secondary potassium-rich zeolites, clays and hydrated glasses in modern seafloor basalts have been observed in a few cases (Andrews, 1978; Scarfe and Smith, 1977). Isotopic studies (Muelenbachs, 1977) suggest that these rocks were altered under low temperature conditions, possibly as low as $40^{\circ}C$ (Scarfe and Smith, 1977). Similarly, basalt-seawater experiments (Bloch and Bischoff, 1979) have shown that seawater-derived K is fixed in rocks at temperatures below $150^{\circ}C$. This is consistent with low temperature K-fixation in preference to Na-fixation deduced using thermodynamic criteria (Munha et al., 1979). Alternately, the potassium-enrichment observed in these rocks may be due to a superimposed alteration. However, the otherwise spilitic mineralogy displayed by these rocks and their association

with spilites in the Genex Mine area suggests that the alteration occurred at water/rock ratios below 40.

While K-rich spilites are rare in the Genex Mine area (and in the rock record; Hughes, 1973), potassium-keratophyres are the most abundant altered felsic rocks in the Genex Mine area. The most obvious result of alteration in these rocks is the development of potassium feldspar at the expense of igneous plagioclase phenocrysts as well as the replacement of glass fragments and groundmass constituents (probably after glass in massive flow-banded rocks) by potassium feldspar and sericite (as well as chlorite, biotite and carbonate). This process, is reflected in significantly higher K contents (and volatile contents) and apparent depletion in Na (and to a lesser extent Ca) while at the same time, the total alkali content remains constant compared to less altered felsic volcanic rocks. Compared with samples of least-altered felsic volcanic in the Genex Mine area, the progressive potassium-enrichment trends displayed in the Mt-Jamieson Rhyolite formation (Table 7) is apparently associated with a minor decrease in total Fe as well as Ca; density, total alkali-content, Si, Mg and immobile element contents and their ratios (Al, Zr, Ti etc.) do not significantly vary in any systematic sense (Table 7). This suggests that adularization is a largely isovolumetric, alkali-exchange process.

Low-grade hydrothermal alteration of felsic volcanic rocks involving K-enrichment has been observed in older submarine rocks as well as subaerial rocks. The most important

TABLE 7: Analyses of some Potassium Keratophyres from the Genex Mine and Kamiskotia areas

Sample#:	23767	23770	23584	23585	PG-2	PG-4	70-718
SiO ₂	80.1	75.7	80.8	78.9	73.9	69.6	76.7
Al ₂ O ₃	10.8	12.7	10.6	10.5	12.4	15.5	10.9
CaO	0.85	0.58	0.72	0.67	0.50	0.86	0.49
MgO	1.71	2.56	1.92	3.01	0.34	0.24	0.32
Na ₂ O	0.73	0.61	0.55	0.15	1.21	0.35	0.73
K ₂ O	3.78	4.03	3.78	3.31	9.17	11.1	7.19
Fe ₂ O ₃	1.78	3.39	1.90	3.16	2.13	1.95	1.60
MnO	0.03	0.03	0.03	0.03	0.06	0.05	0.26
TiO ₂	0.13	0.28	0.12	0.24	0.26	0.17	0.30
P ₂ O ₅	0.02	0.03	0.02	0.03	0.01	0.02	---
Cr ₂ O ₃	<0.01	<0.01	<0.01	<0.01	---	---	---
(L.O.I.)	2.77	2.93	2.23	2.54	---	---	---
Total	100.0	99.9	99.3	99.0	100.8	100.0	98.49
Ba	---	---	---	---	---	---	600
Cr	---	---	---	---	---	---	200
V	---	---	---	---	---	---	10
Y	---	---	---	---	---	---	300
Rb	100	140	80	100	---	---	---
Sr	<10	<10	<10	10	---	---	<10
Zr	200	400	190	340	---	---	400
Cu	12.0	7.0	13.0	10.0	---	---	---
Zn	46.0	74.0	85.0	67.0	---	---	---

Note, major elements recalculated to 100 wt% volatile-free.

AA-23767 coarse felsic fragmental volcanic, Lower Felsic Unit, south of Forbes Lake (carbonatized, potassium-keratophyre).

AA-23770 massive quartz- and weakly adularia-bearing felsic volcanic, Lower Felsic Unit, south of Forbes Lake (carbonatized, potassium-keratophyre).

AA-23584 massive felsic volcanic, Lower Felsic Unit, south of Forbes Lake (potassium-keratophyre).

AA-23585 massive felsic volcanic, Lower Felsic Unit, south of Forbes Lake (potassium-keratophyre).

PG-2 massive, quartzophytic-textured, quartz- and adularia-bearing felsic volcanic, Mt-Jamieson Rhyolite formation, Con. 4-5 boundary, lot 8, Godfrey Township (potassium-keratophyre) courtesy P. Degagne, Laurentian University.

PG-4 massive, quartz- and adularia-bearing felsic volcanic, Mt-Jamieson Rhyolite formation, Con. 4-5 boundary, lot 8, Godfrey Township (potassium-keratophyre) courtesy P. Degagne, Laurentian University.

70-718 massive rhyolite, (potassium-keratophyre) Mt-Jamieson Rhyolite formation, Con. 5, lot 8; Godfrey Township (Middleton, 1975).

chemical feature in other studies of potassic-keratophyres is the total substitution of K for Na (as well as general oxidation and depletion of some mobile elements: Mn, Zn, Pb, Cu; see Munha et al., 1979; Hughes, 1973; Battey, 1955; Scott, 1971; Thurston et al., 1978). Isotopic studies on some adularia-bearing keratophyres from the Cercal-Odemirra region of Portugal (Munha et al., 1979) suggest that the alkali-exchange reactions between the rock and a fluid (probably seawater) occurred between 90 and 130°C; this is consistent with the results of basalt-seawater experiments (Bloch and Bischoff, 1979) which show that low temperatures favour K fixation in basaltic rocks (below 150°C). Munha et al. (1979) estimated that the minimum unreacted seawater/rock ratio required to form potassic-keratophyres to be approximately 100.

The extremely high water/rock ratios invoked by the conclusions of Munha et al. (1979), as pointed out by Legault et al. (1985) contradicts in part the low-grade nature of K-feldspar alteration in the Kamiskotia area (ie. the presence of albite megacrysts and the preservation of many delicate textures in rocks with 7 wt% or more K₂O as well as the interbedded nature of keratophyres and potassium-keratophyres in the rock record (Battey, 1955). It seems more likely that the potassium-keratophyres in the Genex Mine area were hydrothermally altered under conditions of low-temperature (below 150°C) and low water/rock ratios (comparable to keratophyres and spilites) by a K-enriched fluid rather than unreacted seawater. This fluid could be a highly reacted seawater rich in K₂O from previous albitization reactions as suggested by

Bathey (1955) and Legault et al. (1985).

Carbonate alteration is a pervasive low-grade igneous-texture destructive alteration which affects most of the rocks in the Genex Mine area and results in the development of up to 30 volume % carbonate porphyroblasts. In order to determine the chemical effects of such a carbonate-metasomatism, it is important to assess whether or not the alteration occurred under conditions of constant volume, namely:

1. Constant-volume metasomatism implies a substantial removal of other elements.
2. The addition of up to 30 volume % carbonate under non-isovolumetric conditions would simply result in the dilution of the original constituents.

In Section 4.2, the practice of recalculating the analyses volatile-free for purposes of comparison in part suggested that carbonate alteration was not isovolumetric. The validity of this simple dilution assumption is shown (though not proven) by the following evidence:

1. Rocks which display progressive carbonate alteration lack primary igneous textures; in other studies, the preservation of igneous textures is the main criterion for assuming constant volume metasomatism (Gibson, 1979; MacGeehan, 1978; Riverin and Hodgson, 1980).
2. Un-adjusted chemical data from progressively carbonatized rocks displaying a common magmatic chemistry (ie, similar trace element ratios) show considerable scatter; in contrast analyses adjusted volatile-free (carbonate-free) show remarkable uniformity, (Tables 5,6; figs. 51, 52, 53). In addition, none of the components from these adjusted analyses display abnormal concentrations (except in rare cases where samples contained abundant carbonate in veins). For carbonatization to have been isovolumetric would require the proportional removal of every other component as pointed out by Costa et al. (1983), Kerrich (1983) and Finlow-Bates and Stumpfl (1981).

Carbonate (calcite, ferrodolomite, ferroan ankerite), epi-

dote (epidote-clinozoisite) and to a lesser extent actinolite are the Ca-bearing minerals in the Genex Mine area. Rocks which contain appreciable carbonate lack significant epidote; consistent with this, rocks which have been affected by feldspar-destructive pipe alteration do not contain appreciable epidote or carbonate (except in the form of minor secondary veinlets). In fact, Ca-bearing phases generally occur together only if mutually replaced (fig. 42); the stability of Ca-bearing minerals is governed by the availability of CO_2 . In some cases, rocks which have been affected by carbonate alteration contain sericite; it is unclear whether the K-enrichment is a result of the carbonatization or due to other alteration (see Section 4.3.3).

The conventional method for calculating gains and losses of elements during low-grade alteration has been to inspect analyses of unaltered/altered rock pairs thought to have a common magmatic origin. This method has been shown to be unsatisfactory in calculating mass-transfer in more intense alteration systems, particularly if there appears to be large variations in the abundances of component oxides (Gibson et al., 1983; Costa et al., 1983) for the following reasons:

1. Because the component oxides are constrained to a constant sum, no single component is independent of the others, and an infinite number of solutions exist.
2. Comparisons of bulk compositions are generally made assuming constant volume metasomatism.

In the case of silicification and volatilization associated with diabase dykes (Table 10), it is apparent that SiO_2 and volatile content vary inversely with the rest of the

components and that a simple calculation of the metasomatic effects is not possible.

In order to determine if the chemical changes are a real or apparent effect of the alteration, specific-gravity data for a suite of strongly altered rocks from the Genex Mine area has been incorporated into two-way mass-balance calculation following the method described by Gresens (1967) and Babcock (1973) (Tables 8,9). Gresens' equation for rocks can be expressed as follows:

$$X_n = a \left\{ F_v X_n^{\beta} \left(\frac{\rho^{\beta}}{\rho^{\alpha}} \right) - X_n^{\alpha} \right\}$$

where

X_n is the gain (or loss) of component n in producing the altered rock (β) from the parent rock (α).

a is the initial quantity.

F_v is the volume factor between the product/parent rock pair.

$X_n^{\alpha\beta}$ is the weight (or mole) fractions of component n in the parent (α) and altered (β) rocks.

$\rho^{\alpha}\rho^{\beta}$ are the specific gravities of the parent (α) and altered (β) rocks.

In this way, fixing either volume change (F_v) or the behaviour of one chemical component during a reaction provides a unique solution.

For any alteration reaction, volume factors may be calculated which correspond to the isochemical behaviour of individual components; rather than relying on petrographic methods for measuring volume changes which have been demonstrated to be susceptible to error, Babcock (1973), Appleyard and Wooley (1978), Costa et al. (1983) and Kerrich (1983) have used the evidence of simultaneous clustering of volume

TABLE 8: ANALYSES OF ALTERED MAFIC VOLCANICS FROM THE GENEX MINE AREA.

Sample#	2655*	2657*	2850*	23564	23618	23625	23635	23640	23650
SiO ₂	24.4	60.7	59.8	48.5	73.0	80.6	68.9	54.9	60.7
Al ₂ O ₃	19.5	13.1	11.4	12.7	11.0	9.45	13.8	13.0	13.5
CaO	0.74	0.29	5.91	5.25	0.26	0.33	1.56	5.82	0.31
MgO	11.5	4.39	3.14	7.47	4.07	0.52	3.46	3.09	8.00
Na ₂ O	<0.01	<0.01	2.38	1.89	0.08	0.25	2.33	4.13	0.08
K ₂ O	0.02	1.45	2.10	0.09	1.77	2.96	2.33	0.42	1.00
Fe ₂ O ₃	30.2	13.4	10.7	14.6	5.85	1.03	4.02	11.4	10.9
MnO	0.09	0.08	0.27	0.08	0.02	<0.01	0.04	0.22	0.04
TiO ₂	2.92	1.10	0.92	1.29	0.85	1.21	1.03	1.91	1.03
P ₂ O ₅	0.56	0.21	0.20	0.11	0.18	0.22	0.21	0.22	0.22
Cr ₂ O ₃	-	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
(L.O.I.)	8.54	4.23	2.85	7.85	3.00	1.70	2.23	3.85	4.62
Total:	98.4	99.0	99.7	99.8	100.1	98.3	100.0	99.0	100.4
Cr ₂ O ₃	70	130	130	-	-	-	-	-	-
Rb	10	20	40	<10	30	60	50	<10	20
Sr	<10	<10	50	50	<10	<10	40	130	<10
Zr	410	250	230	80	210	150	250	170	290
Y	20	50	30	-	-	-	-	-	-
Nb	<10	40	20	-	-	-	-	-	-
Cu	<0.5	33	31	5	3.5	310	22	39	3
Zn	400	250	140	57	130	>4000	74	120	260
S.G.	2.91	2.81	1.83	2.71	2.72	2.74	2.68	2.84	2.76

AA-2655: massive chlorite from Cycle 1, massive to pillowed, high-TiO₂ mafic volcanic (strong chlorite in situ breccia alteration).

AA-2657: amygdaloidal, synvolcanic, low-TiO₂ mafic dyke (quartz-chlorite alteration with progressive fracture-controlled quartz-sericite alteration).

AA-2850: pillowed, low-TiO₂ mafic from Cycle 1 (potassium-spilite).

AA-23564: massive low-Zr fine-grained mafic intrusion (carbonate alteration).

AA-23618: amygdaloidal, pillowed low-TiO₂, Cycle 1 mafic volcanic (moderate quartz-sericite alteration).

AA-23625: altered high-TiO₂, Cycle 1 mafic volcanic with sphalerite stringers (strong pervasive quartz-sericite alteration).

AA-23635: pillowed, low-TiO₂, Cycle 1 mafic volcanic (silicified and volatitized carbonate alteration).

AA-23640: massive, fine-grained, high-TiO₂ mafic intrusion within Cycle 1 (spilitized).

AA-23650: massive, fine-grained low-TiO₂ intrusion (quartz-chlorite with weak progressive quartz-sericite alteration).

TABLE 8 continued:

Sample#	23681	23725	23728	23759	23763	28957	28960	28989	
SiO ₂	42.6	28.7	72.2	55.6	58.8	59.9	60.1	66.0	-
Al ₂ O ₃	16.9	17.7	9.59	14.2	11.5	11.9	13.4	12.4	-
CaO	5.00	2.27	0.89	0.69	0.57	0.29	4.22	3.36	-
MgO	5.04	17.6	4.89	10.2	7.77	10.3	1.95	1.60	-
Na ₂ O	0.05	0.01	0.71	0.02	<0.01	0.06	2.10	5.47	-
K ₂ O	4.12	0.27	0.88	0.77	0.38	0.14	1.86	0.34	-
Fe ₂ O ₃	13.1	19.6	6.51	10.9	14.7	10.8	11.6	6.37	-
MnO	0.20	0.20	0.05	0.05	0.19	0.05	0.29	0.18	-
TiO ₂	1.30	2.58	0.80	1.78	1.61	0.94	1.76	0.96	-
P ₂ O ₅	0.21	0.20	0.58	0.48	0.37	0.18	0.49	0.21	-
Cr ₂ O ₃	<100	<100	<100	<100	<100	<100	<100	100	-
(L.O.I)	10.0	9.16	3.08	5.62	4.70	5.47	1.85	3.39	-
Total	98.6	98.3	100.2	100.3	100.6	100.1	99.7	100.3	-
Rb	80	20	20	20	0	20	50	20	-
Sr	40	0	30	10	10	0	90	90	-
Zr	350	250	190	270	190	240	220	240	-
Cu	33	27	120	140	53	120	40	24	-
Zn	230	720	1000	420	580	590	180	80	-
S.G.	2.80	2.88	2.71	2.79	2.80	2.72	2.83	2.73	-

AA-23681 amygdaloidal, pillowed, low-TiO₂, Cycle 1 mafic volcanic (strong carbonate and quartz-sericite alteration).

AA-23725 massive chlorite from pillowed, high-TiO₂, Cycle 1 mafic volcanic (volatilized superimposed carbonate alteration).

AA-23728 amygdaloidal, pillowed, high-TiO₂, Cycle 1 mafic volcanic (weak progressive quartz-sericite and abundant quartz-veinlets).

AA-23759 pillowed, high-TiO₂, Cycle 1 mafic volcanic (quartz-chlorite with weak progressive quartz-sericite).

AA-23763 pillowed, high-TiO₂, Cycle 1 mafic volcanic (quartz-sericite with weak volatilized carbonate alteration).

AA-28957 amygdaloidal, massive, low-TiO₂, Cycle 1 mafic volcanic (quartz-chlorite alteration).

AA-28960 pillowed, high-TiO₂, Cycle 2 mafic volcanic (silicified and volatilized carbonate alteration).

AA-28989 pillowed, low-TiO₂, Cycle 2 mafic volcanic (silicified and carbonatized).

TABLE 9: Analyses of altered felsic volcanic rocks from the Genex Mine area used in mass balance calculations.

Sample#	23558	23581	23598	23601	23710	23732	23743	23749	28976	28978
SiO ₂	81.0	79.2	77.5	54.1	76.6	81.8	27.8	80.7	78.9	77.3
Al ₂ O ₃	8.38	10.1	7.00	12.9	9.14	5.67	20.9	7.38	10.1	11.3
CaO	0.03	0.06	0.07	0.13	0.10	0.10	0.05	0.10	0.07	0.04
MgO	3.13	2.68	4.00	8.68	3.90	4.85	21.0	3.26	1.96	1.41
Na ₂ O	0.09	0.15	0.07	0.03	0.10	0.11	0.03	0.05	0.01	0.06
K ₂ O	1.69	2.06	0.29	0.07	1.18	0.34	0.10	0.89	3.02	3.40
Fe ₂ O ₃	3.19	3.23	8.20	16.4	5.92	3.30	17.4	5.22	3.52	4.01
MnO	0.04	0.03	0.05	0.10	0.03	0.21	0.12	0.02	0.02	0.07
TiO ₂	0.19	0.21	0.34	1.12	0.29	0.09	0.63	0.15	0.13	0.26
P ₂ O ₅	0.02	0.03	0.04	0.10	0.05	0.02	0.04	0.02	0.02	0.04
Cr ₂ O ₃	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
L.O.I.	2.16	1.93	2.54	5.47	3.00	2.70	10.2	2.62	1.93	2.31
Total	100.0	99.7	100.1	99.1	100.4	99.0	98.3	100.4	99.7	100.3
Rb	60	60	10	<10	20	<10	10	30	70	60
Sr	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Zr	310	290	210	180	300	120	890	190	240	420
Cu	3.0	4.5	43	15	6.0	19	45	20	25	24
Zn	150	86	400	630	38	32	2500	110	22	48
S.G.	2.64	2.59	2.68	2.80	1.89	2.63	2.76	2.69	2.70	2.72

AA-23558 massive felsic volcanic, lower felsic unit (quartz-sericite alteration with minor chlorite).

AA-23581 fragmental felsic volcanic, lower felsic unit (quartz-sericite alteration with minor chlorite).

AA-23598 flow-banded, weakly brecciated felsic flow lobe, lower felsic unit (quartz-sericite with progressive chlorite alteration).

AA-23601 felsic hyaloclastite breccia, lower felsic unit (chlorite alteration with quartz).

AA-23710 massive to brecciated, synvolcanic felsic intrusion (quartz-sericite alteration with minor chlorite).

AA-23732 massive to flow-banded, amygdaloidal synvolcanic felsic intrusion (progressive quartz-sericite alteration).

AA-23743 spotted staurolite-chlorite alteration in massive synvolcanic felsic intrusion.

AA-23749 massive to brecciated, synvolcanic felsic intrusion (progressive quartz-sericite alteration).

AA-28976 massive to flow-banded felsic volcanic, intercycle felsic unit (quartz-sericite alteration).

AA-28978 massive to brecciated felsic volcanic, intercycle felsic unit (quartz-sericite alteration).

factors corresponding to zero mass transfer of several possibly immobile components (Al, Zr, Ti, Y, Sc, Hf etc.) in order to provide a basis for estimating volume change of the alteration reactions. This method is based on the principle that if these elements, present in different mineral phases, maintain constant ratios to one another in a common set of rocks at all stages of alteration, then the elements may be considered to have behaved isochemically. Although some of these elements have been shown to be mobile in some volcanogenic alteration systems (Finlow-Bates and Stumpfl, 1981; Campbell et al., 1982), in the Genex Mine area, Zr, Ti and Al demonstrate remarkable covariance in the majority of mass balance reactions considered.

The effects of silicification and volatilization in mafic volcanic rocks were determined using mass balance for two cases (figs. 76, 77, Tables 8, 12). As expected, the Ti, Al and Zr show good clustering (confirming firstly, that these elements are immobile during alteration and secondly, that these rocks have different parental compositions). For example, zero-change volume factors for the immobile elements confirm that samples AA-23635 and AA-28960 are altered low- TiO_2 and high- TiO_2 mafic volcanic respectively (Table 12); the immobile element data suggest volume increases of about 10% for both rocks during alteration (figs. 76, 77). This is consistent with the tendency observed in thin section for the silicification to be expressed as quartz along fractures and as clots. The gains and losses of chemical components for one

FIGURE 76: Log zero-change volume factor histogram of major and minor elements in mafic rocks affected by silicification and volatilization adjacent to diabase dykes. F_v = average volume factor indicated by zero-change volume factors for Zr, Ti and Al; s = standard deviation; n = number of elements used to calculate F_v . The elements with volume factors below the indicated F_v are enriched relative to the least-altered samples; similarly, elements with volume factors below the indicated F_v are relatively depleted.

COMPARING AA-23637 TO AA-23635

Figure 77: Compositional change-volume factor diagram for major and minor elements, showing the effects of silicification and volatilization on mafic rocks adjacent to diabase dykes.

sample are illustrated in Figure 77. In this example, there was a net addition of Si, K and Rb and a marked depletion in Fe, Ca, Na, Zn, Sr and, to a lesser degree, Cu and Mg. However, as shown in Table 10, the behaviour of Na, K, Cu and Zn is not consistent. The increase in Si and decrease in Ca, Fe and volatiles (as well the volume increase) were predicted by the petrography of all rocks affected by this alteration.

Data for less-altered and silicified low-TiO₂ mafic volcanics from the second mafic volcanic cycle are listed in Table 11. On comparison, it is apparent that SiO₂ consistently varies inversely with Fe₂O₃ and MgO. Zero-change volume factors for Zr, Ti and Al for one example (Table 12) of a low-TiO₂ mafic volcanic from the second mafic volcanic cycle, indicate a net volume increase of 20 % during alteration. Figure 78 shows a substantial addition of Si and Na and Sr to a lesser extent as well as a net decrease in Mg, total Fe, Zn and Cu during silicification. The inverse correlation of Si with Mg and Fe (total Fe as Fe³⁺) is in part predictable by the petrography in an increase in modal quartz at the expense of chlorite; in contrast the volume increase in this case was not obvious due to the characteristic lack of igneous textures in these volcanics. The minor increases in Na and Ca as well as decreases in Zn and Cu do not appear to be consistent in all the examples (Table 11).

The chemical pattern of silicification observed in the Genex Mine area is almost identical to the metasomatic effects associated with constant volume silicification in the Noranda area by Gibson (1979), Parry and Hutchinson (1981)

TABLE 10: Gains and losses of selected major oxides during devolatilization and silicification adjacent to diabase dykes expressed as wt% gain or loss relative to least-altered sample.

AA-sample	23635/23637	23666/23667	23614/23613	28960/28960
Pair				
SiO ₂	+15.6	+3.7	+10.1	+7.90
Al ₂ O ₃	+0.70	-0.90	-0.50	-1.20
CaO	-1.31	-0.46	-1.44	-2.82
MgO	-1.66	+1.12	-0.58	-0.72
Na ₂ O	-2.64	-0.26	+0.34	-0.35
K ₂ O	+2.14	-0.21	+0.94	-0.05
Fe ₂ O ₃	-6.14	+0.43	-1.90	-2.50
MnO	-0.05	-0.02	-0.13	-0.15
TiO ₂	-0.15	-0.12	-0.10	-0.19
P ₂ O ₅	-0.02	-0.04	+0.06	+0.05
Cr ₂ O ₃	---	---	---	---
(L.O.I.)	-4.31	-2.69	-4.62	-4.62
(Total)	-0.30	-0.60	-0.20	-0.20

Note all analyses recalculated to 100 wt% volatile-free. Differences are relative to the least-altered sample.

TABLE 11: Analyses of silicified and less altered low-TiO₂ Cycle 2 mafic volcanics.

Sample#	28981	28986	28989	28982	28984
	1	2	3	4	5
SiO ₂	66.7	61.9	68.1	54.5	56.9
Al ₂ O ₃	14.0	12.7	12.8	12.0	14.6
CaO	2.93	9.01	3.47	7.19	5.67
MgO	1.41	1.96	1.65	3.66	2.99
Na ₂ O	6.47	3.73	5.64	1.88	2.25
K ₂ O	0.30	1.15	0.35	0.05	2.58
Fe ₂ O ₃	6.69	8.20	6.57	18.8	13.2
MnO	0.13	0.24	0.18	0.66	0.33
TiO ₂	1.12	0.92	0.99	0.94	1.12
P ₂ O ₅	0.24	0.22	0.21	0.25	0.24
Cr ₂ O ₃	<0.01	<0.01	0.01	<0.01	<0.01
(L.O.I.)		3.54	8.77	3.39	8.54
(Total)	99.5	100.1	100.3	100.1	100.2
Rb	<10	50	20	10	70
Sr	80	120	90	80	90
Zr	260	200	240	200	280
Cu	38	36	24	19	42
Zn	95	84	80	140	120

Note all major elements recalculated to 100% volatile-free. Samples 1 to 3 are silicified low-TiO₂ mafic volcanics, 4 and 5 are less-altered low-TiO₂ mafic volcanics from the same mafic volcanic cycle.

Figure 78: Compositional variation & volume factor diagram for major and minor elements, showing the effects of silicification of a mafic volcanic.

VOLUME FACTOR
COMPARING AA-23637 TO AA-28989

and Gibson et al. (1983). Similarly for the Matagami area, the gross chemical effects of silicification of the footwall basalts described by MacGeehan (1979) and MacGeehan and MacLean (1980a,b), though uncorrected for mass-balance effects, also resemble those from the Genex Mine area. Si was added to rocks and the interacting fluid acquired Fe and Mg from the flows. The fluid responsible for alteration must have been saturated with Si during its movement through the geothermal system; due to Si-solubility constraints as pointed out by MacGeehan (1979) and Gibson et al. (1983), silicification had to occur at pressures below 700 bars and at temperatures above 350°C. These solutions likely obtained the Si from low-temperature halmyrolysis reactions or by equilibration with glass during movement in the cooler parts of the geothermal system (Gibson et al., 1983). Although the scavenging of Fe during high-temperature hydrothermal alteration has been observed in modern sea floor basalts (Humphries and Thompson, 1978) and predicted experimentally (Mottl, 1983), Mg depletion observed in the silicified rocks is not as readily explained in terms of known seawater-basalt interactions.

4.4.3 Petrochemistry of Pipe Alteration in the Genex Mine Area

Defining chemical alteration trends related to pipe alteration in the Genex Mine area is difficult due to the following reasons:

1. Pipe alteration cuts four rock types, each with its own trace element signature.

2. Samples chosen as least-altered parent rocks for the major rock groups, display some evidence of alteration.

Samples of altered mafic volcanics and synvolcanic dykes were compared and zero-change volume factors calculated against both high-TiO₂ and low-TiO₂ least-altered mafic volcanics (AA-23635, AA-23683, AA-23790; Tables 8, 12). The lack of unaltered synvolcanic felsic intrusions was alleviated by choosing two parent rocks (AA-28962, AA-28965) from the inter-cycle felsic unit (Tables 9, 13).

Absolute abundances for major element oxides and selected trace elements for some altered samples from the Genex Mine area are given in Table 8. Zero-change volume factor histograms for the three pipe alteration facies are plotted separately on a logarithmic scale (figs. 79, 81, 83, 84).

It is important to point out that the least-altered mafic volcanics are spilites and weakly silicified and as such are characterized by high Na₂O and SiO₂ contents and are depleted in Al₂O₃ and the remaining alkali, alkaline earth elements as well as Cu, Zn, Rb and Sr relative to average Archean tholeiites. Similarly in the least-altered felsic rocks, whereas total Fe and MgO are significantly more abundant and SiO₂, K₂O and CaO slightly high, Na₂O, Sr, Rb, Cu and Zn are markedly depleted relative to Archean tholeiitic rhyolites.

The frequently made assumption of constant volume hydrothermal alteration associated with metal deposits has been disproved by many recent Gresens/Babcock-type chemical mass balance studies of complex alteration systems (Appleyard and

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TABLE 12: Indicated volume factors for the isochemical behaviour of specified elements involved in the transformation of least-altered low-TiO₂ mafic volcanics (AA-23637) and high-TiO₂ mafic volcanics (AA-23683, AA-23790) to hydrothermally altered products in the Genex Mine area.

Sample#	Indicated Volume Factor									Fv Used
	AA-23637			AA-23683			AA-23790			
	Ti	Al	Zr	Ti	Al	Zr	Ti	Al	Zr	

Quartz-Chlorite Alteration										
AA-23759	1.01	0.62	1.06	1.30	1.05	0.86	1.01	0.95	0.88	1.01
AA-23763	0.68	1.24	1.50	1.43	1.29	1.22	1.11	1.16	1.24	1.24
AA-28957	1.17	1.20	1.19	2.45	1.25	0.97	1.91	1.13	0.99	1.19
Quartz-Sericite Alteration										
AA-2657	1.00	1.08	1.14	2.09	1.13	0.93	1.63	1.02	0.94	1.07
AA-23618	1.33	1.33	1.40	2.79	1.39	1.14	2.17	1.25	1.16	1.37
AA-23625	0.93	1.54	1.94	1.95	1.61	1.58	1.52	1.45	1.61	1.62
AA-23650	1.08	1.07	1.00	2.27	1.12	0.81	1.77	1.01	0.83	1.05
AA-23728	1.42	1.53	1.55	2.98	1.61	1.26	2.32	1.44	1.29	1.50
Chlorite										
AA-2655	0.36	0.70	0.67	0.76	0.74	0.55	0.59	0.66	0.56	0.64
AA-23725	0.41	0.78	1.10	0.87	0.82	0.90	0.67	0.73	0.92	0.82

Silicification										
AA-28989	1.17	1.18	1.21	2.46	1.23	0.94	1.92	1.10	1.01	1.18
Silicification and Volatilization around diabase dykes										
AA-23635	1.12	1.08	1.19	2.34	1.13	0.97	1.82	1.01	0.99	1.13
AA-28960	0.62	1.05	1.28	1.29	1.10	1.04	1.01	0.99	1.06	1.08

Figure 79: Log zero-change volume factor histogram of major and minor elements in mafic rocks affected by quartz-chlorite pipe alteration. F_v = average volume factor indicated by zero-change volume factors for Zr, Ti and Al; S = standard deviation; n = number of elements used to calculate F_v .

Figure 79: Log zero-change volume factor histogram of major and minor elements in mafic rocks affected by quartz-chlorite pipe alteration. F_v = average volume factor indicated by zero-change volume factors for Zr, Ti and Al; S = standard deviation; n = number of elements used to calculate F_v .

COMPARING AA-23637 TO AA-23759

Figure 80: Compositional variation - volume factor diagram for major and minor elements, showing the effects of quartz-chlorite alteration of a mafic volcanic.

canics results in massive additions of Mg, Si, Zn as well as Cu, and in a large reduction in Na, Ca, Sr and Rb. K and Fe are increased slightly while P, Mn and Cr show no identifiable changes either way. The mass movement trends are shown on Figure 80. The chemical transfers observed describe exactly the physical effects of quartz-chlorite pipe alteration predicted by the petrography; for example, the replacement of groundmass feldspars by quartz is reflected in the massive depletion of alkalis as well as Sr and Rb and an increase in Si; in addition the presence of ubiquitous chlorite and the lack of actinolite or epidote describes alkali depletion and concomitant increases in Mg and Fe.

Figure 81 illustrates progressive quartz-sericite alteration observed in the mafic volcanic rocks; AA-2657 is a synvolcanic mafic dyke which shows the effects of moderate fracture-controlled quartz-sericite alteration superimposed upon quartz-chlorite alteration; AA-23625 is an example of a rock at the opposite end of the alteration spectrum and has been totally replaced by sericite and quartz. Obvious alteration patterns are pronounced Si, K, Cu and Zn enrichment, and massive depletion in Na and Ca, with concomitant increases in volume up to 60 % (fig.81, Table 12). The pattern of alteration is also from initial, weak Fe and Mg enrichment to strong Fe and Mg depletion under the strongest conditions of quartz-sericite alteration; the effects of quartz-sericite alteration are illustrated in Figure 82. Again the remarkably stable, coherent behaviour of Al, Zr and Ti during alteration confirms their immobile nature as well as the high-low-TiO₂

Log of Zero-change Volume Factors

Figure 81: Log zero-change - volume factor histogram of minor and major elements in mafic rocks affected by quartz-sericite pipe alteration. F_v = average volume factor indicated by zero-change volume factors for Zr, Zr, Ti and Al; s = standard deviation; n = number of elements used to calculate F_v .

Figure 82: Compositional variation - volume factor diagram for major and minor elements, showing the effects of quartz-sericite alteration of a mafic volcanic.

division (Table 12).

The chemical pattern of alteration is compatible with the reactions observed in thin section: quartz-sericite alteration is generally fracture-controlled consistent with the volume increases predicted by the trace element data; quartz-sericite alteration is superimposed on quartz-chlorite alteration, is associated with Zn and Cu sulphide mineralization and is feldspar- and igneous texture-destructive (characterized by Na, Ca, Sr, Rb, Mg and Fe depletion and by Si, K, Cu and Zn enrichment).

The chemical pattern of alteration displayed by the felsic intrusions directly associated with the Cu-Zn mineralization is generally the same as the character of the lower felsic unit 500 to 600 m from mineralization (fig.83). The salient features of quartz-sericite alteration are the near-quantitative losses in Na, Ca, Sr and to a lesser extent Rb, and consistently higher Si relative to the least-altered felsic rocks (Table 9); this is similar to the patterns observed in quartz-chlorite and quartz-sericite altered mafic rocks and is attributable to feldspar destruction and the precipitation of quartz which are quite evident in these rocks. Cu and Zn do not show consistent depletions or enrichments in quartz-sericite altered rocks relative to the least-altered felsic volcanics. The effects of quartz-sericite alteration in the lower felsic unit is illustrated in Figure 85.

A notable difference in the pattern of quartz-sericite

TABLE 13: Volume factors for the isochemical behaviour of specified elements involved in the transformation of least-altered intercycle felsic unit (AA-28962, AA-28965) to hydrothermally altered products in the lower felsic formation, synvolcanic intrusion and intercycle felsic unit in the Genex Mine Area.

Sample#	Volume Factors						Volume Factor used
	AA-28962			AA-28965			
	Ti	Al	Zr	Ti	Al	Zr	
Quartz-Sericite Alteration							
AA-23558	1.57	1.48	1.10	1.39	1.43	1.35	1.38
AA-23581	1.45	1.25	1.20	1.29	1.21	1.47	1.31
AA-23598	.866 ¹	1.74	1.59	.768 ¹	1.69	1.96	1.75
AA-23710	1.44	1.89	1.58	1.28	1.84	1.95	1.64
AA-23732	3.33	2.19	2.84	2.95	2.13	3.49	2.77
AA-23749	1.95	1.64	1.76	1.73	1.60	2.16	1.80
AA-28976	2.25 ²	1.20	1.39	1.99 ²	1.16	1.70	1.36
AA-28978	1.12	1.06	0.786	.989	1.03	.965	0.986

Chlorite Alteration							
AA-23743	0.464	0.566	0.365	0.402	0.550	0.449	0.459
AA-23601	0.252	0.904	1.78	0.223	0.879	2.19	0.747 ³

¹The volume factor for Ti is systematically lower than the mean of the volume factors for Al and Zr, signifying either addition of Ti relative to the other elements or a spurious comparison

²The volume factor to Ti is higher than the mean of the volume factors for Al and Zr, signifying depletion of Ti relative to the other elements.

³The lack of clustering of zero-change volume factors suggests either spurious comparison or mobility of the elements.

FIGURE 83B:

Log of Zero-change Volume Factors

Figure 84: Log zero-change volume factor histogram of major and minor elements for mafic and felsic rocks affected by chlorite pipe alteration. F_v = average volume factor indicated by zero-change volume factors for Zr, Ti and Al; S = standard deviation; n = number of elements used to calculate F_v .

Figure 85: Compositional variation - volume factor diagram for major and minor elements, showing the effects of progressive quartz-sericite alteration of felsic rocks within the lower felsic formation.

COMPARING AA-28962 TO AA-28976

Figure 86: Compositional change - volume factor diagrams for major and minor elements, showing the effects of intense quartz-sericite alteration of felsic volcanics.

alteration for these felsic rocks is that K is generally lower and Fe and Mg consistently higher than in the least-altered felsic rocks (fig.85). This can be attributed to the unusually high K abundance displayed by the least-altered rocks and by the fact that chlorite is generally always present. Only in two samples which display the strongest sericite alteration (AA-28976, AA-28978) does the K abundance register a gain and Fe and Mg exhibit moderate depletions (figs.83,86). Quartz-sericite pipe alteration can therefore be distinguished from low-grade potassic-feldspar alteration on the basis of strong Ca, Na, Sr and Rb depletion, moderate Fe and Mg depletion, lower total alkali content (less than about 3 wt%) and higher Si content; felsic volcanics affected by potassium feldspar alteration have consistently higher total alkali contents (>5%) and average Mg, Fe and Si contents.

Most important is the relatively stable coherent behaviour of Ti, Al and Zr during alteration. The zero-change volume factors which the element abundances and densities describe with minor scatter, indicate that, relative to the two least-altered samples of intercycle felsic unit, these rocks have a tendency for volume increases (up to 80%) during alteration (fig.83, Table 13). This is consistent with the features observed in outcrop and in thin section; for example total lack of igneous textures, the abundance of quartz veinlets and open space filling textures and the occurrence of quartz-sericite alteration occur along fractures. Such volume increases are similar to those reported from the

TABLE 14: Summary of alteration trends in the Genex Mine area.

Alteration	Rock Type	Gains	Losses	Fv
Potassic-Feldspar	Fels	K	Na, Ca	1.0
Carbonate	Maf/Fels	CO ₂		>1.0
Silicification and Volatilization	Maf/Fels	Si, Rb,	CO ₂ Fe, Ca	1.1
Silicification	Maf	Si (Na)	Fe, Mg	1.20
Quartz-chlorite	Maf	Si, Mg, Fe, Cu, Zn	Sr, Rb, Ca, Na	1.00
Quartz-sericite	Maf/Fels	Si, K, Cu, Zn	Ca, Na, Fe, Mg, Sr, Rb	>1.20
Chlorite	Maf/Fels	Mg, Fe, Cu, Zn	Ca, Na, Si, K Sr, Rb	<0.60

 maf=mafic volcanic, fels=felsic volcanic, Fv=volume factor
 indicated by immobile element clustering.
 Note, only major trends are indicated.

Figure 87: Compositional change - volume factor diagrams for major and minor elements, showing the effects of chlorite alteration of mafic volcanics.

COMPARING AA-23683 TO AA-2655

COMPARING AA-28962 TO AA-23743

figure 88: Compositional change - volume factor diagrams for major and minor elements, showing the effects of chlorite alteration of a felsic intrusion.

Na, Ca, Sr and Rb and to a lesser degree K (representing feldspar-epidote-actinolite destruction). Localized zero-change of Ca in sample AA-23725 may corresponds to minor carbonate contamination associated with a nearby fine-grained mafic sill and abundant faults in the area. The increase in Si in the chloritic alteration represented by AA-23601, an altered felsic breccia (fig.15) contrasts with the Si-depletion trend reflected by all the other examples of chloritic pipe alteration in felsic and mafic rocks. This suggests formation under slightly different conditions; AA-23601 is from the lower felsic formation, 300 m stratigraphically below the H- and A-zone stringer-sulphide ore zones (see below) whereas AA-23743, AA-23725 and AA-2655 are immediately adjacent to mineralization.

From inspection of the data, Zr, Al and Ti in most cases show stable coherent behaviour during chlorite alteration (Tables 12,13). However, sample AA-23601 shows strong scatter in the zero-change volume factors for all three immobile elements; this suggests that there may have been a spurious comparison or that these elements were mobile. The immobile element data for the other samples of chlorite alteration show remarkable clustering and indicate major volume decreases (up to 60%) during chlorite pipe alteration reactions; more importantly, the primary trace element signature of mafic and felsic volcanics is retained. Similar decreases in volume accompanying chlorite pipe alteration have been described by Costa et al. (1983) in the Matagami region of Quebec. Intense chlorite pipe alteration is there-

stability field is reached during lower conformable high-temperature alteration. At constant high temperatures within the core of the vent zone, the production of chlorite consumes Mg and causes a pH drop until the stability field of sericite is reached. Riverin and Hodgson (1980) and Watkins (1980) showed that the stability field of sericite could also be reached by a decrease in temperature.

A schematic alteration model has been developed based on the distribution and stability of phases identified within the alteration pipe. A Si-, Fe-, metal-rich and Mg-poor evolved fluid within a rapidly rising hydrothermal plume mixes with relatively unreacted seawater and reacts with the footwall rocks to produce chlorite. Eventually the central part of the pipe becomes an Mg-Fe-rich chlorite core. As chlorite is produced, the fluid composition changes such that sericite becomes stable and the fluid streaming upward and reacting along the margins of the core zone reacts with the rocks to form sericite. Similarly, rapid cooling of the fluid near the seawater interface also has the effect of producing sericite zones. As the core become totally altered to chlorite, fresh fluids flowing upward through this lower region no longer have a tendency to shift to sericite stability; consequently the upper sericitic parts of the pipe are progressively replaced by chlorite.

Precipitation of sericite, **chlorite** and quartz along subvertically oriented fracture networks (fig.63) suggest significant cooling of a fluid plume. As pointed out by Watkins (1980) and Franklin et al. (1981), the presence of

system, silica saturation is attained and may be enhanced by the fact that the footwall rocks in the area are glass- and Si-rich felsic flows and that Si content of fluids is greater in contact with glass than in equilibrium with quartz (Gibson et al., 1983).

Although high-temperature seawater-rock interactions have been shown to enrich percolating fluids in metals (Mottl, 1983; MacGeehan, 1979), to form an average ore-grade sulphide deposit by leaching ppm level Zn and Cu would require a very large and efficient geothermal cell. However, the low-grade interactions described above would result in a metal-rich fluid significantly depleted in Mg and rich in Fe and Si as observed in most modern geothermal systems (Mottl, 1983; Edmond et al., 1979). The special situation suggested by the coincidence of Mg-Fe-Cu-Zn enrichment observed in many Archean sulphide deposits, could be the result of at least three possible mechanisms:

1. Mixing of a deeply circulated, evolved fluid (rich in Cu, Zn and Fe and depleted in Mg and S) with relatively unreacted seawater (containing Mg and S). The mixing could occur at the confluence of a shallow circulation regime carrying fresh seawater and an upwelling evolved fluid channel (Costa et al., 1983).
2. Supply of Mg from seawater above the vent; mixing occurring during downward recycling of seawater and discharging hydrothermal fluids (Costa et al., 1983).
3. The supply of Mg, Fe, Zn and Cu to the fluid by silicification of the footwall rocks observed in some fossil geothermal systems surrounding volcanogenic sulphide deposits (MacGeehan, 1979; Gibson et al., 1983).

Despite the presence of silicification in the Genex Mine area, because the footwall strata are dominantly felsic, the latter alternative seems less likely to have dominated the

TABLE 14: Summary of alteration trends in the Genex Mine area.

Alteration	Rock Type	Gains	Losses	Fv
Potassic-Feldspar	Fels	K	Na, Ca	1.0
Carbonate	Maf/Fels	CO ₂		>1.0
Silicification and Volatilization	Maf/Fels	Si, Rb,	CO ₂ Fe, Ca	1.1
Silicification	Maf	Si (Na)	Fe, Mg	1.20
Quartz-chlorite	Maf	Si, Mg, Fe, Cu, Zn	Sr, Rb, Ca, Na	1.00
Quartz-sericite	Maf/Fels	Si, K, Cu, Zn	Ca, Na, Fe, Mg, Sr, Rb	>1.20
Chlorite	Maf/Fels	Mg, Fe, Cu, Zn	Ca, Na, Si, K Sr, Rb	<0.60

 maf=mafic volcanic, fels=felsic volcanic, Fv=volume factor
 indicated by immobile element clustering.
 Note, only major trends are indicated.

system. The first alternative seems to provide the choice model given the high water/rock ratio background alteration present in the Genex Mine strata.

It is evident, from the points described above, that quartz-chlorite alteration in the Genex Mine area may have formed by fluids and fluid regimes different from those which resulted in higher grade quartz-sericite and chlorite pipe alteration directly associated with Cu-Zn mineralization in the Genex Mine area. Quartz-chlorite pipe alteration is interpreted to have been the result of basalt interactions with relatively unreacted superheated seawater being drawn rapidly from medial regions and discharged via active fracture-rich volcanic vent zones. The model presented below requires two different stages of pipe alteration in the Genex Mine area whereby chlorite and quartz-sericite alteration were the result of rapidly rising fluids streaming through vent-zone rocks previously affected by quartz-chlorite alteration; this would explain the observed pattern of pipe alteration in the Genex Mine area (ie. fracture-controlled chlorite and quartz-sericite always superimposed upon pervasive quartz-chlorite alteration and Cu-Zn mineralization not directly associated with quartz-chlorite alteration).

Riverin and Hodgson (1980), Watkins (1980) and Larson (1984), using thermodynamic data and component activities for the system $MgO + K_2O + Al_2O_3 + SiO_2 + H_2O$, were able to model chlorite and sericite alteration facies relations. According to Larson (1984), and predicted by Mottl (1983) the chlorite

stability field is reached during lower conformable high-temperature alteration. At constant high temperatures within the core of the vent zone, the production of chlorite consumes Mg and causes a pH drop until the stability field of sericite is reached. Riverin and Hodgson (1980) and Watkins (1980) showed that the stability field of sericite could also be reached by a decrease in temperature.

A schematic alteration model has been developed based on the distribution and stability of phases identified within the alteration pipe. A Si-, Fe-, metal-rich and Mg-poor evolved fluid within a rapidly rising hydrothermal plume mixes with relatively unreacted seawater and reacts with the footwall rocks to produce chlorite. Eventually the central part of the pipe becomes an Mg-Fe-rich chlorite core. As chlorite is produced, the fluid composition changes such that sericite becomes stable and the fluid streaming upward and reacting along the margins of the core zone reacts with the rocks to form sericite. Similarly, rapid cooling of the fluid near the seawater interface also has the effect of producing sericite zones. As the core become totally altered to chlorite, fresh fluids flowing upward through this lower region no longer have a tendency to shift to sericite stability; consequently the upper sericitic parts of the pipe are progressively replaced by chlorite.

Precipitation of sericite, **chlorite** and quartz along subvertically oriented fracture networks (fig.63) suggest significant cooling of a fluid plume. As pointed out by Watkins (1980) and Franklin et al. (1981), the presence of

vertically extensive stringer ore zones suggests that precipitation occurred as a result of rapid heat loss and sulphide precipitation possibly due to boiling of the fluid; this boiling suggests that the environment of ore-formation in the Genex Mine area was in relatively shallow water to form the stringer zones yet deep enough so that massive sulphides could be precipitated on the ocean floor. This is consistent with the shallow conditions of extrusion postulated for the strongly amygdaloidal mafic volcanics in the Genex Mine area.

With regard to silica abundance, the overall pattern of Si enrichment peripheral to the vent zones with Si depletion in the core associated with stringer sulphide mineralization could also be accounted for by fluid boiling. Si enrichment associated with quartz-sericite alteration and chloritic alteration of felsic rocks within the lower felsic formation is the result of quartz-saturation during cooling. Boiling at shallow depths could result in separation of a volatile phase containing CO_2 which had the effect of leaving the residual hydrothermal fluid within the chloritic zone undersaturated with respect to quartz.

5.0 CONCLUSIONS-SUMMARY

The principal conclusions of this study on the geology and alteration in the Genex Mine area are as follows:

1. The area is underlain by a generally north-trending, east-facing, steeply dipping to overturned, Early Archean-age succession of felsic flows and fragmental rocks, and pillowed to massive mafic flows, with associated mafic and felsic intrusions. These rocks are cut by north-trending, steeply dipping, fine-to medium-grained, Early to Middle Precambrian hypersthene-labradorite diabase dykes.
2. The supracrustal rocks of the Genex Mine area consist of three principal stratigraphic units: (a) a lower felsic unit, made up of a complex sequence of massive felsic flows, breccias and coarse felsic fragmental rocks; (b) a middle, dominantly mafic unit at least 600 m in thickness, made up of two massive to pillowed flows separated by a thin, up to 40 m thick felsic flow; (c) the overlying Mt-Jamieson rhyolite formation.
3. Massive to brecciated synvolcanic felsic intrusions cut the first mafic volcanic cycle and likely were feeder dykes for the intercycle felsic flow. At least five petrographically and chemically distinct, medium-grained to aphanitic mafic intrusions cut the lower felsic unit and occupy most of the stratigraphic footwall to the first mafic volcanic cycle; they also occur as sills higher in the stratigraphy.
4. Synvolcanic fault zones controlled the location of lava extrusion, acted as physical barriers which impeded flow and focussed hydrothermal alteration and mineralization along

three different zones within the first mafic cycle.

5. The rocks in the Genex Mine area display regional greenschist-facies metamorphism except near the contact of thick Middle to Early Precambrian diabase dykes where upper greenschist-grade biotite-staurolite facies is developed.

6. Peripheral to areas of strong alteration, trace element data and relict igneous textures from the least-altered mafic volcanic rocks show that they are tholeiitic basalts, while the felsic rocks are quartz- and weakly feldspar-phyric tholeiitic rhyolites. In addition, two trace element-distinct types of mafic volcanics comprise the dominantly mafic formation; there are low- and high-Ti lavas and associated intrusions. Relative to the composition of average pristine tholeiitic basalts, the mafic rocks are enriched in Na, Si, Cu and Zn and depleted in K, Fe and Ca; this background alteration is probably due to low-grade sea water alteration at moderate water/rock ratios and temperatures above 150°C.

7. Compared with Archean rhyolites, the least-altered felsic rocks are enriched in Si, K, Fe and Mg and depleted in Ca and Na resulting from potassic-feldspar alteration; this alteration is preserved in areas peripheral to high-temperature, hydrothermal alteration proximal to volcanogenic massive sulphide deposits and reflects alteration below 150°C, and at low water/rock ratios by evolved seawater fluid rich in K released from previous higher temperature albitization reactions.

8. Silicification of the mafic rocks appears to be contempo-

aneous with volcanism and results in a slight volume increase as well as Fe, Mg and, to a lesser extent Ca, Cu and Zn being released into solution.

9. Cu-Zn sulphide mineralization in the Genex Mine area is directly related to three narrow, discordant zones of hydrothermal alteration within the first mafic volcanic cycle and to a lesser extent, the intercycle felsic formation.

10. The alteration zones comprise an inner chlorite zone and a marginal quartz-sericite zone. These zones grade outward into a quartz-chlorite zone and finally into relatively unaltered mafic and felsic volcanic rocks. The alteration zones coalesce to form a broad region of alteration which **may be traced** for over 700 m below the zone of hydrothermal discharge.

11. Variably altered mafic and felsic rocks adjacent to the ore zones are all characterized by consistent ratios of Ti, Al and Zr which reflect parental compositions and provide a basis for constraining volume changes which range from -40% (leaching) during chlorite alteration to >80% (dilation and precipitation) associated with quartz-sericite alteration.

12. Calculations of chemical mass balance which take into account changes in volume and specific gravity, indicate that pipe alteration **occurred** as a result of at least 3 sequential steps which culminated in a massive addition of Mg, Fe, Cu and Zn and concomitant, nearly quantitative depletion of Na, Ca, K, Si, Y, Nb, Sr and Rb.

13. Quartz-chlorite alteration is the result of high-tempera-

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textures and in the formation of ferroan dolomite porphyroblasts. It postdates the mineralization.

17. Later intrusion of diabase dykes caused silicification and volatilization of the wall rocks and promoted the development of pyroxene hornfels facies biotite, andalusite and staurolite along narrow zones adjacent to the dykes.

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APPENDIX A: GEOCHEMICAL ANALYSES

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APPENDIX A: GEOCHEMICAL ANALYSES

Geochemical analyses are presented in a data set available
upon request from:

Marc H. Legault
1619 Claymor Ave.
Ottawa, Ontario.
K2C 1T4

Dr. D.H. Watkinson
Department of Geology
Carleton University
Ottawa, Ontario.
K1S 5B6

APPENDIX B: ANALYTICAL METHODS

APPENDIX B

All the geochemical analyses were performed by:

X-Ray Assay Laboratories Limited
1885 Leslie Street
Don Mills, Ontario
M3B 3J4

Major element oxides (SiO_2 , Al_2O_3 , CaO , MgO , Na_2O , K_2O , Fe_2O_3 , MnO , TiO_2 , P_2O_5 and Cr_2O_3) together with Zr, Y, Nb, Sr, Rb, and Cr were analyzed using standard wavelength dispersive x-ray fluorescence spectrometry on a Phillips PW1600 simultaneous x-ray spectrometer. Ni, Co, Pb, Ag, Cu and Zn were analyzed using argon plasma emission spectrometry. Au determinations were made using a combination of the classical lead fire assay procedure with plasma emission spectrometry.

A set of data tables on XRF instrument precision, stability and reproducibility can be supplied by X-Ray Assay Ltd. on request. Roughly 5 sample batches were sent for analysis over a period of two years (1981-83); an internal system of duplicates and standards was therefore introduced into the sample population in order to check reproducibility between and within batch populations sent for analyses and to determine a reference level of expected variance for individual elements in any given set of analyses. Simple inspection of Table B1 shows that although there is some random variability in the analyses of the internal standards, these are generally small and within the margin of error defined by X-Ray Assay Labs; the five data sets representing over 350 rock samples, within the margins of instrument error, are congru-

ent and can be considered as forming one data set.

Duplicate rock samples (which consisted of physically breaking a 1 to 2 kg-sized rock sample into two portions) inserted at a rate of one every ten to twenty, were generally included in each batch of samples sent for analyses. The results, listed in Table B2, show that some rock pairs show marked differences in composition; for example, SiO_2 may vary on average as much as 3.3 % (the arithmetic mean difference plus one standard deviation) or more; Fe_2O_3 , as much as 1.4 %; the rest of the elements on average (plus one standard deviation) show much less than 0.5 % of difference. The section above suggests that these differences are not due to analytical error but more likely because the rock samples are not homogeneous; this inhomogeneity could have been reduced substantially had the duplicates been obtained from a crushed rock powder (as was the case for the standards).

Volume measurements used in mass balance calculations were made using a Beckman 930 model air compression pycnometer (accurate to ± 0.005 ml) calibrated using steel ball reference standards; mass measurements were subsequently done on a standard fixed-beam balance to provide a density value for selected samples. Mass balance calculations were made using a Fortran IV program designed by Appleyard and de Beer (1980).

Table B1. Mean and Standard Deviations of Major Element and Selected Trace Elements Abundances for 6 High-Potassium Rhyolite Standards (AA-23690, AA-23698, AA-23699, AA-23700, AA-23705, AA-23799)

	Mean (%)	Standard Deviation (%)
SiO ₂	76.0	0.427
Al ₂ O ₃	10.92	0.041
CaO	0.73	0.026
MgO	0.31	0.051
Na ₂ O	0.80	0.048
K ₂ O	7.22	0.039
Fe ₂ O ₃	1.33	0.094
MnO	0.01	0.005
TiO ₂	0.23	0.006
Cr ₂ O ₃	0.01 (4)	0.005
L.O.I.	1.08	0.130
Zr	290 ppm	5.2
Rb	110 ppm	16.
Sr	<10 ppm	4.1
Cr	170 ppm (2)	0

APPENDIX D: PETROGRAPHIC DESCRIPTIONS

				On B. Ser. Act. Ep. All. Ch. Vol.				Texture				
AA	23611	alt. fels. intrus.	giz. ser. alt. - 10% ch. - 10%	2	5	10	75	30	10% 3mm ch. - giz. amyg.			
AA	23625	alt. fels. intrus.	giz. ser. alt. - 10% ch. - 10%	8	15	TR	78	80	10% rubile - strongly recrystallized			
AA	23635	alt. fels. intrus.	giz. ser. alt. - 10% ch. - 10%	1-2	5-7	2-3	65	20-70	2% 2-3mm giz. amyg. - 2-3% relict carb. perthite			
AA	23647	alt. fels. intrus.	giz. ser. alt. - 10% ch. - 10%	22			20	15	10	ferrous dolomite		
AA	23640	alt. fels. intrus.	giz. ser. alt. - 10% ch. - 10%	5	TR		10	30	23	10	5-7	calcite?
AA	23650	alt. fels. intrus.	giz. ser. alt. - 10% ch. - 10%	V	1-2	TR	50	40				1-2 rare iron-rich igneous textures
AA	23681	alt. fels. intrus.	giz. ser. alt. - 10% ch. - 10%	22	20		50	20	10			30% giz. carb. vein material - 50% through and analysis
AA	23683	alt. fels. intrus.	giz. ser. alt. - 10% ch. - 10%	V			20	20	5	50		average made from spl. - giz. carb.
AA	23686	alt. fels. intrus.	giz. ser. alt. - 10% ch. - 10%	5	25		10	10	20	40		5% pseudom. carb. (encl. in 10% giz. veinlets) - 10% recryst. - spherical?
AA	23687	alt. fels. intrus.	giz. ser. alt. - 10% ch. - 10%		5-7		10	22	40	710		10% pseudom. carb. (encl. in 10% giz. veinlets) - 10% recryst. - spherical?
AA	23710	alt. fels. intrus.	giz. ser. alt. - 10% ch. - 10%	2-3	13	9	15	60	25	17	30	3% giz. in matrix of Qtz - 10% pseudom. carb. (encl. in 10% giz. veinlets) - 10% recryst. - spherical?
AA	23728	alt. fels. intrus.	giz. ser. alt. - 10% ch. - 10%	1	1-2		50	50				10% pseudom. carb. (encl. in 10% giz. veinlets) - 10% recryst. - spherical?
AA	23732	alt. fels. intrus.	giz. ser. alt. - 10% ch. - 10%	V	10		75	20	30			1% giz. amyg. - 10% pseudom. carb. (encl. in 10% giz. veinlets) - 10% recryst. - spherical?
AA	23743	alt. fels. intrus.	giz. ser. alt. - 10% ch. - 10%	5-7	V			90				2% staurolite = sericite - 10% pseudom. carb. (encl. in 10% giz. veinlets) - 10% recryst. - spherical?
AA	23743	alt. fels. intrus.	giz. ser. alt. - 10% ch. - 10%	10				70				20% staurolite = sericite - 20% ch. after cordierite? - 10% pseudom. carb. (encl. in 10% giz. veinlets) - 10% recryst. - spherical?
AA	23744	alt. fels. intrus.	giz. ser. alt. - 10% ch. - 10%	5	10	15	30	45	50			10% pseudom. carb. (encl. in 10% giz. veinlets) - 10% recryst. - spherical?
AA	23745	alt. fels. intrus.	giz. ser. alt. - 10% ch. - 10%	10	12		40	60				30% pseudom. carb. (encl. in 10% giz. veinlets) - 10% recryst. - spherical?
AA	23746	alt. fels. intrus.	giz. ser. alt. - 10% ch. - 10%	12	2	12	70	25	30			10% pseudom. carb. (encl. in 10% giz. veinlets) - 10% recryst. - spherical?
AA	23749	alt. fels. intrus.	giz. ser. alt. - 10% ch. - 10%	10	12		70	30				10% pseudom. carb. (encl. in 10% giz. veinlets) - 10% recryst. - spherical?
AA	23758	alt. fels. intrus.	giz. ser. alt. - 10% ch. - 10%	V	1-2	TR	40	60				10% pseudom. carb. (encl. in 10% giz. veinlets) - 10% recryst. - spherical?
AA	23763	alt. fels. intrus.	giz. ser. alt. - 10% ch. - 10%	10	TR	TR	20	60				5% relict carb. perthite?
AA	23767	alt. fels. intrus.	giz. ser. alt. - 10% ch. - 10%	2-3	10	25	60	15	57			10% pseudom. carb. (encl. in 10% giz. veinlets) - 10% recryst. - spherical?
AA	23771	alt. fels. intrus.	giz. ser. alt. - 10% ch. - 10%	25	30	10	45	10	35			10% pseudom. carb. (encl. in 10% giz. veinlets) - 10% recryst. - spherical?
AA	23772	alt. fels. intrus.	giz. ser. alt. - 10% ch. - 10%	20	10	10	50	2	2	5		10% pseudom. carb. (encl. in 10% giz. veinlets) - 10% recryst. - spherical?

Jan

THE TOWNSHIP OF GODFREY

DISTRICT OF
COCHRANE

PORCUPINE
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NOTES

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WAS.

2

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1995: 10

7. 10

32.

slip against mass
SE shift + joint pattern E-W trend
which more developed towards
No. 100 at outcrop
No. 100 alteration

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No. 100 alteration

5

4

180f

3

lb

4

5. 1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14. 15. 16. 17. 18. 19. 20. 21. 22. 23. 24. 25. 26. 27. 28. 29. 30. 31. 32. 33. 34. 35. 36. 37. 38. 39. 40. 41. 42. 43. 44. 45. 46. 47. 48. 49. 50. 51. 52. 53. 54. 55. 56. 57. 58. 59. 60. 61. 62. 63. 64. 65. 66. 67. 68. 69. 70. 71. 72. 73. 74. 75. 76. 77. 78. 79. 80. 81. 82. 83. 84. 85. 86. 87. 88. 89. 90. 91. 92. 93. 94. 95. 96. 97. 98. 99. 100.

lp

3

225789

4423790

5

lp?

lan

lb

1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14. 15. 16. 17. 18. 19. 20. 21. 22. 23. 24. 25. 26. 27. 28. 29. 30. 31. 32. 33. 34. 35. 36. 37. 38. 39. 40. 41. 42. 43. 44. 45. 46. 47. 48. 49. 50. 51. 52. 53. 54. 55. 56. 57. 58. 59. 60. 61. 62. 63. 64. 65. 66. 67. 68. 69. 70. 71. 72. 73. 74. 75. 76. 77. 78. 79. 80. 81. 82. 83. 84. 85. 86. 87. 88. 89. 90. 91. 92. 93. 94. 95. 96. 97. 98. 99. 100.

lp?

5

lb

3

3

3

3

4 - 1m

200F

LOT

4 220F

iddle Precambrian

ASE: Fine to medium grained, sometimes weakly glomeroporphyritic (up to 5% 3 to 5mm fo

etavolcanics

C META-INTRUSION:

Massive aphanitic to very fine grained, sometimes weakly mafic porphyritic (trace to 2% 0.5 to 2mm
lots—phenocrysts).

Feldspar Porphyry: 1 to 10% 1 to 3 mm euhedral feldspar phenocrysts in a fine grained mafic to i
Dabbroic Intrusive.

IC META-INTRUSION:

Weakly quartz porphyritic (trace to 0.5 to 2mm quartz eyes) and weakly amygdaloidal. Generally b

240F

CIN
CIN

SYMBOLS AND ABBREVIATIONS

-bedding: vertical, inclined, overturned, unknown dip

-attitude of pillows: dip known, unknown

-flow contact: observed, approximate, assumed

-intraflow contact (facies change i.e. massive to pillowed): observed, approximate, assumed

-intrusive contact: observed, approximate, assumed

-fault: defined, approximate, assumed

-fault: inclined, vertical, unknown., arrows indicate relative movement

-shearing

S_2 fracture cleavage: vertical, inclined, unknown dip

- S_1 schistosity: vertical, inclined, unknown dip

-flow banding.

-breccia

-glacial striae (ice flow direction) known, unknown

-outcrop outline and actual exposure

-cliff edge

in feldspar glomerocrysts).

to 2mm long subhedral mafic

c to intermediate matrix.

ally brecciated and flow banded.

250F

CLSP

p

-massive

mas

-disseminated

dissem

-stringers

strgs

-veinlets

vnls

-quartz

qtz

-carbonate (ankerite, dolomite, calcite)

carb (ank, dol, calc)

-chlorite

chl

-actinolite

act

-epidote

ep

ned

ite

n dip

ALTERATION

-weak -moderate -strong

wk, mod, st

-pervasive

○, perv

-fracture controlled

⊖, fract. cont.

-insitu-brecciation

⊖, insitu. bre.

-chlorite

●

-silica-sericite

○, sil - ser

260F

KEY MAP

SCALE 1" = 8 miles

LOT 1

LOT 10

with carb... nature controlled sericite alteration

3

FELSIC

270F

Wea

2

FELSIC

Mass

up to

f: Fragr

quart

b: Brecc

t: triffa

1

MAFIC

m: Massi

p: Pillow

amyg

a m: Massi

b, h b: Pillow

META-INTRUSION:

quartz porphyritic (trace to 0.5 to 2mm quartz eyes) and weakly amygdaloidal. Generally brecciated

METAVOLCANIC:

to weakly autobrecciated, generally weakly quartz porphyritic (1 to 10% 0.5 to 2mm quartz eyes) and
% mm-sized chloritic vitric fragments.

tal Felsic Volcanic (possibly autobreccia): ash to block size generally unsorted and nonstratified and
hyric felsic fragments

is

METAVOLCANIC:

aphanitic to very fine grained volcanic.

volcanic (bun to mattress type, lava tubes and welded megapillows), generally moderate to strongly
oidal (up to 30% 1 to 30mm size).

amygdaloidal volcanic, up to 10% 1 to 20mm quartz/carbonate amygdules.

breccia, generally broken-pillow breccia (b) or pillow-bearing hyaloclastic (hb).

ited and flow banded.

and may contain

angular to subangular

ngly quartz/carbonate

-breccia

-glacial stride (ice flow direction) known, unknown

-outcrop outline and actual exposure

-cliff edge

-trench, pit and rock dump

-shaft

-crown legal survey pin

-swamp

-path

-road

-pipeline (abandoned)

-creek

-baseline

-grid line: line number

-buildings

-claim post

-sample location and identification number

-chalcopyrite

-pyrite

-sphalerite

-magnetite

-pyrrhotite (pyrrhotine)

290F

CLSP

BL 3W

L 2400 N

●AA 23790

cpy

py

sphal

mag

po

-fracture controlled

⊖, fract. cont.

-insitu-brecciation

⊖, insitu.bre.

-chlorite

-silica-sericite

○, sil - ser

-diamond drill hole: inclined, vertical

-diamond drill hole: geology vertically projected

△ CLSP

Ac: Aconda Mines

Al: Alameda Mines

300F30

S: Brouillan Reef Mines

G-51: Kidd Creek Mines

M: Millbren Copper Mines

Mo: Mordey Copper Mines

75: P.J. O'Neill

NW: New Walcoro Mines

60: J.P. Sheridan

61: J.P. Sheridan

KIDD CREEK MINES LTD.

GENEX MINE AREA
GODFREY TOWNSHIP

PRELIMINARY GEOLOGY

Date of Survey Summer, 83

Drawn by D E Last

Survey by Legault (Bula, Degagné)

NTS 42 - A / 5 8 12

END

22104.86

FIN