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PRECAMBRIAN GEOLOGY OF THE PENNY LAKE AREA, MARQUETTE GREENSTONE BELT, MICHIGAN

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Table of Contents

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JAMES R. SMALL and T.J. BORNHORST

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INTRODUCTION

The primary purpose of this project was to provide a geologic interpretation of the northwestern corner of the northern block of the Marquette Greenstone Belt. The fundamental data base is a geologic map showing the major rock units at a scale of 1:9000 (Plate 1). This is supplemented by descriptions of the rock units in detail, using petrographic, and whole rock geochemical data, which address specifically the existence of precious metal anomalies within the region. This project extends northward the previous mapping by Johnson et.al.(1987). Funding for this project was provided by the Michigan Geological Survey and the Department of Geological Engineering, Geology, and Geophysics at Michigan Technological University.

LOCATION

The study area is located northwest of Marquette, Michigan in Marquette County and is within the Negaunee NW and Silver Lake Basin 7.5 minute quadrangles (latitude 87° 45' and longitude 46° 40'). The area includes sections 1 and 2 of T.49 N., R.28 W., and 25, 26, 27, 34, 35, and 36 of T.50 N., R.28 W. (Fig. 1). A small portion of section 28 T.50 N. R.28 W. was mapped to complete the northwesternmost known extension of the greenstone belt.

ACCESSIBILITY AND GEOGRAPHIC FEATURES

Access to the vicinity of the study area is along County Road 510, a partially paved road off U.S. 41. Off County Road 510, access is fair to poor along the Red Road (gravel), the Triple A Road (gravel), and an unimproved logging trail south of the hairpin curve located on County Road 510 (Figure 1). Access by foot is hampered from the north by the 75 meter ravine of the Yellow Dog River and from the west by the 50 to 75 meter cliff along the Mulligan and Outlet Creeks. The geography is typical of a northern Precambrian shield area.

Drainage is poor, and swamps and small cliffs are common. Sporadic logging over several decades has left various aged stands of hardwoods and small areas of mature pines, hemlock, and hardwoods.

FIELD MAPPING

Field work was conducted during the summer of 1988 using a combination of mapping from topographic features and pace and compass methods. Topography was used to locate the position of as much outcrop as possible. In flat areas and swamps, where topographic mapping was not possible, traverse lines were used to locate outcrop. Average traverse spacing was 229 meters (750 feet).

Contacts were inferred between outcrops except where high outcrop density allowed more accurate contact location. Clusters of small outcrops were enlarged on the map in order to indicate geologic relationships, and some very large outcrops along cliffs were not entirely mapped and are left open on the map (Plate 1).

Quaternary alluvium is found throughout the area but is only shown on the map where bedrock geology cannot accurately be determined. One day was spent in reconnaissance sample collecting of granitoid rocks in various locations near the greenstone belt.

LABORATORY PROCEDURES

Thin sections were prepared of 47 samples representing all rock types located within the study area (Appendix A). Point count determinations were performed on all of the granitoid intrusive rocks within the Penny Lake Area to accurately determine their mineralogy. Mineral proportions of the remainder of the thin sections were estimated.

Whole rock chemical compositions were determined for 40 samples, representing most rock types, by X-ray fluorescence spectrometry at Michigan Technological University using a modification of the technique described by Rose et.al. (1986). Gold content was determined using fire assay methods by Nuclear Activation Services Limited of Hamilton, Ontario, Canada.

PREVIOUS WORK

Only regional geologic mapping has been completed in the project area. On a regional basis, Bodwell (1972) reviewed the mineral potential of the Northern Complex and Morgan and DeCristoforo (1980) and Bornhorst (1988) described the history of the greenstone belt. The rocks of the Penny Lake Area have not been studied in any detail before this study. To the south of the area, detailed geological mapping has been completed by Owens and Bornhorst (1985), Johnson et.al. (1987), Baxter et.al. (1987), and MacLellan and Bornhorst (1989).

PRECAMBRIAN GEOLOGIC SETTING

INTRODUCTION

The Archean Marquette Greenstone Belt has been divided into three distinct lithostratiographic blocks by Bornhorst (1988) (Figure 1). The study area is within the northern block. The southern part of this block is composed mainly of a thick sequence of pillowed basalt flows with minor interbedded breccia units and an iron formation. These units have been intruded by dikes and sill-like bodies of gabbro followed by rhyolite dikes. The

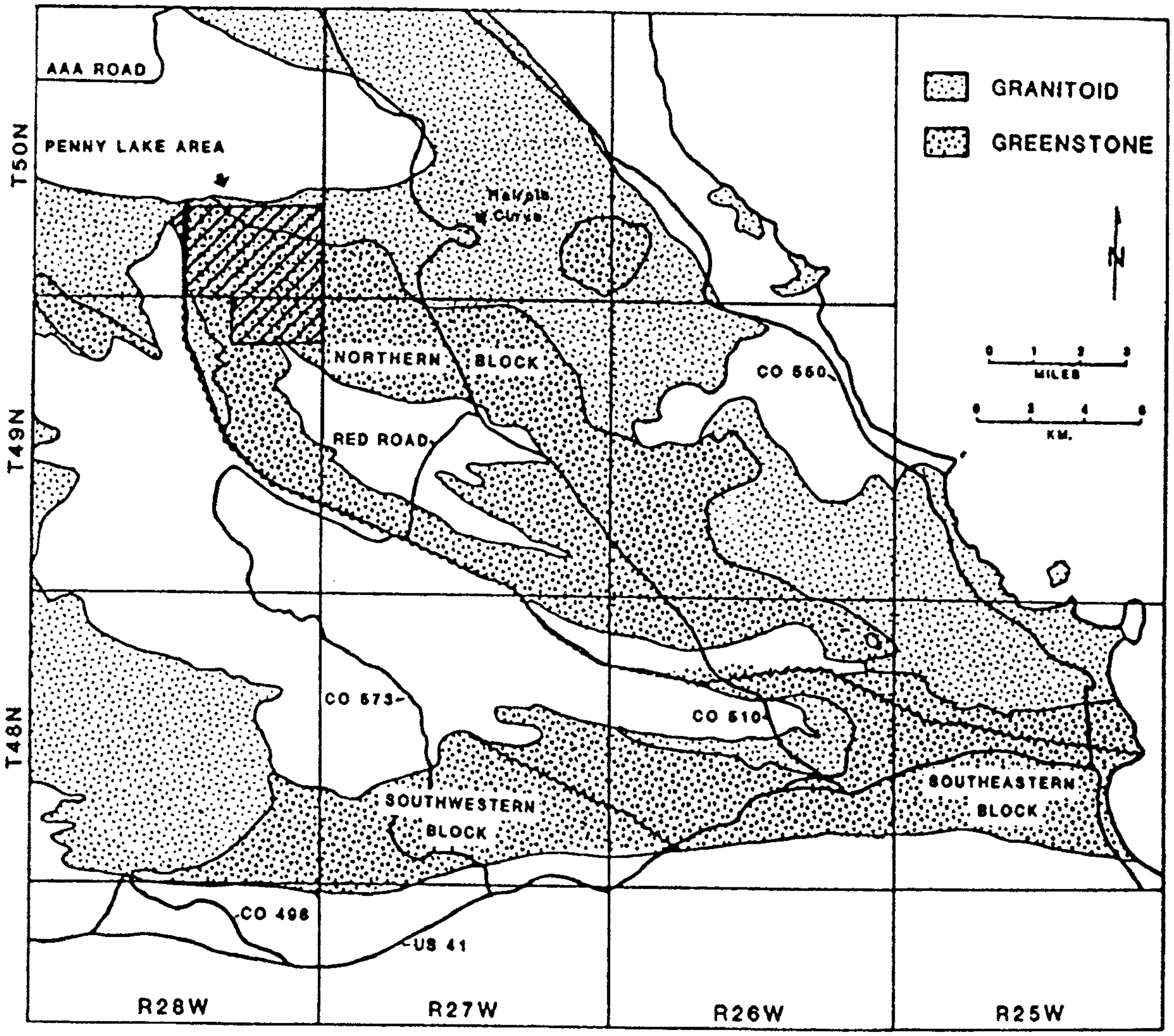

Figure 1. Lithostratigraphic blocks within the Marquette Greenstone Belt (after Bornhorst, 1988)

northern block is bounded by Archean granitoid gneisses to the west and north, and is separated from the southern blocks by early Proterozoic sediments of the Dead River Basin. Archean rocks in the center part of the northern block are covered by early Proterozoic sediments of the Clark Creek Basin.

Regional metamorphism in the greenstone belt is typically greenschist facies. The grade increases to amphibolite facies in vicinity of the contact with granitoid rocks such as the north half of the northern block. The majority of the Archean units within the Penny Lake Area have been metamorphosed to amphibolite or epidote-amphibolite grade.

STRATIGRAPHY

The Penny Lake Area is composed mainly of deformed and metamorphosed Archean volcanics and various types of intrusive rocks (Figures 2,3). Pillowed basalts with volumetrically minor interbedded sediments and iron formation (Volcanics of Silver Mine Lakes) are the oldest rocks in the area. These rocks have been intruded by dikes and sills of gabbro (Gabbro of Clark Creek) and rhyolite dikes (Rhyolite Intrusive of Fire Center Mine). In turn, the mafic rocks have been intruded by granitoid bodies (Granodiorite of Rocking Chair Lakes) and granite dikes. The gabbro may be related to the basalt and the rhyolite may be related to the granodiorite (Bornhorst 1988). The age of the gneissic plutons in the north half of the field area is difficult to determine. The gneiss may be either contemporaneous with, or older than, the Granodiorite of Rocking Chair Lakes, and both are cut by the granite dikes. The diorite plutons are less altered than the more felsic intrusives and have not been observed to be cut by any granitoid dikes or quartz veins. These may represent a minor, late stage intrusive event.

Two ages of diabase dikes cut the Archean rocks. Two types of metamorphosed middle Proterozoic dikes and Keweenawan dikes have been mapped in the Penny Lake Area.

STRUCTURE

The rocks in the Penny Lake Area were affected by several deformational events in both the Archean and lower Proterozoic. The most significant structural feature is the continuation of the large scale fold which was mapped to the south (see Figure 7). The attitude of a

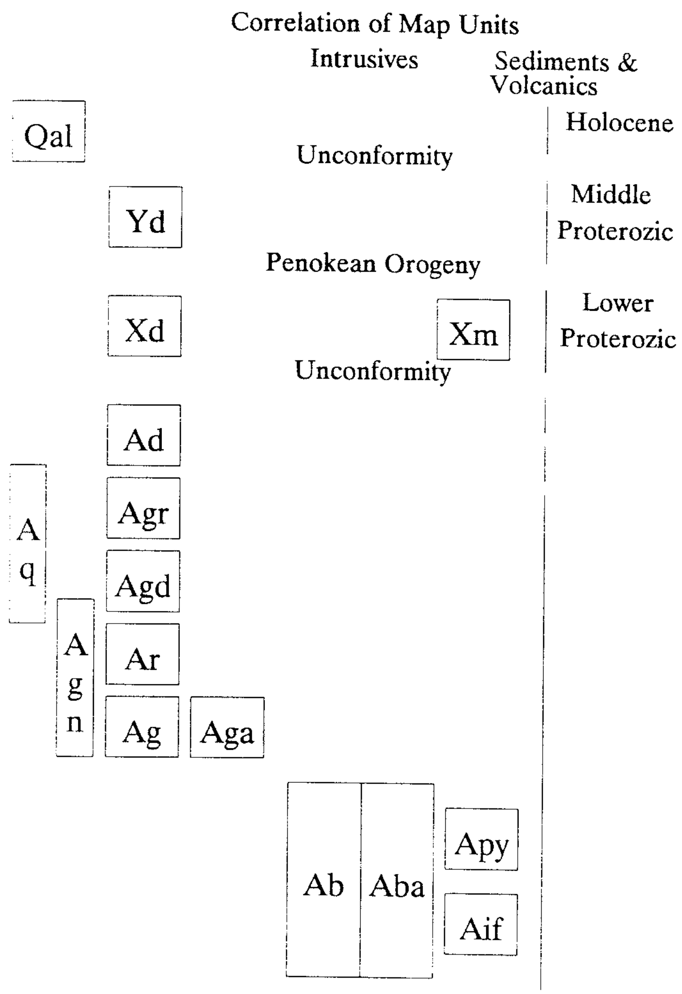

Figure 2. Correlation of map units in the Penny Lake Area

LEGEND

Qal	Quaternary Alluvium
Yd	Keweenawan Diabase
Xd	L. Proterozoic Diabase
Xm	Michigamme Formation
Aq	Quartzite Veins
Ad	Diorite
Agr	Granite
Agd	Granodiorite of Rocking Chair Lakes
Agn	Gneiss
Ar	Rhyolite Intrusive of Fire Center Mine
Ag	Gabbro of Clark Creek
Aga	Highly Altered Variety
	Volcanics of Silver Mine Lakes
Ab	Pillow Basalt Member
Aba	Highly Altered Variety
Apy	Hill's Lake Pyroclastic Member
Aif	Iron Formation Member

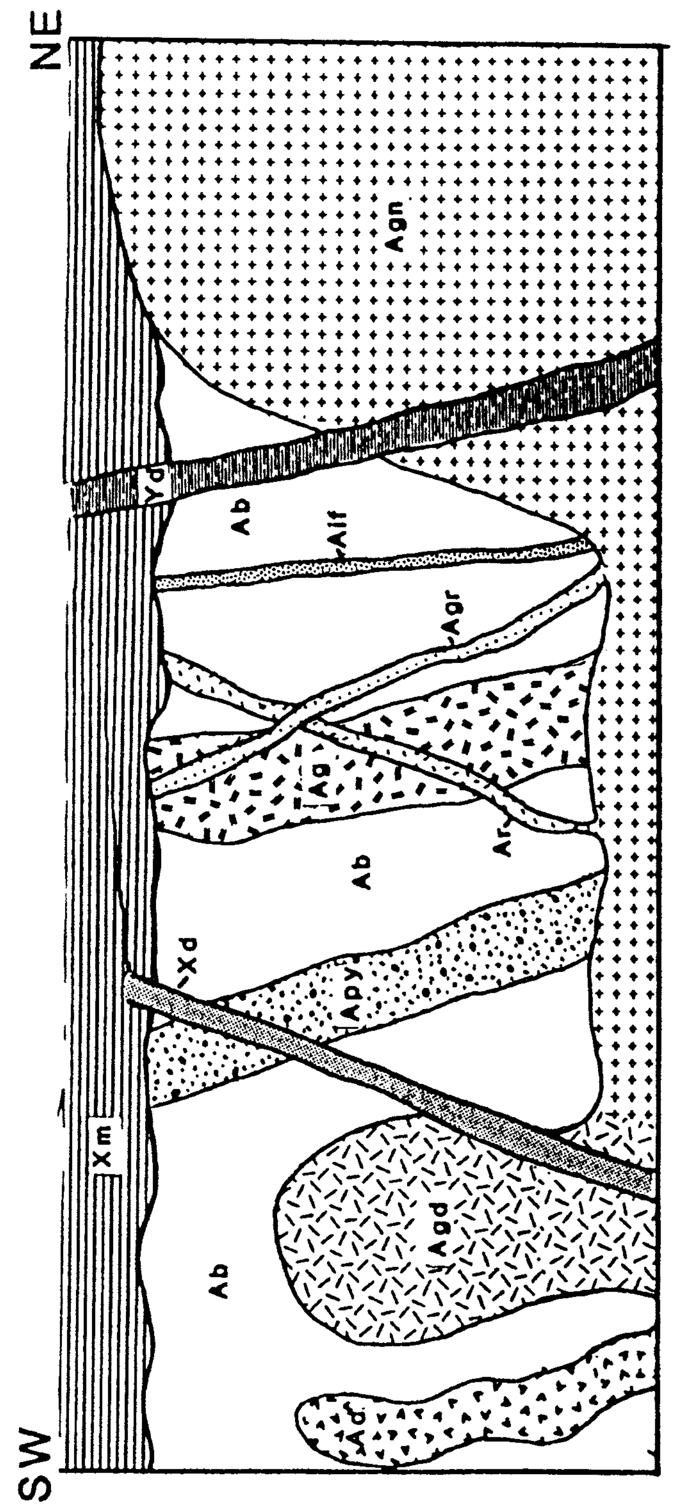

Figure 3. Stratigraphic cartoon of major rock units within the Penny Lake Area. Legend same as figure 2.

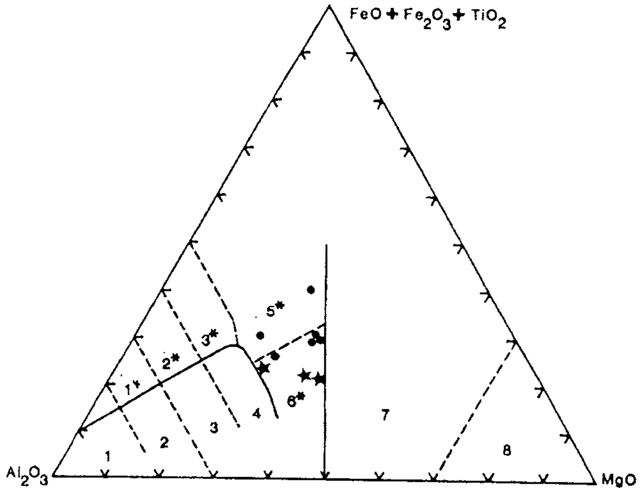

Figure 4a. Jensen cation plot for Pillowed Basalt Member. Symbols; dots - Normal Variety, stars - Highly Altered Variety. (See Figure 4b for field names).

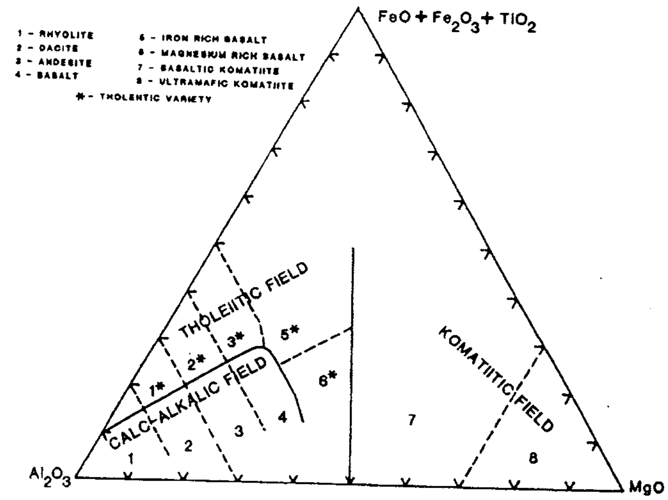

Figure 4b. Jensen cation plot with field names (Jensen and Langford 1985).

thick gabbro sill and of the Hill's Lakes Pyroclastic Member, outlined a synformal anticline immediately south of the Penny Lake Area (Johnson et.al. 1987). The strike of these units clearly reverses back towards the northeast, indicating an antiformal syncline. This is confirmed by the strike of the discontinuous Iron Formation Member which Johnson (1989) could trace via aeromagnetic data from exposures in the south under the early Proterozoic cover.

There are a large number of faults (see Figure 9) and high strain zones in the area. It is difficult to establish displacement along many high strain zones. Only the major faults are included on the map (Plate 1). As is true to the south, the Archean units are offset by older northwest- southeast faults, often containing rhyolite intrusives, and younger north-south and northeast-southwest trending faults. A large topographic lineament trends north-south along Outlet Creek and is postulated to be a fault. It may have been reactivated during the early Proterozoic, as indicated by highly altered early Proterozoic sediments along the west side of the lineament.

In the northwestern part of the area, the volcanics are ductilely deformed, and the structure of this area is very complex.

ROCK UNITS

INTRODUCTION

All rock units within the Penny Lake Area are described using field and hand sample observations, thin section descriptions, and whole rock chemical analysis. Units are named according to previous nomenclature where possible, and new units are referred to by rock type. For details on nomenclature and unit definitions, the reader is referred to Owens and Bornhorst (1985), Johnson et.al.(1987), Baxter et.al.(1987), and MacLellan and Bornhorst (1989). When large areas of highly altered rock occur within a unit, the area is designated a highly altered variety. Most units contain some altered segments, and some of these small areas of highly altered rock were too small to show on the map.

VOLCANICS OF SILVER MINE LAKES

The Volcanics of Silver Mine Lakes is the name assigned to a succession of Archean units, and is the dominant lithology which crops out in the Penny Lake Area (Plate 1). In the Penny Lake Area, this unit is subdivided into three members; the Pillowed Basalt Member, the Hill's Lakes Pyroclastic Member, and the Iron Formation Member.

The total thickness of the Volcanics of Silver Mine Lakes is estimated to be approximately 2000 meters in the Penny Lake Area. Stratigraphic tops of the volcanics could not be determined in the area due to the high degree of deformation, but are assumed to be towards the southeast within most of the area, using evidence cited by Johnson et al. (1987).

Pillowed Basalt Member

The Pillowed Basalt Member composes the majority of the Volcanics of Silver Mine Lakes, and is stratigraphically above and below the other two members. The outcrops occur as glacially polished ridges and knobs with occasional small cliffs. The member has been divided into normal and highly altered varieties.

Normal Variety

The normal variety of the Pillowed Basalt Member is composed of unfoliated to highly foliated, black to dark green basalt lava flows. The appearance of the rocks correlates with the metamorphic grade. Rocks of upper greenschist facies are often dark green, foliated, very fine grained, and occasionally contain distorted, ameoboid shaped pillow structures with no obvious vesicles. As the metamorphic grade increases to epidote-amphibolite, the basalt appears black in color with an obvious increase in grain size. On a fresh surface, fine grained, nematoblastic hornblende gives the rock a sparkling appearance. Thin, lighter colored bands, which may be distorted pillow rinds, show ptygmatic folding and give the weathered surfaces an appearance of being ductility deformed. Amphibolite facies basalt has a distinct banded appearance with up to 1 centimeter thick bands. The bands contain varying proportions of recrystallized metamorphic minerals. The presence of small, tightly folded, granite dikes indicates that the banding in the basalts is due to ductile deformation.

The mineralogy of the basalts also varies with metamorphic grade (Tables 1 and 2). Upper greenschist facies is characterized by light green, pleochroic actinolite, albite, sericite, and epidote/clinozoisite, with minor disseminated carbonate and pyrite. Epidote-amphibolite facies is characterized by blue-green pleochroic hornblende, oligoclase to labradorite plagioclase, and epidote-clinozoisite, with minor sericite, sphene, and opaques. Amphibolite facies contains light brown and green hornblende, and calcic plagioclase, with minor hypersthene, epidote/clinozoisite, and sphene.

The basalts of the Pillowed Basalt Member are magnesian to iron-rich tholeiites (Figure 4, Table 3). These compositions are very similar to the chemistry of the basalts found in the areas to the south, suggesting that the elements used in the Jensen plot are relatively unaffected by the increase in metamorphic grade.

Highly Altered Variety

The Highly Altered Variety of the Pillowed Basalt Member occurs as foliated and massive types. The foliated basalt is found in narrow, highly strained zones and is a green, chlorite-rich phyllonite. In addition to chlorite, these zones often contain thin quartz-sericite-carbonate rich layers, with minor albite and disseminated pyrite (Table 4). These foliated and altered zones are often less than two meters thick and define small shear zones or sheared contacts with contrasting rock types. Because these zones were too thin to map, none appear on Plate 1. One such unmapped altered zone is located in the center of section 35, next to the thin rhyolite body along Boise Creek.

The massive type of the Highly Altered Variety is found in sections 1, 2, and 25 of the Penny Lake Area. These scattered areas are composed of varied assemblages of chlorite, epidote/clinozoisite, sericite, carbonate, and quartz (Table 4). The altered variety is finer grained and lighter in color than the surrounding unaltered basalts.

One zone of altered basalt, in the southeast corner of section 25, was mapped in detail (Plate 1, detail A). The basalt in this area is aphanitic, weakly foliated, and contains retrograde chlorite after hornblende. Sulfides within this zone include pyrite, chalcopyrite, and sphalerite. There are numerous .5 to 5 meter thick, coarse grained, granite dikes associated with the basalt. These dikes contain large amounts of specular hematite, and this would seem to indicate that the dikes are either contemporaneous or predate the alteration and mineralization. The south side of this alteration zone is truncated by a 5 meter thick, unmineralized, quartz vein. The other boundaries of the zone are rather gradational, therefore, it seems as though the vein may have impeded fluid flow to the south, or that the vein is younger than the alteration and was emplaced along a fault which truncated the alteration zone.

Another alteration zone of note is located in the east-central part of section 2. This area is bounded on the east and south by major faults and on the west by the Hill's Lakes Pyroclastic Member. The alteration is truncated by the faults, but is gradational into the pyroclastic. The basalts are sericitized and silicified and contain a large number of thin (2-5mm) crosscutting carbonate veinlets. Sulfides are rare and consist of very fine grained disseminated pyrite and sphalerite.

Chemical analysis of the altered basalt indicates that these samples are depleted in iron and titanium relative to the normal variety (Figure 4, Table 5). This change may reflect the alteration of the amphiboles to chlorite.

Hill's Lakes Pyroclastic Member

The Hill's Lakes Pyroclastic Member is 50 to 100 meters thick and crops out in sections 2 and 35, with possible northwest extensions into sections 34 and 27. The southernmost exposures strike northeast and have a near vertical dip, but the strike changes towards the northwest, and dips 65 to 70 degrees towards the east. Dips are based on the orientation of flattened clasts in the southern exposures, and on banding within the unit in the north.

Pumiceous lapilli similar to that described by Johnson et.al.(1987) are visible in the small, rounded, and widely scattered outcrops in the southern part of the unit. Towards the north, individual lapilli are no longer distinguishable, and it appears as a highly schistose, banded volcaniclastic unit which contains a large number of garnet porphyroblasts. The lithology change could be due to a facies change within the unit, and the rocks within the Penny Lake Area might represent a more distal portion of this volcanic-sedimentary unit. Another possible reason for the change in appearance, but less favored, is that the lapilli have been more highly strained in the north, and their original shapes have been completely obliterated.

Where the rock retains its pumiceous character, the lapilli are composed of plagioclase and quartz with minor hornblende, sericite, and epidote/clinozoisite. The matrix is composed of hornblende and plagioclase with minor biotite, chlorite, epidote/clinozoisite, sericite, and garnet. The banded variety is coarser grained and contains the same minerals as both the matrix and lapilli, but is banded due to alternating quartz-rich and plagioclase-chlorite rich layers (Table 6).

The unit in the north part of section 34 is composed of plagioclase, quartz, muscovite, and chlorite in nearly equal proportions (Table 7). It is a highly schistose rock and is thought to be part of the Hill's Lakes Pyroclastic Member due to its location, thickness, and difference in composition and texture as compared to the surrounding basalts.

The northernmost exposure of the Hill's Lakes Pyroclastic Member occurs on the west side of the large hill located in the northwest corner of the Penny Lake Area (Plate 1). This rock is composed of hornblende, plagioclase, quartz, biotite, and large (5 to 7mm), poikioblastic garnets (Table 7). This exposure is quite near the contact with the intrusive gneiss and is in contact with amphibolite grade, plastically deformed basalt.

The whole rock chemical composition of the Hill's Lakes Pyroclastic Member shows a rather wide variation in many elements (Figure 5, Table 8). This is due to the variability

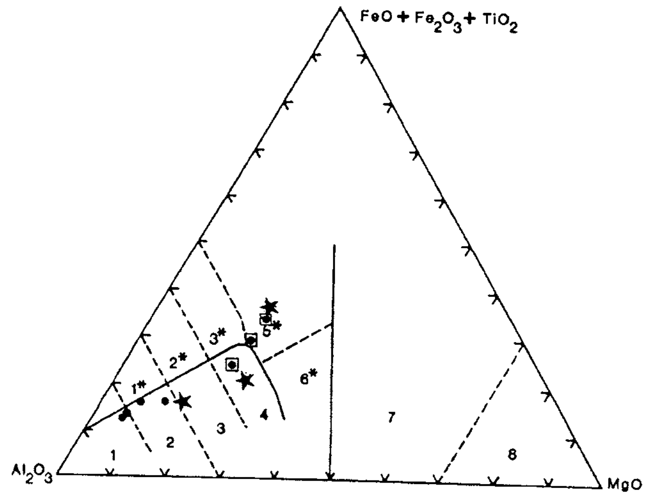

Figure 5 Jensen cation plot for Hill's Lake Pyroclastic Member. Symbols; dots - Morrissay 1987 (box - matrix, no box, clasts), stars - Penny Lake Area.

in clast to matrix ratio of the samples, and for some elements, the grade of metamorphism. In an earlier study (Morrissay, unpublished data) the pyroclastic was found to contain andesite to dacite fragments in a basaltic matrix. The two lower metamorphic grade samples of this study are classified as calc-alkalic andesite and basalt, representing a clast-rich and a matrix-rich sample. The third sample plots in the iron rich thoeliitic basalt field, possibly due to the large number of iron rich garnets located within this sample relative to the other two.

Iron Formation Member

The Iron Formation Member is located in sections 25 and 26, near the contact of the Volcanics of Silver Mine Lakes with the gneissic plutonic rocks. It is a very thin unit, with a maximum exposed thickness of three meters, and was found in only three locations (Plate 1). The unit strikes N 80 W and dips 71 degrees towards the south, based on laminations. It is located within topographic lows or on the edge of small cliffs. The mineralogy of the iron formation differs from what was observed in the southern part of the northern block by MacLellan and Bornhorst (1989) and Baxter et.al. (1987), but, based on structural evidence, the iron formation in the Penny Lake Area is believed to be stratigraphically equivalent to the unit found to the south (Johnson, 1989). The minerals, mainly magnetite and epidote, are divided into bands averaging one centimeter thick. The magnetite content is relatively constant at about 35 percent, but because of its thickness, the unit does not have as strong of a magnetic signature as it does to the south. The Iron Formation Member can be delineated, however, on an aeromagnetic map of the area. Other minerals within the bands include hornblende, chlorite, and pyrite (Table 9). Table 10 compares the chemical composition of the Iron Formation Member found within the Penny Lake Area to the composition of the unit to the south.

AGE AND ORIGIN OF THE VOLCANICS OF SILVER MINE LAKES

The Volcanics of Silver Mine Lakes is the oldest Archean unit found within the Penny Lake Area, and is believed to be about 2.7 billion years old (Bornhorst, 1988). It represents sub-aqueously deposited basalt flows with interbedded volcanic-sedimentary and iron formation horizons. The Hill's Lakes Pyroclastic Member is interpreted as a subaqueously deposited volcanic breccia which grades laterally into finer grained volcaniclastic sediments. This may represent the transition from proximal to distal facies, and would therefore indicate source volcanic vent(s) to the south. The Iron Formation Member was deposited as an exhalite during a hiatus in basalt extrusion. The more lensoidal and sporatic occurrences of the iron formation in the Penny Lake Area is consistent with a more distal position with respect to source vent(s).

GABBRO OF CLARK CREEK

The Gabbro of Clark Creek is the name used for coarse-grained mafic intrusives which crop out in the northern block of the Marquette Greenstone Belt. There are two uniformly thick (up to 300 meter) sill like, gabbroic bodies in the Penny Lake Area. The outcrops occur as small to large rounded knobs, and do not cause any change in the topography of the area. The intrusives are subparallel to the trend of bedding as indicated by the Hill's Lakes Pyroclastic and Iron Formation Members. This unit has been subdivided into normal and altered varieties based on the relative amount of alteration minerals.

Normal Variety

The normal variety is the most common and is a very dark green to black, massive, coarse-grained gabbro. The interior of the sill, located in sections 1, 36, and 35, has a felty texture and is very coarse grained, whereas at the contact with the basalts, the gabbro has a very distinctive finer grained ophitic texture and the weathered surface has an obvious spotted appearance. The gabbro consists of blue- green hornblende and plagioclase with minor amounts of sericite, epidote/clinozoisite, sphene, and opaques (Table 11). The gabbro body located in section 27 is amphibolite facies and is composed mainly of green-brown hornblende with minor plagioclase, sericite, and opaques (Table 12).

Highly Altered Variety

The Altered Variety of the Gabbro of Clark Creek has been mapped in only two locations. The gabbro was designated as an altered variety only if the rock was comprised almost completely of alteration minerals (retrograde after metamorphic minerals). One area is located within the detail section A (Plate 1). The rocks in this area are highly chloritized and are indistinguishable from the altered basalt. The contact between these two units was extrapolated to connect the two unaltered areas of the gabbroic sill. The other area of altered gabbro occurs in section 35 (Plate 1), just south of a zone of sheared gabbro along a conspicuous east-west trending ravine. The gabbro in this area is highly epidotized, but still contains a clearly ophitic texture, caused by clots of mafic minerals (Table 13).

AGE AND ORIGIN OF THE GABBRO OF CLARK CREEK

The Gabbro of Clark Creek is Archean in age; it cuts the Volcanics of Silver Mine Lakes and is cut by the Archean aged Rhyolite Intrusive of Fire Center Mine in the southern part of the Northern Block (Owens and Bornhorst, 1985). No rhyolites have been observed to cut the Gabbro of Clark Creek in the Penny Lake Area. The gabbro is truncated by gneiss in the north part of the area.

The intrusives have been interpreted to be sill-like bodies because they are subparallel to the strike of the Hill's Lakes Pyroclastic and Iron Formation Members. The gabbros cannot be very thick basalt flows, because the northern gabbro body cuts the stratified Iron Formation Member. Chemical comparisons between the gabbros and basalts have shown that the units are very similar and may be petrogenetically related to one another (Bornhorst and Baxter, 1987).

RHYOLITE INTRUSIVE OF FIRE CENTER MINE

The Rhyolite Intrusive of Fire Center Mine is the name used for rhyolite dikes which are quite common and cut the basalts in the southern part of the northern block. In the Penny Lake Area rhyolite dikes are less common. The dikes ranged in thickness from less than .5 meter to over 12 meters. Only dikes with a thickness of greater than 10 meters are shown on Plate 1. Rhyolite dikes are often located along topographic lows or along the edges of narrow ravines. Because of this, and their narrow width, they are often difficult to trace along strike.

The rhyolite varies in color on a fresh surface from a light green to light brown and often has a porphyritic texture. The phenocrysts are composed mainly of quartz with a minor amount of feldspar. The groundmass is dominated by equigranular quartz and feldspar in proportions equal to that of the phenocrysts, and contains minor amounts of carbonate, chlorite, opaques, and sericite (Table 14).

AGE AND ORIGIN OF THE RHYOLITE INTRUSIVE OF FIRE CENTER MINE

The Rhyolite Intrusive of Fire Center Mine is considered to be Archean in age. Rhyolite dikes cut the Volcanics of Silver Mine Lakes but were not observed to cut any of the granitoid intrusives in the area. In one location, a rhyolite was found to be cut by a granite dike. Bornhorst and Baxter (1987) proposed that the rhyolite dikes are contemporaneous with, and late stage differentiates of the larger granitoid intrusives. Field evidence from the Penny Lake Area does not refute this claim.

ARCHEAN PLUTONIC ROCKS

Introduction

The Archean plutonic section in the Penny Lake Area has been subdivided into four different types: Gneiss, Granodiorite of Rocking Chair Lakes, Granite (dikes), and Diorite (stocks). The Gneiss and Granodiorite of Rocking Chair Lakes are similar in composition and are divided on the basis of textural differences, the former has gneissic texture and the latter is massive. The Granite and Diorite are distinct in composition and form relatively small intrusive bodies. Chemical analyses of the plutonic rocks are listed in Table 15.

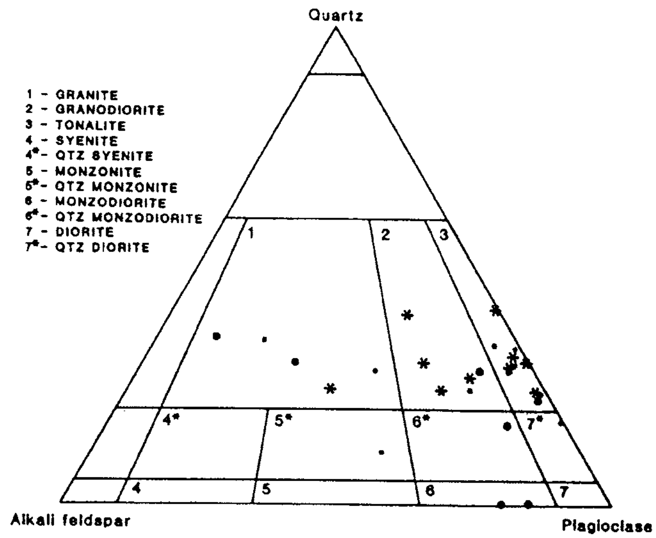

Figure 6. Streckeisen plot of plutonic rocks in th Penny Lake Area (Streckeisen, 1975). Symbols: asterisks - gneiss, dots - granite, star - Granodiorite of Rocking Chair Lakes, x's - diorite.

Gneiss

Gneiss is the name given to the medium to coarse grained gneissic granitoid rocks found mainly in the northern half of the Penny Lake Area. The Gneiss is tan to pink, strongly to poorly gneissic, and ranges in composition from quartz monzonite to tonalite (Figure 6). The outcrops form widely scattered, low, rounded knobs surrounded by Quaternary alluvium in sections 25 and 26. In section 27, the Gneiss is found along the edge of the large cliff near Outlet Creek (Plate 1). Mafic zones are occasionally found within the Gneiss, especially near the contact with the basalts. These zones are elongate and contorted, with the mafic zones parallel to the layering in the gneisses. Late stage, relatively undeformed, coarse-grained, 1 to 5 meter, granitic dikes (not shown on map) cut the gneiss. The mineralogy of the gneiss consists of varying amounts of quartz, plagioclase, and potassium feldspar with minor amounts of dark minerals, including biotite, hornblende, and pseudomorphic chlorite after biotite (Table 16).

Altered varieties of the Gneiss do exist within the Penny Lake Area but were not mapped as a separate unit. One area, on the north end of the large hill in the west side of section 27, is almost completely altered to carbonate and chlorite (Table 17). Another area, in the northwest corner of section 34, is highly silicified and also contains some carbonate (Table 17).

Age and Origin of Gneiss

The Gneiss is considered to be Archean in age, but its exact stratigraphic position is uncertain. The unit could be interpreted as either being a part of the basement, upon which the basalts were deposited, reactivated basement, or a post basalt batholithic intrusion. The batholithic intrusion hypothesis is preferred because of the following reasons:

	35-13	35-17	27-5	34-23	27-16	25-3	15-27-2	34-16	34-12	36-27	27-20
SIO2	57.87	71.36	52.83	68.62	50.95	68.42	47.45	48.57	51.68	71.64	47.65
TIO2	.65	.13	.75	.34	.90	.29	.58	2.29	.96	.07	.86
AL2O3	15.34	14.65	13.96	14.65	11.77	14.68	14.31	11.60	14.25	15.45	14.43
FE2O3	1.89	.30	2.42	.78	2.85	.80	2.97	5.23	3.04	.19	3.92
FEO	3.77	.60	4.85	1.57	5.71	1.61	5.94	10.47	6.07	.38	7.84
MNO	.11	.02	.13	.04	.16	.04	.15	.13	.15	.02	.17
MGO	5.29	.46	7.11	1.17	10.10	1.19	9.04	8.52	7.51	.24	10.02
CAO	4.74	.86	5.20	1.45	8.55	1.51	10.05	5.57	8.27	.38	6.32
NA2O	3.85	4.98	4.25	4.81	2.51	5.68	1.89	2.05	3.41	10.52	1.67
K2O	2.30	4.25	2.68	3.15	2.40	2.31	2.35	.15	1.92	.41	2.69
H2O	2.04	.60	2.35	1.50	1.90	1.34	2.54	6.92	1.34	.65	11.58
P2O5	.35	.05	.37	.12	.52	.10	.38	.30	.51	.02	.26
TOTAL	98.62	98.32	97.45	98.38	98.91	98.19	98.32	103.29	99.69	100.02	108.28
NB	9	7	8	10	5	9	2	14	6	7	5
ZR	128	58	163	143	185	121	25	90	163	61	42
Y	12	14	13	14	10	10	7	8	11	4	12
SR	606	236	464	392	888	403	195	124	752	41	197
RB	78	97	40	78	38	57	45	nd	27	nd	62
LA	15	nd	nd	nd	36	15	nd	nd	37	nd	nd
ZN	87	19	89	52	98	73	57	867	86	6	92
CU	42	30	77	35	99	64	176	63	42	128	42
NI	53	nd	43	nd	98	nd	81	30	32	nd	194
CR	172	nd	138	15	411	7	427	217	139	nd	301
V	110	3	124	39	166	30	133	459	167	nd	182
S	59	27	134	29	54	199	268	2529	75	76	44

nd - below detection limits, see table A2.

NORMS:

	35-13	35-17	27-5	34-23	27-16	25-3	15-27-2	34-16	34-12	36-27	27-20
AP	.85	.11	.84	.29	1.20	.24	.86	.82	1.18	.06	.63
IL	1.39	.26	1.53	.68	1.81	.59	1.12	5.37	1.71	.13	1.82
MT	3.06	.45	3.76	1.14	4.40	1.23	4.40	9.35	4.62		6.36
OR	15.15	25.81	16.89	19.48	15.03	14.36	14.13	1.12	11.90	2.45	17.75
AB	36.32	43.35	38.42	42.55	22.55	50.71	16.32	21.27	30.26	77.87	15.79
AN	19.86	4.05	11.82	6.69	14.58	7.19	24.09	27.04	18.71		26.73
DI	3.37		11.51		23.43		21.02	3.85	17.97	1.47	5.56
HY	10.70	1.03	5.32	2.71	8.78	2.71	2.31	21.46	6.56	.27	13.14
OL			9.92		8.23		15.76		7.09		12.21
AC										.56	
C		.84		2.07		.72					
Q	9.31	24.10		24.39		22.14		9.74		14.56	
NS										2.64	

35-13 - Gneiss (quartz monzonite)
35-17 - Granite (white dike)
27-5 - Diorite (monzodiorite)
34-23 - Gneiss (granodiorite)
27-16 - Diorite (monzodiorite)
25-3 - Gneiss (tonalite)
15-27-2 - monzodiorite dike (contact of Gneiss with volcanics)
34-16 - highly foliated Granodiorite of Rocking Chair Lakes
34-12 - Diorite (monzodiorite)
36-27 - Granite (pink dike)
27-20 - highly carbonate altered Gneiss

Table 15. Chemical analysis of granitoid samples.

1.) The metamorphic grade of the basalts decreases symmetrically away from the gneiss, which thus might be the cause of the metamorphism.

2.) The contact of the basalt and gneiss is complex. Dike like bodies with composition intermediate between basalt and gneiss intrude the basalts, and basalt zenoliths can be found within the gneiss.

3.) Foliation in the basalts becomes much more intense near the contact with the gneiss; all primary structures are completely obliterated.

4.) The gneiss is compositionally similar to the Granodiorite of Rocking Chair Lakes, a unit that has been shown by Johnson et.al.(1987) to cut the volcanic dominated section.

Granodiorite of Rocking Chair Lakes

The Granodiorite of Rocking Chair Lakes is the name used for relatively massive, small stock sized bodies of quartz monzodiorite to tonalite in composition. Johnson et.al. (1987) used this name for the plutonic rocks which intrude the hinge region of the large fold to the south of the Penny Lake Area, and along the Mulligan Cliff. Within the Penny Lake Area, this unit occurs as rounded, stock-like bodies. The outcrops are low and rounded, widely scattered in the swamps, except along the cliff on the west side of the area.

The Granodiorite of Rocking Chair Lakes is a light grey to pink, massive, slightly altered, quartz monzodiorite to tonalite. The samples commonly contain abundant andesine plagioclase, with variable amounts of quartz, potassium feldspar, and biotite (often altered to chlorite). Table 18 contains descriptions of two samples from two different intrusive bodies. The Granodiorite of Rocking Chair Lakes also contains highly altered zones that were too small to map. Table 19 contains the description of one altered sample from the face of the Mulligan Cliff.

Age and Origin of Granodiorite of Rocking Chair Lakes

The Granodiorite of Rocking Chair Lakes is considered to be Archean in age. It intrudes the Volcanics of Silver Mine Lakes, and was found by Johnson et.al.(1987) to cut the Gabbro of Clark Creek. The unit is believed to be younger than the gneiss located to the north. The range in composition of this unit is quite similar to that of the gneisses, which suggests that the two units may be related. Because of the massive texture of the unit, as compared to the Gneiss which has an obvious foliated texture, it is believed to be late to post orogenic

Granite

Granite is the name used for dikes of granite. Granite dikes within the Penny Lake Area range in thickness from 2 centimeters to over 20 meters. Only those greater than 20 meters in thickness (5 meters in detail areas) are shown on the map (Plate I). Some thicker dikes were followed along strike for over 300 meters. The dikes cut the Volcanics of Silver Mine Lakes, the Gneiss, and the Granodiorite of Rocking Chair Lakes. Contacts of the granite with the other rock types are sharp, and the amount of deformation within individual dikes varies greatly. In some areas, thin (1 to 10 centimeter) granite dikes show ptygmatic folding, consistent with the amphibolite grade basalts. In other areas, the granite dikes seem to have intruded along fractures in the more brittle deformed basalt, and are themselves often offset by late brittle faults.

The Granite is pink to dark red and is composed of microcline feldspar, quartz, and plagioclase, with minor amounts of muscovite and biotite (Table 20). Alteration is restricted to minor sericite alteration of the plagioclase. Another variety of Granite is white in color and much finer grained than the pink type. This aplitic type is found as thin dikes, 1cm to 2 meters in thickness, and are composed of orthoclase feldspar, quartz, and andesine.

Age and Origin of the Granite

Due to the widespread abundance of the granite dikes and relative scarcity of rhyolites within the Penny Lake Area, the opposite as compared to areas farther south in the northern block, perhaps the granite dikes represent a deeper seated part of the Rhyolite Intrusive of Fire Center Mine. However, within detail area B (Plate 1) the granite was observed to cut the rhyolite, thereby proving that at least one of the granite dikes is younger. In addition, the fact that granite and rhyolite dikes occur in the same area complicates a deep seated model. The thin, ptygmatically folded dikes are possibly metamorphic sweat-outs from the basalts, and would therefore be unrelated to the normal, late stage granitic dikes.

Diorite

Diorite is the name used for stock-sized bodies of dark red and black massive (and occasionally gneissic) hornblende diorite or monzodiorite. The Diorite is found in sections 34 and 27 as relatively small intrusive stocks with an average diameter of 250 meters. Topographic highs are formed in vicinity of these more erosion resistant stocks, leaving glacially polished knobs of diorite.

Mineralogy of the Diorite includes hornblende and plagioclase with minor amounts of microcline, chlorite, and sericite (Table 21). The Diorite is most often coarse-grained and massive, with large euhedral hornblende crystals with interstitial feldspars. One stock in section 34 however, has a gneissic texture, and has an unusual contact metamorphic zone around it. This zone is composed of a banded basalt rock and a biotite-garnet rock with up to 5 percent base metal sulfides (Table 22). This intrusive is shown in detail area C (Plate 1).

Age and Origin of Diorite

The Diorite is believed to be the youngest of the Archean igneous intrusive rocks within the Penny Lake Area. It has not been observed to be cut by any Archean granite dikes. Most of the diorite bodies are massive and are believed to be post orogenic intrusions, possibly unrelated to the older granitoid intrusives. The contact zone around the one Diorite body indicates that the intrusion took place after the regional metamorphism which may be related to emplacement of the Gneiss, since little retrograde alteration has occurred within the garnet-biotite rock, to the typical amphibolite facies mineralogy.

QUARTZ VEINS

Quartz veins are widespread but rare within the Penny Lake Area. Only one has been shown on the map, in detail area A (Plate 1), since most are too small to show at the scale of mapping. The veins range in thickness from under 1 centimeter up to nearly 5 meters (the width of the vein in detail map area A). They are commonly white to light grey massive quartz.

The quartz vein in area A is a light grey massive variety and contains no visible sulfides. The rocks to the north of the vein are highly altered, but the relationship of the vein with the alteration is difficult to determine. Other small quartz veins within the Penny Lake Area can contain significant amounts of chalcopyrite, pyrite, and sphalerite, but no gold anomalies were found in the two samples assayed associated with these base metal occurrences.

Age of Quartz Veins

Quartz veins have been observed to cut the units of the Volcanics of Silver Mine Lakes, and all of the granitoid intrusives. Most quartz veins are assumed to be Archean in age. The diorite was not observed to be cut by the quartz, but this could be due to the small number of diorite outcrops located. Multiple stages of quartz vein intrusion are possible. Most are probably Archean in age although some of them may be Lower Proterozoic.

PROTEROZOIC UNITS

Michigamme Formation

Rocks which have been assigned to the Michigamme Formation were found in two locations within the Penny Lake Area. The hill to the west of Outlet Creek in section 34 is composed of a highly carbonate altered light green quartz pebble conglomerate with a slatey matrix (Table 23).

Cobbles of dark green and grey laminated fine grained slates were found along the southernmost part of Clark Creek in sections 1 and 2. No actual outcrops were located, therefore the area was mapped as Quaternary alluvium. The Michigamme Formation is considered to be Lower Proterozoic in age (Clark, et al, 1975 and Sims, et al. 1984). Lower Proterozoic Diabase

Dikes of Lower Proterozoic diabase cut all of the Archean rocks in the Penny Lake Area. The dikes are up to 20 meters in thickness and have been followed along strike for over 200 meters in some locations. One set of dikes strike east-west and are dark green to black, medium grained, altered diabase. These dikes are composed of actinolite, epidote, sericite altered plagioclase, chlorite and opaques (Table 24). The other type of Lower Proterozoic dikes commonly strike north-south and are composed of actinolite, slightly sericite altered plagioclase, and chlorite, with minor epidote, carbonate, and opaques (Table 25).

The metamorphic grade of the dikes is greenschist. This fact makes identification of Lower Proterozoic diabase dikes quite easy when they are located within the amphibolite grade Volcanics of Silver Mine Lakes. The quantity of these dikes in the area indicates that more lower Proterozoic diabase may exist in the previously mapped areas, but were not identified as such due to their similarity to the greenschist grade basalts and gabbros. Table 26 lists the whole rock chemical composition of three of these Lower Proterozoic dikes.

These dikes are presumed to be lower Proterozoic in age because they can be found to cut all Archean rocks in the area, and are consistent in composition and metamorphic grade to Lower Proterozoic recognized to the south and east (Puffett, 1974, and Gair and Thaden, 1968). The east-west dikes are cut by the north-south variety. The diabase of this age are greenschist facies as compared to Keweenawan dikes which are not. In a few locations in section 26, they have been observed to be cut by the younger Keweenawan diabase dikes.

Keweenawan Diabase

East-west striking Keweenawan diabase are located within the Penny Lake Area. They cut all older rock units. The diabase is dark brown to dark grey-green, medium to coarse grained, with a definite diabasic texture. They form flat topped ridges, especially in the granitoid bodies, and are up to 75 meters thick and over 3.5 kilometers long. One east-west diabase which is located in the south parts of sections 25, 26, and 27, can be traced over 65 kilometers to the west by its magnetic signature. The east-west dikes contain plagioclase and clinopyroxene, with minor opaques, chlorite, and olivine (Table 27).

The east-west diabase have been observed to cut the Lower Proterozoic dikes in the Penny Lake Area, and are therefore younger. The degree of metamorphism in the north- south dikes also indicates that they are older than the almost completely unaltered east-west dikes.

The Keweenawan diabase dikes are considered to be Middle Proterozoic (Gair and Thaden, 1968, Puffett, 1974, and Clark et al., 1975) and related to Keweenawan rifting and magmatism.

STRUCTURE

INTRODUCTION

The rocks within the Penny Lake Area indicate a complex structural history. Two or more major deformational events affected the entire greenstone belt. Two or more Archean deformational events folded the Volcanics of Silver Mine Lakes and the Gabbro of Clark Creek, and the Lower Proterozoic Penokean Orogeny deformed the Michigamme Formation, and affected the Archean rocks to an unknown extent. A more localized structural signature was formed by the emplacement of the granitoid plutons. These intrusions induced structural features that were only observed within a few thousand meters of the large granitoid intrusion in the north part of the Penny Lake Area, and to within 100 meters of the smaller bodies.

ATTITUDE OF BEDDING

The attitude of stratification within the Volcanics of Silver Mine Lakes can be determined by the orientation of the Iron Formation Member, and the Hill's Lakes Pyroclastic Member. The Iron Formation Member dips 71 ° south in the north part of the Penny Lake Area. In the south part of section 2, the contact of the Hill's Lakes Pyroclastic Member with the basalts, as well as clasts within the unit, dip nearly vertically. It is therefore believed that bedding of all the Archean units within the Penny Lake Area is at a high angle to horizontal.

FOLDS

This geological mapping of the Penny Lake Area confirms the northward continuation of the large scale fold which was first described by Johnson et.al.(1987). Johnson identified the synformal anticline that was expressed by the attitude of a folded gabbro sill, the strike of bedding as defined by the Hill's Lakes Pyroclastic Member, the Iron Formation Member as mapped by Baxter et.al.(1987) and Owens and Bornhorst (1985), and by stratigraphic top indications via pillows.

In the Penny Lake Area, the attitude of the same gabbro sill and the Hill's Lakes Pyroclastic Member indicates an antiformal syncline (Figure 7). Within the Penny Lake Area, iron formation is exposed in three localities. On the basis of aeromagnetic maps, Johnson (1989) suggested that the iron formation in the southern portion of the northern block continues under unconformably overlying Lower Proterozoic sediments and is then exposed in the northern portion of the northern block. The outcrops in the Penny Lake Area confirm the aeromagnetic interpretation and has led to its correlation as the Iron Formation Member. The strike of this unit in the Penny Lake Area is parallel to the Hill's Lake Pyroclastic Member and the gabbro sill in the Penny Lake Area.

The few pillow structures located within the area are too distorted to give accurate younging, but the symmetry of the fold and tops indicators to the south indicates that the stratigraphic top of the Volcanics of Silver Mine Lakes is towards the southwest throughout most of the Penny Lake Area. Mineral lineations found in some of the

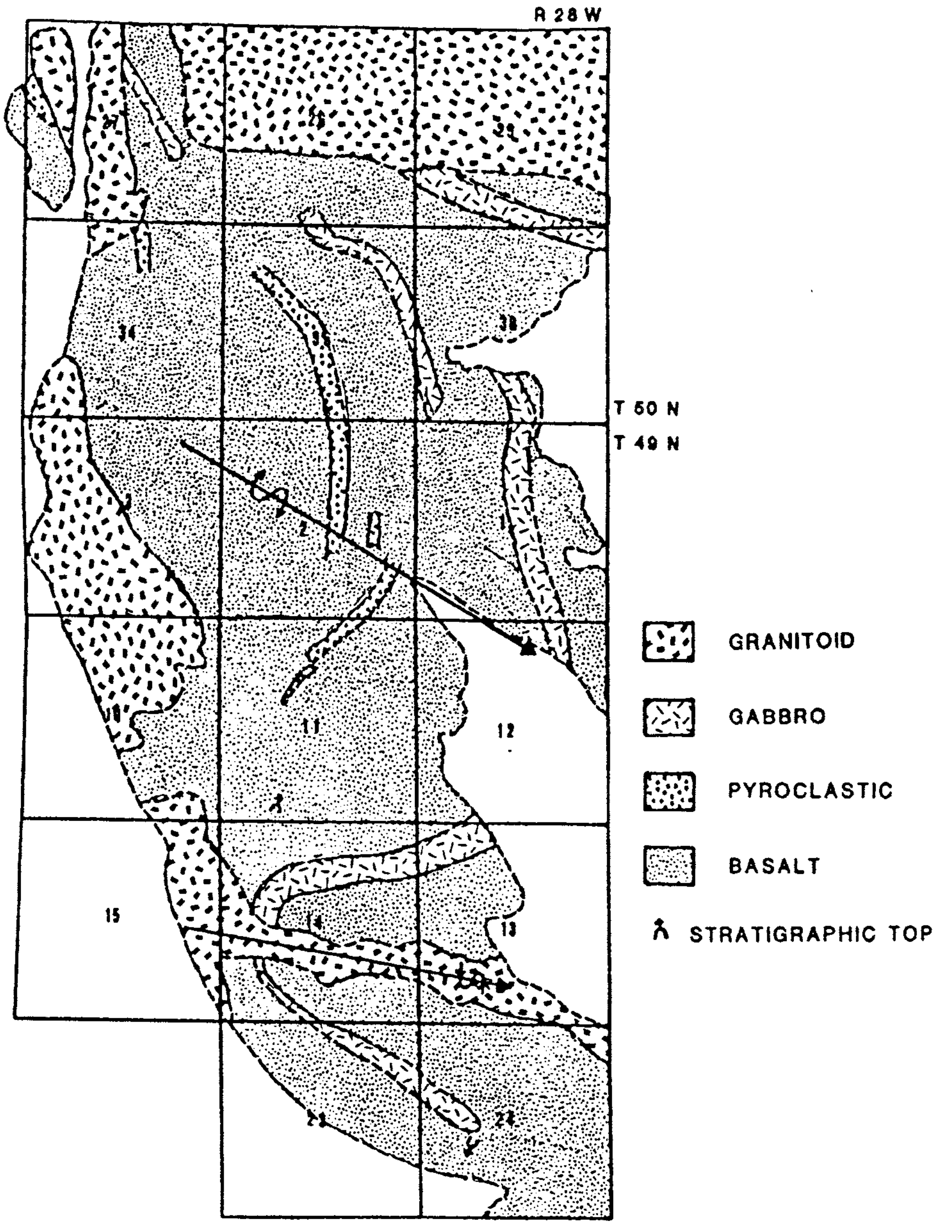

Figure 7. Map of Penny Lake Area and area mapped by Johnson (1987), showing location of major fold.

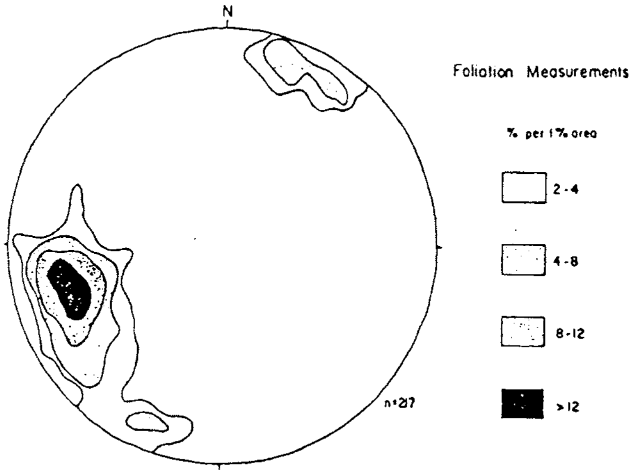

Figure 8. Diagram showing Archean foliation.

nematoblastic basalts in the northern part of the Volcanics of Silver Mine Lakes indicate a steep plunge of 65° degrees to the east, agreeing with observations of Johnson (1987) that the fold is overturned. Therefore, the Penny Lake Area is part of a steeply plunging synformal anticline and antiformal syncline that dominate the structure of the northern block of the Marquette Greenstone Belt.

In the northern part of the area, near the contact with the plutonic rocks, small scale, tight folds are shown by narrow (2cm) granitic dikelets. These features are thought to have intruded along foliation planes in the basalts, which were subsequently refolded. Where the granite dikes are not observed, the basalts indicate rather planar foliations, occasionally with ptygmatic folding of quartz veins and bands of alteration minerals.

FOLIATIONS

Foliation within the Penny Lake Area is defined by slaty cleavage caused by lepidioblastic chlorite in the greenschist facies basalts, and by the orientation of nematoblastic hornblende in the amphibolite facies. A stereonet plot of poles to foliations in the Archean rocks indicates multiple deformational events because of the existence of two concentrations of poles to foliations

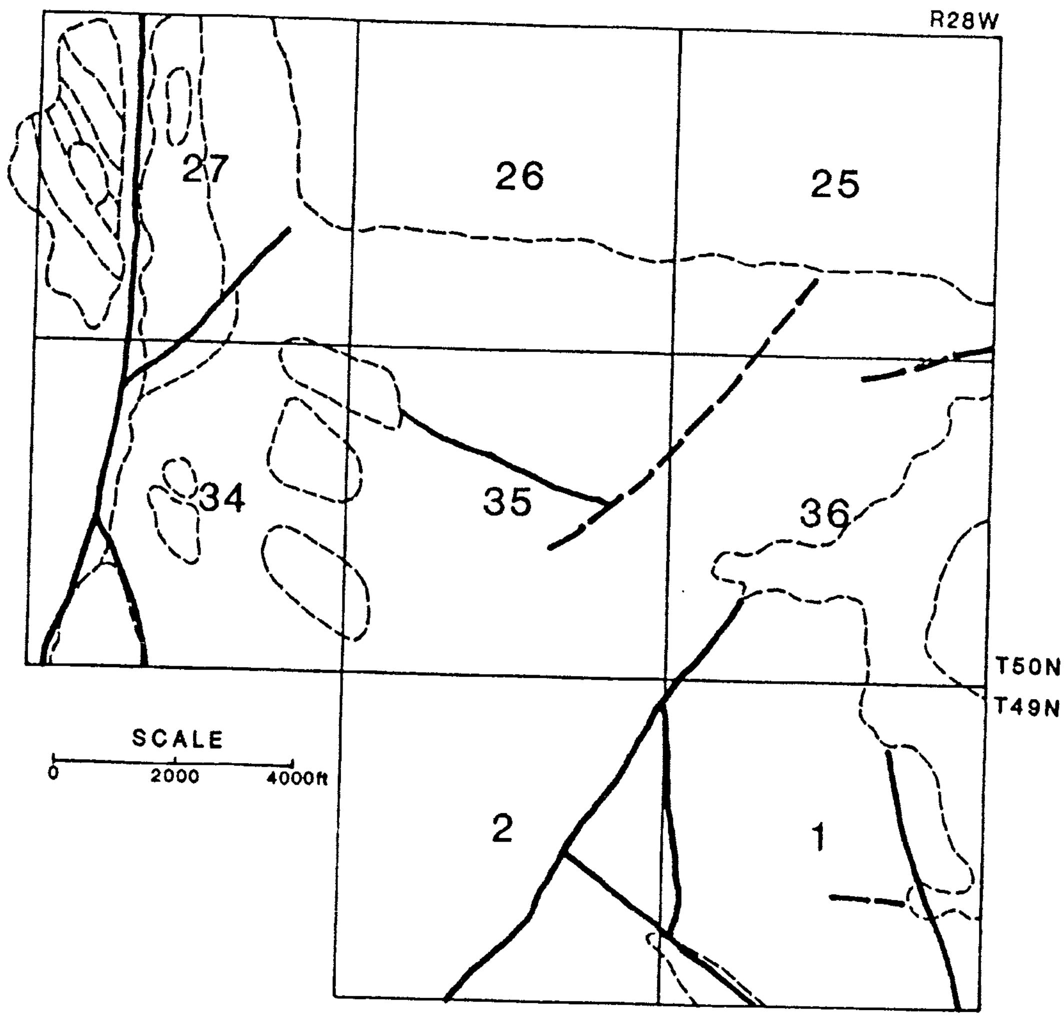

Figure 9. Location of major faults in the Penny Lake Area. Heavy dashed lines indicate faults not shown on figure 1.

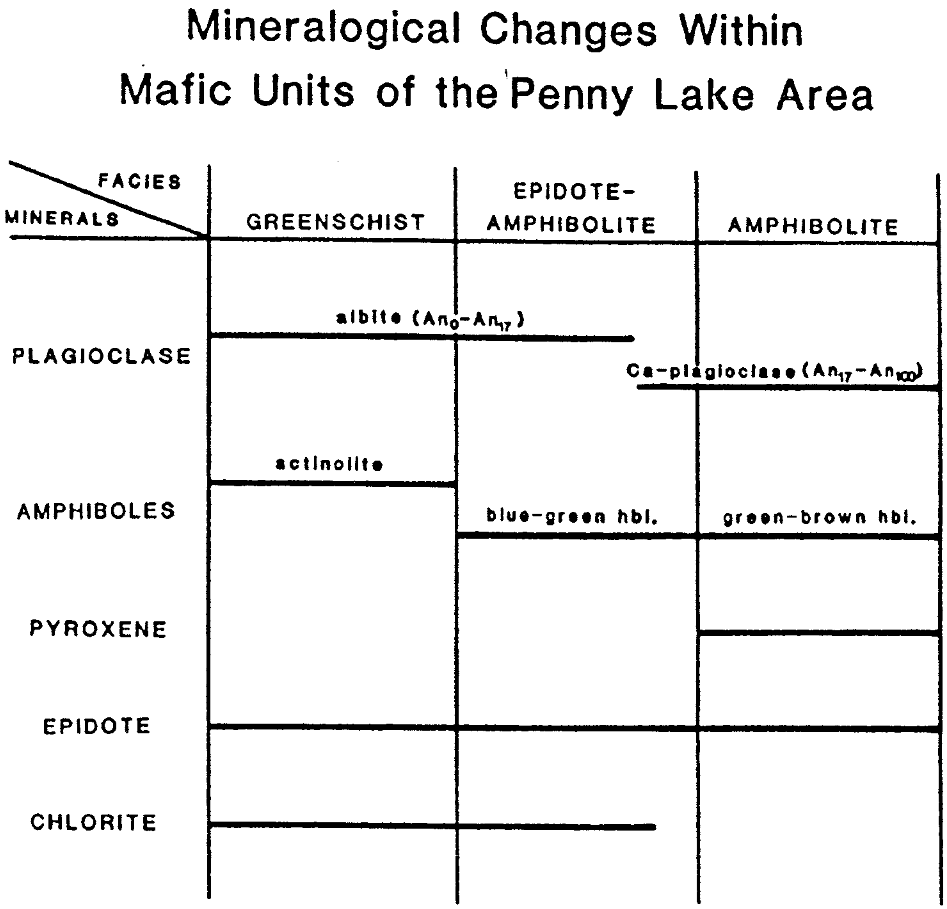

Figure 10. Mineralogical criteria used for determining metamorphic facies (Miyashiro, 1961)

(Figure 8). One group of foliations in the area strikes N 65° W to N 70° W and dips within 12 degrees north and south of vertical. This foliation is similar to what was found by Johnson et.al.(1987). The second group of poles indicates foliation striking N 15° W and dipping 62 degrees to the east. These foliations are partly from highly foliated basalts in the north part of section 27 between two bodies of gneiss, and partly from foliations developed along north-south trending faults.

Lower Proterozoic foliation can be observed in the slates and slaty conglomerates of the Michigamme Formation. Only one outcrop of this unit was located within the Penny Lake Area.

FAULTS

Faults are quite common in the Penny Lake Area, and appear to be of several generations. Figure 9 shows the location of all major faults that are shown on Plate 1, as well as a few of the smaller, less obvious zones indicating areas of high strain. Faults were located in the field by the presence of foliated rocks, the offset of rock units, and topographic lineaments.

The oldest faults in the area are those striking northwest-southeast and north-south. These two types are often associated with rhyolite dikes, and for this reason are believed to be Archean in age. The cliff along Outlet Creek is possibly one of the north-south faults, and can be traced to the south for over five miles. This particular fault may have been reactivated during the Proterozoic, as indicated by the intense alteration of lower Proterozoic sediments near this structure.

Northeast striking faults are also found within the Penny Lake Area. These faults are occasionally intruded by rhyolite and are sometimes associated with mineralization. These are also believed to be Archean in age.

METAMORPHISM

INTRODUCTION

The study of the metamorphism in the Penny Lake Area had two objectives. First was to map the location of the metamorphic facies using field and limited thin section observations. The second objective was to investigate the chemical change within the basalts due to the increase in metamorphic grade.

METAMORPHIC FACIES WITHIN THE PENNY LAKE AREA

Estimates of the metamorphic facies within the area were made during the field mapping. The existence of chlorite in massive, fine grained basalt was often indicative of greenschist facies, whereas the presence of nematoblastic amphiboles in medium grained basalt indicated epidote-amphibolite or amphibolite facies.

The metamorphic facies of the mafic Archean units were determined in thin section using the criteria listed by

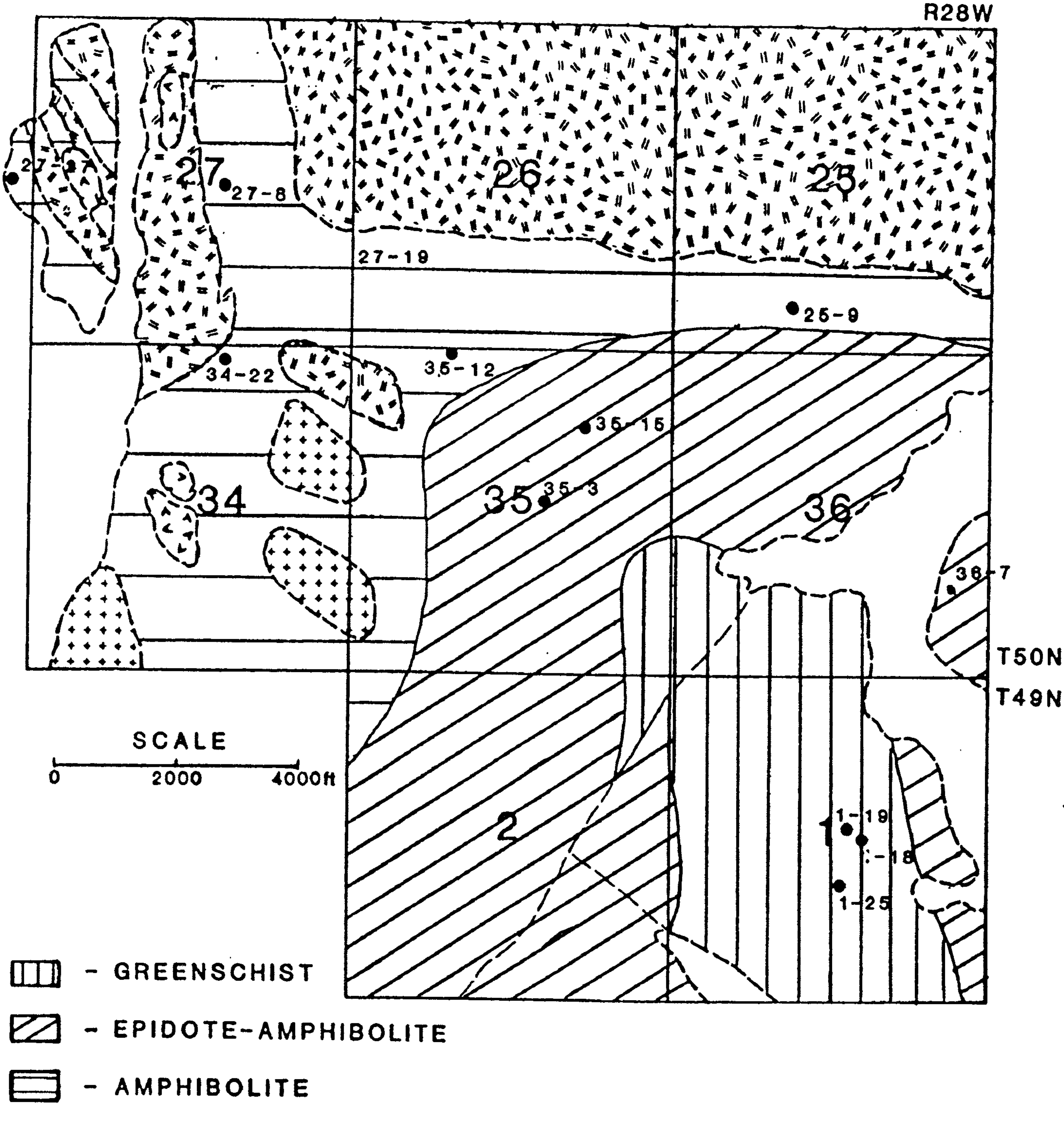

Figure 11. Probable location of metamorphic facies in the Penny Lake Area. Dots represent thin section data.

Miyashiro (1961) (Figure 10). Figure 11 shows the location of the various metamorphic facies within the Penny Lake Area. It can be observed that the metamorphic grade increases toward the granitoid intrusives, perhaps related to contact effects, and the zone of amphibolite facies basalt is 500 to 1000 meters wide. If related to the granitoids, then the amphibolite facies indicates a moderately deep level of emplacement (5 to 10 km) (Jensen and Langford, 1983).

EFFECTS OF METAMORPHISM ON BASALT COMPOSITION

The whole rock chemical analyses for six samples of unaltered amphibolite and epidote-amphibolite facies basalt were compared with 16 greenschist facies basalt samples from Johnson et.al. (1987), Baxter et.al. (1988), and MacLellan and Bornhorst (1989). Assuming constant mass, the means and standard deviations of the two groups were calculated and compared using a T-test (Table 29). The following elements from the higher metamorphic grade group had a low probability of belonging to the greenschist facies population: P, Sr, Y, Ni, Si, and Na. This means that the elements listed are either mobile during metamorphism of the basalts, or the two groups differed in these elements originally. The remaining elements are similar for both groups, indicating that the rocks were the same composition prior to metamorphism and amphibolite grade metamorphism did not enrich or deplete these elements. The means of the elements were also calculated using equivalent mass calculations, assuming Al as an immobile element in this environment. Similar results were obtained, with the exception that Ni was no longer found to be statistically different in the two groups. Overall, this comparison suggests that during the increase of metamorphic grade from greenschist to amphibolite, there was only minor modification of the chemical composition of the pillowed basalts.

MINERALIZATION

HISTORICAL EXPLORATION ACTIVITY

The Marquette Greenstone Belt has been explored for precious metals since the late 1800's. Most activity has taken place in the southwestern block, near the present location of the Ropes gold mine owned by Callahan Mining Corporation. Within the northern block, historical exploration has been sparse with the exception of the exploration program conducted by the Norgan Gold Mining Company in the mid 1930's (Kelly, 1936), and recent activity by several mining companies.

Two old prospects were located by Johnson et.al.(1987) less than one mile from the southern boundary of the Penny Lake Area, and Bodwell (1972) reported the existence of placer gold occurrences on the Yellow Dog River just northwest of the area. No old prospects are known to exist within the Penny Lake Area

GOLD ASSAY DATA

Twenty-two samples from the Penny Lake Area were assayed for gold. The abundance of gold was determined by combined fire assay and neutron activation analysis, providing a detection limit of one part per billion. Most samples were collected in an attempt to locate anomalous amounts of gold, but two samples were analyzed to determine background gold values in unaltered amphibolite facies basalt. Anomalous gold content was considered to be any value greater than 10 ppb (Kwong and Crocket, 1978). Table 28 describes the samples which contained background gold content, and Table 29 describes samples containing anomalous amounts of gold. Figure 12 gives the locations of all samples assayed and their relative gold content. Because the assay sampling was reconnaissance in nature, the assay values may not accurately represent gold mineralization in the area. Any additional exploration should include detailed geochemical sampling, especially in areas of anomalous gold as indicated in this report.

NATURE OF MINERALIZATION

The location of anomalous gold values within the area appears to be correlated with several factors: shear zones, yellow sulfide mineral abundance, and degree and type of post-peak metamorphic alteration. In all rock types, the most important factor is the existence of faults and highly foliated rock. All samples with anomalous gold values lie near to at least small zones of sheared rock. Apparently, these zones provided pathways for hydrothermal fluids which deposited the gold.

Areas with precious metal anomalies are notable for the presence of sulfides. All samples containing anomalous gold also contain significant amounts of yellow sulfides. The following metallic minerals were found within the Penny Lake Area: pyrite, chalcopyrite, pyrrhotite, galena, sphalerite, and hematite. Pyrite is by far the most widely distributed of the sulfides. It occurs in all rock types, commonly as fine grained, disseminated, euhedral grains. Anomalous concentrations of pyrite often occur within strongly foliated areas within units, in which the individual pyrite grains are concentrated along the foliation. In some foliated areas, such as the thin rhyolite located in the northwestern part of section 36, the rock can contain up to 30 percent sulfide. Anomalous gold was found associated primarily with the very fine grained pyrite. Galena, sphalerite, and chalopyrite were found often in narrow, late-stage quartz veins and contained only background amounts of gold. The sulfides in these veins were often concentrated in clots within the quartz, or disseminated within brecciated mafic fragments. Hematite was found within late-stage pegmatitic granite dikes. It occurs as fine to coarse grained specular hematite and commonly forms thin (under 1cm) massive hematite veins within the granite, possibly originating as fracture fillings.

The location of anomalous gold, found by the limited number of assays, is associated with altered zones within the Volcanics of Silver Mine Lakes. The altered zones are bounded by faults and are smaller in extent, as compared to the altered areas located in the southern portion of the northern block. The common types of alteration include: chloritization, seritization, epidotization, silicification, and carbonatization.

Chloritization of mafic minerals and seritization of feldspars has occurred throughout the Penny Lake Area associated with Archean metamorphism. In greenschist facies areas it is not possible to distinguish chlorite and sericite produced by metamorphism from those induced by localized hydrothermal alteration, except where this alteration is intense. However, in amphibolite facies rocks,

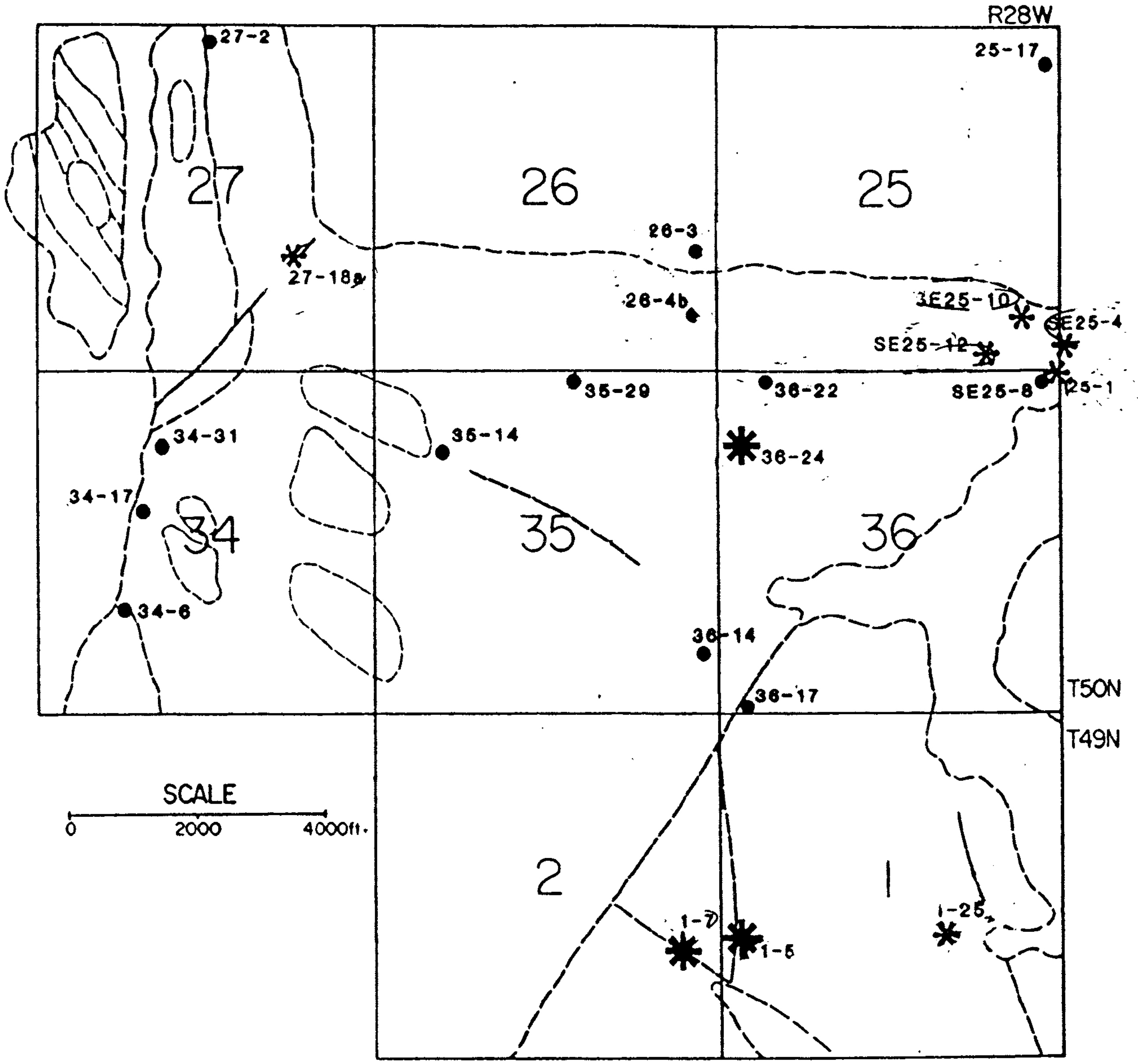

Figure 12. Location map of assay values in the Penny Lake Area. Symbols; dots - background, small asterisks - 10 to 100 ppb, large asterisks - greater than 100 ppb.

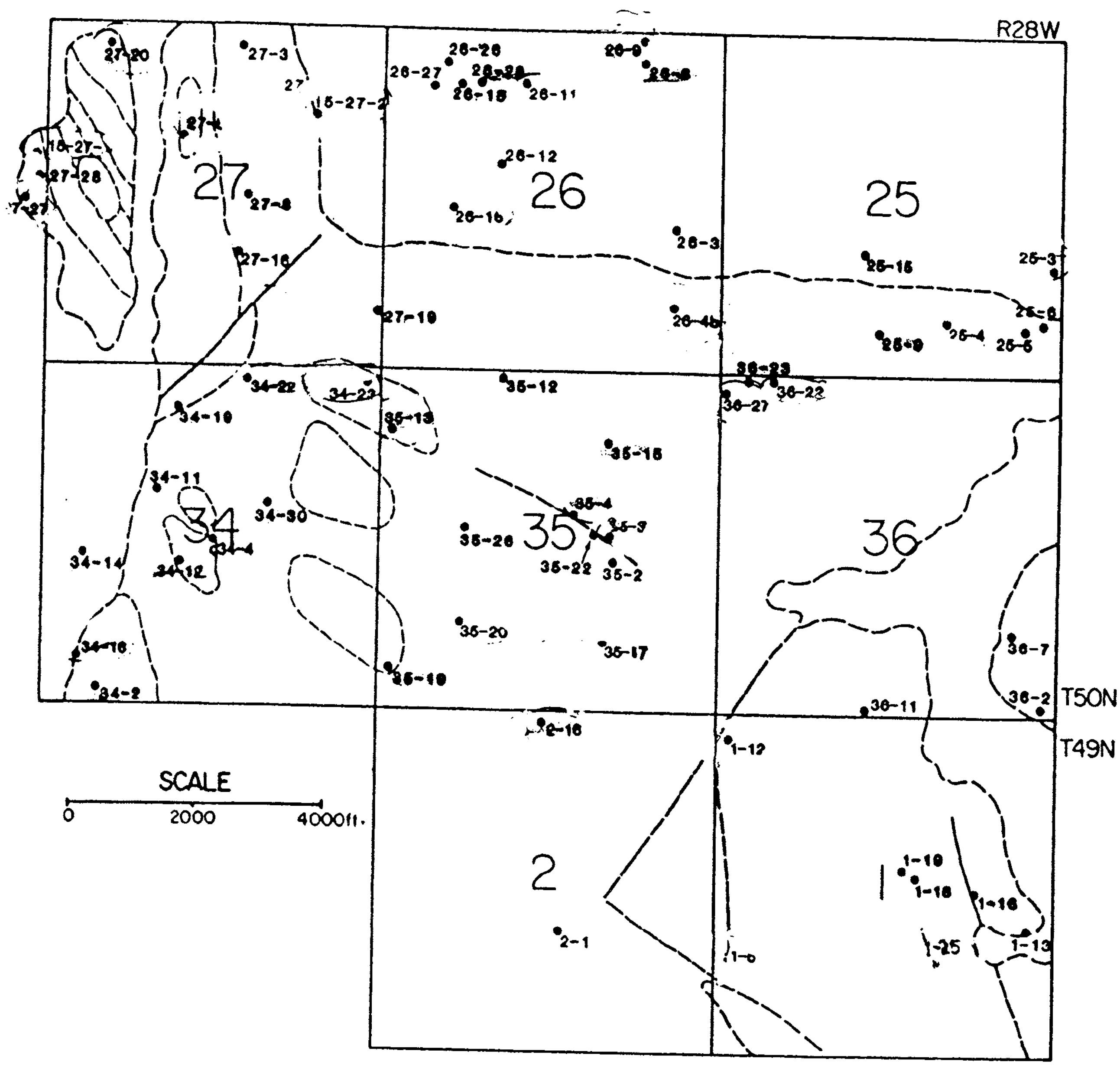

Figure 13. Location map of samples analyzed in the Penny Lake Area.

the existence of chlorite and sericite in abundance clearly represents secondary hydrothermal alteration.

Intense epidotization has occurred in a small area within the Gabbro of Clark Creek in section 35 (Plate 1). Epidote and clinozoisite have completely replaced the plagioclase within the ophitic gabbro, and the amphiboles are partly replaced by chlorite, giving the rock a bright green and black, spotted appearance. Silicification within the Penny Lake Area is expressed as the small quartz veins which are common in the Volcanics of Silver Mine Lakes. Carbonate alteration can be classified into three types. It is found as disseminated grains in narrow shear zones and pillow margins in greenschist facies basalts; as narrow, cross cutting quartz-carbonate veinlets in highly silicified and seritized volcanics; and as complete carbonate (ankerite) replacement of rocks near major faults, such as along the cliff on the west side of the Penny Lake Area. This last type of carbonate alteration is believed to be Early Proterozoic in age because it has been found in the Michigamme Formation in section 34. Much of the Penny Lake Area has undergone epidote-amphibolite to amphibolite facies metamorphism. The hydrothermal alteration minerals are retrograde, indicating that the precious metal mineralization is post-peak metamorphism. Although uncertain, the age of gold bearing mineralization is probably Archean in age, whereas the gold poor, base metal sulfide mineralization may be much younger.

ANOMALOUS AREAS

Two locations within the Penny Lake Area with anomalous gold content are notable for their contrasting alteration types. The first area, located on the section line between sections 1 and 2, consists of silicified greenschist facies basalt with numerous carbonate veinlets. Sulfides consist of minor amounts of fine grained pyrite and sphalerite. The area is bounded on two sides by major faults which form large cliffs

of foliated rock. Gold assays from two samples taken in the area had values of 240 and 180 ppb.

The second area is in the southwest corner of section 25 (Plate 1, Detail A). In this area, the amphibolite facies basalts and gabbros are altered to chlorite, and contain disseminated pyrite and chalcopyrite. This area may be a shear zone. Within the alteration zone there is a thick quartz vein and hematite-rich granite dikes. Assay values from this area ranged from 6 to 50 ppb. More details on the character of alteration for these two areas were given in the Highly Altered Basalt section of the rock unit descriptions.

GEOLOGIC HISTORY

The earliest known event to have occurred within the Penny Lake Area was the extrusion of subaqueous, tholeiitic basalts. During the period of basalt extrusion, an exhalative banded iron formation and a volcaniclastic unit were also deposited. These units are believed to be a more distal equivalent of similar units found in the southern part of the northern block. The age of these units is about 2700 Ma. The subaqueous volcanic pile was then intruded by gabbroic sills and dikes. Following this, these mafic units were intruded by small rhyolite dikes and the synkinematic, composite, batholithic intrusions, possibly related to the Kenoran Orogeny between 2700 and 2600 Ma. During this orogenic period, the volcanic units were regionally metamorphosed to greenschist facies, and to amphibolite facies near the diapiric batholith. Emplacement of the intra-belt plutons and granite dikes, along with alteration, faulting, and mineralization occurred during the later stages of deformation.

The Archean rocks of the Penny Lake Area were then subject to 5 to 10 km of uplift and erosion, followed by the deposition of slates and conglomerates of the Michigamme Formation and intrusion of Lower Proterozoic diabase dikes (2100 to 1900? Ma). The area was once again deformed and metamorphosed during the Penokean Orogeny (1890 - 1830 Ma) which reactivated some of the Archean faults, facilitating the alteration of the Michigamme Formation sediments. After a period of erosional activity, the area was intruded by Keweenawan diabase dikes (1100 Ma) associated with extensional tectonics of the Mid-Continent Rift System.

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TABLE 1

Petrographic descriptions of greenschist and epidote-amphibolite facies Pillowed Basalt Member of the Volcanics of Silver Mine Lakes.

SAMPLE 1-25 GREENSCHIST FACIES BASALT

Granoblastic, blue-green, .15 mm, subidioblastic actinolite (Z C 14); colorless, .1 mm, xenoblastic albite, sericite altered; colorless, .02 mm, subidioblastic sericite, in plagioclase; light yellow, .2 mm, idio- to subidioblastic epidote/clinozoisite; colorless, .1 mm, xenoblastic carbonate, found in pods with quartz; .1 mm, xenoblastic opaques (pyrite?); colorless, .05 mm, xenoblastic quartz.

MINERALOGY

actinolite	45%
albite	20%
sericite	20%
ep/cz	10%
carbonate	4%
opaques	tr
quartz	tr

(estimated)

SAMPLE 35-12 EPIDOTE-AMPHIBOLITE FACIES BASALT

Granoblastic, blue-green, .25 mm, idioblastic hornblende (Z C 17); colorless, .15 mm, xenoblastic albite; green-brown, .2 mm, idioblastic chlorite, altered from biotite; colorless, .01 mm, subidioblastic sericite, in plagioclase; .1 mm, subidioblastic opaques; light yellow, .1 mm, xenoblastic epidote/clinozoisite; brown, .1 mm, subidioblastic sphene.

MINERALOGY

hornblende	63%
albite	20%
chlorite	10%
sericite	5%
opaques	2%
epi/cz	tr
sphene	tr

(estimated)

TABLE 2

Petrographic descriptions of amphibolite facies samples Pillowed Basalt Member of the Volcanics of Silver Mine Lakes.

SAMPLE 27-19 GRANOBLASTIC AMPHIBOLITE BASALT

Nematoblastic, brown-green, 1 mm, idioblastic hornblende (Z C 19); colorless, .2 mm, subidioblastic labradorite; colorless, .01 mm, subidioblastic sericite; light brown, .05 mm, subidioblastic sphene; colorless, .05 mm, xenoblastic quartz; green-blue, 1 mm, subidioblastic hypersthene.

MINERALOGY

hornblende	65%
labradorite	30%
sericite	2%
sphene	2%
quartz	tr
hypersthene	tr

(estimated)

SAMPLE 27-27 BANDED AMPHIBOLITE FACIES BASALT

Nematoblastic, green-brown, .75 mm, idioblastic hornblende (Z C 16); colorless, .2 mm, xenoblastic labradorite, sericite altered; colorless, .6 mm, xenoblastic quartz, concentrated in bands; green, .5 mm, idioblastic chlorite, light yellow, .2 mm, subidioblastic epidote/clinozoisite; colorless, .01 mm, subidioblastic sericite;colorless, .01 mm, euhedral apatite.

MINERALOGY

labradorite 35%
hornblende 25%
quartz 15%
chlorite 15%
epi/cz 5%
sericite 5%
apatite tr
(estimated)

TABLE 4

Petrographic descriptions of the Highly Altered Variety of the Pillowed Basalt Member of the Volcanics of Silver Mine Lakes.

SAMPLE 35-4 FOLLIATED ALTERED BASALT (Epidote-Amphibolite Facies)

Lepidioblastic, light green, .05 mm, subidioblastic chlorite; colorless, .02 mm, subidioblastic sericite, plagioclase alteration; colorless, .1 mm, xenoblastic quartz; colorless, .2 mm, xenoblastic carbonate, in veins and disseminated; colorless, .1 mm, relict, anhedral plagioclase, .1 mm, xenoblastic opaques(pyrite?).

MINERALOGY

chlorite 35%
sericite 25%
quartz 15%
carbonate 15%
plagioclase 5%
opaques 5%
(estimated)

SAMPLE 35-22 MASSIVE ALTERED BASALT (Epidote-Amphibolite Facies)

Light yellow, .05 to .5 mm, idioblastic to xenoblastic epidote/clinozoisite; colorless, .1 mm, xenoblastic plagioclase;light green, .4 mm, subidioblastic hornblende; light brown, .01 mm, xenoblastic sphene; .01mm clay particles.

MINERALOGY

epi/cz 30%
plagioclase 30%
hornblende 15%
clays 25%
sphene tr
(estimated)

TABLE 6

Petrographic descriptions of the southern part of the Hill's Lakes Pyroclastic Member of the Volcanics of Silver Mine Lakes.

SAMPLE 2-16 HILL'S LAKES PYROCLASTIC

(located near N 1/4 corner of section 2) Colorless, .15 mm, anhedral quartz; colorless, .05 mm, subidioblastic sericite; lepidioblastic, light brown, .05to .3 mm, subidioblastic biotite, partly altered to chlorite;colorless, .1 mm, xenoblastic plagioclase, highly altered tosericite; skeletal, light green, .25 mm, subidioblastic hornblende; light yellow, .05 mm, xenoblastic epidote/clinozoisite.

MINERALOGY

quartz 55%
sericite 20%
biotite 20%
plagioclase 2%
hornblende 2%
epi/cz tr
(estimated)

SAMPLE 35-26 BANDED HILL'S LAKES PYROCLASTIC

(located in center section 35) Colorless, .5 mm, xenoblastic labradorite; colorless, .2 mm, anhedral quartz, with undulose extinction; lepidioblastic, brown, .1 mm, idioblastic biotite, partly altered to chlorite;green-brown, .2 mm, subidioblastic hornblende; light green, .1 mm, subidioblastic chlorite; poikiloblastic, light pink, .75 mm, subidioblastic garnet; light yellow, .01 mm, xenoblastic epidote/clinozoisite; colorless, .01 mm, subidioblastic sericite, found in plagioclase; .01 mm, xenoblastic opaques.

MINERALOGY

labradorite..40%
quartz 35%
biotite 10%
hornblende 10%
chlorite 3%
garnet tr
epi/cz tr
sericite tr
opaques tr
(estimated)

TABLE 7

Petrographic descriptions of the northern part of the Hill's Lakes Pyroclastic Member of the Volcanics of Silver Mine Lakes.

SAMPLE 34-22 MUSCOVITE-CHLORITE SCHIST VARIETY

(clast rich equivalent?) Colorless, .25 mm, anhedral quartz, with undulose extinction; colorless, .3 mm, xenoblastic andesine, sericite altered; lepidioblastic, green, 1.0 mm, subidioblastic chlorite; lepidioblastic, colorless, 1.5 mm, idioblastic muscovite;colorless, .01 mm, subidioblastic sphene, in chlorite; colorless, .01 mm, subidioblastic apatite, in quartz; .2 mm, xenoblastic opaques.

MINERALOGY

andesine 30%
chlorite 25%

quartz 22%
muscovite 20%
sphene tr
apatite tr
opaques tr
(estimated)

SAMPLE 27-28 SECTION 27 VARIETY

(matrix rich equivalent?) Green-brown, .5 mm, idioblastic hornblende; colorless, .5 mm, xenoblastic labradorite, sericite altered; colorless, .3 mm, anhedral quartz, with undulose extinction; poikiloblastic, pink, .5cm, idioblastic garnet; biotite and quartz inclusions; brown, .75 mm, subidioblastic biotite, some chlorite alteration; light green, .01 mm, xenoblastic epidote/clinozoisite; .01 mm, subidioblastic opaques; colorless, .01 mm, subidioblastic sericite.

MINERALOGY
hornblende 40%
labradorite 30%
quartz 15%
garnet 10%
biotite 5%
epi/cz 2%
opaques tr
sericite tr
(estimated)

TABLE 9

Petrographic description of the Iron Formation Member of the Volcanics of Silver Mine Lakes.

SAMPLE 26-4b EPIDOTE-MAGNETITE IRON FORMATION

Blue-green and yellow-green, .1 to .25 mm, subidioblastic hornblende;yellow-green, .1 to .5 mm, idio-to subidioblastic epidote/clinozoisite; .2 mm, euhedral magnetite, in bands;colorless, .2 mm, anhedral quartz, undulose extinction; fibrous, light green, .05 mm, subidioblastic chlorite, found within quartz;red, .01 mm, euhedral rutile, in quartz.

MINERALOGY
hornblende..35%
epi/cz 30%
magnetite 25%
quartz 6%
chlorite 4%
rutile tr
(estimated)

TABLE 11

Petrographic descriptions of Gabbro of Clark Creek. Cross section through a sill (greenschist facies).

SAMPLE 1-18 SILL INTERIOR (FELTY TEXTURE)

Felty, green-yellow, 2cm, subidioblastic actinolite (Z C 14); colorless, .01 mm, subidioblastic sericite; colorless, .25 mm, xenoblastic plagioclase, almost completely altered to sericite; light green, .2 mm, idioblastic chlorite, light yellow, .05 mm, subidioblastic epidote/clinozoisite; skeletal, .5 mm, xenoblastic opaques(magnetite?); colorless, .05 mm, xenoblastic carbonate.

MINERALOGY
actinolite 65%
sericite 22%
opaques 5%
plagioclase 3%
chlorite 2%
epi/cz 2%
carbonate tr
(estimated)

SAMPLE 1-19 SILL MARGIN (OPHITIC TEXTURE)

Green-yellow, .5cm, subidioblastic actinolite, relict ophitic texture; colorless, .2 mm, xenoblastic albite, some relict labradorite within actinolite; light yellow, .05 mm, xenoblastic epidote/clinozoisite; light brown, .05 mm, subidioblastic sphene, with opaques; colorless, .01 mm, subidioblastic sericite; .02 mm, xenoblastic opaques (magnetite?).

MINERALOGY
actinolite 55%
plagioclase 35%
epi/cz 5%
sphene 2%
sericite 2%
opaques tr
(estimated)

TABLE 12

Petrographic descriptions of samples of the Gabbro of ClarkCreek.

SAMPLE 27-8 AMPHIBOLITE FACIES GABBRO

Felty, green-brown, .5 to10 mm, subidioblastic hornblende; colorless, .01 mm, subidioblastic sericite; .01 mm, xenoblastic opaques (magnetite?);colorless, .25 mm, xenoblastic oligoclase?, untwinned;poikiloblastic, light pink, .8 mm, idioblastic garnet, colorless, .01 mm, xenoblastic carbonate.

MINERALOGY
hornblende 93%
sericite 5%
opaques 2%
plagioclase tr
garnet tr
carbonate tr
(estimated)

SAMPLE 25-9 AMPHIBOLITE FACIES GABBRO

Colorless, .4 mm, xenoblastic labradorite; porphyroblastic, green-brown, 1.5 mm, subidioblastic hornblende (Z C 19); light green, .1 mm, idioblastic to xenoblastic epidote/clinozoisite.

MINERALOGY
labradorite 65%
hornblende 25%
epidote 10%
(estimated)

TABLE 13

Petrographic description of the Highly Altered Variety of the Gabbro of Clark Creek.

SAMPLE 35-15 EPIDOTIZED OPHITIC GABBRO

Light yellow, .2 mm, idioblastic to subidioblastic epidote/clinozoisite; ophitic, blue-green, 2 mm, subidioblastic hornblende (Z C 17); colorless, .25 mm, xenoblastic albite; light green, .25 mm, subidioblastic chlorite; light brown, .1 mm, idioblastic sphene, with opaques; .05 mm, subhedral opaques (magnetite?); colorless, .05 mm, subidioblastic sericite, in plagioclase.

MINERALOGY

epi/cz 55%
hornblende 25%
albite 7%
chlorite 5%
sphene 5%
opaques tr
sericite tr
(estimated)

TABLE 14

Petrographic description of the Rhyolite Intrusive of Fire Center Mine.

SAMPLE 1-16 SLIGHTLY ALTERED RHYOLITE

Colorless, 1.5 mm, xenoblastic quartz phenocrysts; colorless, .01 mm, xenoblastic quartz, mosaic groundmass; colorless, .25 mm, subidioblastic albite phenocrysts; colorless, .01 mm, albite groundmass;colorless, .05 mm, xenoblastic carbonate; .05 mm, xenoblastic opaques (pyrite?); lepidioblastic, light green, .01 mm, subidioblastic chlorite; colorless, .01 mm, xenoblastic sericite.

MINERALOGY

quartz 90%
albite 5%
carbonate 2%
opaques 2%
chlorite tr
sericite tr
(estimated)

TABLE 16

Petrographic descriptions of representative samples of the Gneiss.

SAMPLE 26-8 TONALITE GNEISS

Colorless, 1 to 2 mm, anhedral andesine, slightly altered to clay; colorless, 1 to 2 mm, anhedral quartz, undulose; light green, .2 mm, subidioblastic chlorite, interstitial; 2 mm, subhedral opaques.

MINERALOGY

andesine 66.5%
quartz 27.9%
chlorite 5.2%
opaques tr
(308 points)

SAMPLE 35-13 TONALITE GNEISS

Colorless, 1 mm, subhedral andesine, highly sericite altered; seriate, porphyroblastic, green-yellow, .2 to 3 mm, idioblastic hornblende; colorless, 1 mm, anhedral quartz, undulose; lepidioblastic, brown and green, .2 mm, idioblastic biotite, partly altered to chlorite; colorless, 1 mm, anhedral orthoclase, partly altered to clay; light yellow, .01 mm, xenoblastic epidote/clinozoisite; light brown, .01 mm, idioblastic sphene.

MINERALOGY

andesine 51.9%
hornblende 17.8%
quartz 12.5%
biotite 10.8%
orthoclase 0.9%
ep/cz 0.7%
sphene tr
(491 points)

TABLE 17

Petrographic descriptions of altered varieties of the Gneiss.

SAMPLE 27-20 CARBONATE ALTERED GNEISS

Cloudy, .25 mm, xenoblastic carbonate (ankerite?); white, .5 mm, xenoblastic plagioclase, highly sericite altered; lepidioblastic, light green, .25 mm, subidioblastic chlorite; colorless, .1 mm, subidioblastic muscovite, coarse grained sericite alteration of plagioclase; colorless, .1 mm, anhedral quartz; .25 mm, xenoblastic opaques, somewhat sheared; colorless, .01 mm, xenoblastic sphene, in chlorite.

MINERALOGY

carbonate 65%
plagioclase 10%
chlorite 10%
muscovite 10%
quartz 2%
opaques 2%
sphene tr
(estimated)

SAMPLE 34-19 SILICIFIED QUARTZ MONZONITE GNEISS

Colorless, 2.5 mm, subhedral andesine, partly altered to sericite; green, .1 to 1 mm, idioblastic to subidioblastic chlorite, altered from biotite; colorless, 1 mm, anhedral quartz, undulose; colorless, 1.5 mm, subhedral orthoclase, some clay alteration; colorless, .01 mm, subidioblastic sphene, in chlorites; colorless, .01 mm, subidioblastic sericite; colorless, .01 mm, xenoblastic carbonate.

MINERALOGY

andesine 57.1%
chlorite 21.6%
quartz 13.3%
orthoclase 7.8%
sphene tr
sericite tr
carbonate tr
(473 points)

SAMPLE 25-15 ALTERED GRANODIORITE GNEISS

Colorless, .5 to 1 mm, subhedral andesine, some sericite alteration; colorless, 2 to5 mm, anhedral quartz, undulose; colorless, .5 mm, anhedralmicrocline; green, .1 to .75 mm, idioblastic chlorite, afterbiotite; colorless, .02 mm, subhedral muscovite; colorless, .01 mm, subidioblastic sericite; .5 mm, anhedral opaques;colorless, .01 mm, euhedral apatite, in quartz.

MINERALOGY

andesine 54.3%
quartz 22.0%
microcline 18.5%
chlorite 4.6%
mus/ser 0.5%
opaques tr
apatite tr
(368 points)

TABLE 18

Petrographic descriptions of selected samples of the Granodiorite of Rocking Chair Lakes.

SAMPLE 35-19 COARSE GRAINED GRANODIORITE

Colorless, 2 to 4 mm, subhedral andesine, sericite altered; colorless, 1 to 2 mm, anhedral quartz, undulose; colorless, 1 to 2 mm, anhedral microcline, unaltered; green, .5 to 1 mm, subidioblastic biotite, partly altered to chlorite; colorless, .5 mm, euhedral muscovite;.1 mm, anhedral opaques, with biotite; yellow-green, .05 mm, xenoblastic epidote/clinozoisite.

MINERALOGY

andesine 58.3%
quartz 26.0%
microcline 9.4%
biotite 5.5%
muscovite tr
opaques tr
epi/cz tr
(288 points)

SAMPLE 34-2 QUARTZ DIORITE

Colorless, 2 to 3 mm, subhedral andesine, some kinked, clay alteration; colorless, .5 mm, anhedral quartz, undulose; red, .75 mm, anhedral opaques (rutile?);lepidioblastic, green, .1 mm, subidioblastic chlorite, after biotite; colorless, .1 mm, xenoblastic carbonate, along fractures;green- yellow, .1 mm, xenoblastic epidote/clinozoisite, in plagioclase; colorless, .05 mm, euhedral apatite, in plagioclase.

MINERALOGY

andesine 80%
quartz 10%
opaques 5%
chlorite 2%
carbonate 1%
epi/cz 1%
apatite tr

TABLE 19

Petrographic description of a highly altered part of the Granodiorite of Rocking Chair Lakes.

SAMPLE 34-16 FOLIATED GRANODIORITE?

Colorless, .25 mm, subhedral andesine, partly clay altered; colorless, .01 mm, xenoblastic plagioclase; lepidioblastic, green, 2 mm, subidioblastic chlorite; colorless, .1 mm, xenoblastic carbonate, disseminated and in veins; .05 mm, xenoblastic opaques (pyrite?), highly foliated.

MINERALOGY

plagioclase 50%
chlorite 22%
carbonate 13%
opaques 15%
(estimated)

TABLE 20

Petrographic descriptions of two representative samples of the Granite dikes.

SAMPLE 34-30 PINK MEDIUM GRAINED GRANITE

Light pink, 4 mm, anhedral microcline, perthitic; colorless, 3 mm, anhedral quartz, undulose; cloudy, 2.5 mm, subhedral to anhedral oligoclase-andesine; colorless, .5 mm, subhedral muscovite; green and brown, .5 mm, subhedral biotite, highly altered to chlorite;colorless, .01 mm, subidioblastic sericite.

MINERALOGY

microcline 42.8%
quartz 30.4%
ande/olig 26.4%
muscovite tr
biotite tr
sericite tr
(280 points)

SAMPLE 34-11 WHITE, APLITIC GRANITE DIKE

White, 2 mm, subhedral orthoclase; colorless, 1.5 to .5 mm, anhedral quartz, undulose;cloudy, 1 mm, subhedral andesine, minor sericite alteration;brown, .5 mm, euhedral biotite, minor chlorite alteration;colorless, .01 mm, subhedral muscovite; colorless, .01 mm, xenoblastic carbonate; colorless, .01 mm, subidioblastic sericite, in andesine and orthoclase; light green, .01 mm, subidioblastic chlorite.

MINERALOGY

orthoclase 51.6%
quartz 33.4%
andesine 10.4%
biotite 3.3%
muscovite 1.2%
carbonate tr
sericite tr
chlorite tr
(574 points)

TABLE 21

Petrographic descriptions of the Diorite intrusives.

SAMPLE 27-5 MEDIUM GRAINED DIORITE

Cloudy, 2.5 mm, subhedral andesine, minor sericite alteration; light green, 2 mm, euhedral to subhedral hornblende, minor chlorite alteration; colorless, 1.5 mm, anhedral microcline, unaltered; green, 1 mm, idioblastic to subidioblastic chlorite, from biotite and hornblende;

colorless, .02 mm, anhedral quartz, undulose; colorless, .1 mm, xenoblastic carbonate; colorless, .01 mm, subidioblastic sericite; light brown, 1.5 mm, euhedral sphene; .2 mm, subidioblastic opaques(pyrite?); light yellow, .01 mm, xenoblastic epidote/clinozoisite.

MINERALOGY

andesine 54.8%
hornblende 31.0%
microcline 9.8%
chlorite 3.4%
quartz 0.4%
carbonate 0.4%
sericite 0.2%
sphene tr
opaques tr
epi/cz tr
(500 points)

SAMPLE 27-16 COARSE GRAINED DIORITE

Yellow-green, 3 mm, euhedral hornblende (Z C 22); colorless, 1 to 2 mm, anhedral andesine, highly sericite altered; colorless, 1 mm, anhedral microcline, unaltered; green, .5 mm, subidioblastic chlorite, in hornblende;yellow-green, .25 mm, subidioblastic epidote/clinozoisite;colorless, .01 mm, xenoblastic sericite; brown, .05 mm, euhedral sphene; colorless, .05 mm, anhedral apatite.

MINERALOGY

hornblende 4.6%
andesine 39.5%
microcline 9.5%
chlorite 4.0%
epi/cz 3.3%
sericite tr
sphene tr
apatite tr
(273 points)

TABLE 22

Petrographic description of the contact metamorphic rock found near the diorite intrusion in central section 34.

SAMPLE C34-4 GARNET-BIOTITE HORNFELS

Porphyroblastic, light pink, 2.5 mm, idioblastic garnet (Fe rich); colorless, .4 mm, subidioblastic oligoclase, some (primary?) grains highly sericite altered; colorless, .1 mm, xenoblastic quartz, clean extinction;brown-green, .75 mm, idioblastic biotite; colorless, .05 mm, subidioblastic sericite; .05 to .1 mm, xenoblastic opaques (galena and pyrite), as blebs in garnet and in matrix; colorless, 1 mm, subidioblastic anthophyllite?, highly sericite altered.

MINERALOGY

garnet 35%
oligoclase 20%
quartz 13%
biotite 10%
sericite 10%
opaques 7%
anthophyllite 5%
(estimated)

TABLE 23

Petrographic description of a carbonate altered variety of the Michigamme Formation.

SAMPLE 34-14 CARBONATE ALTERED CONGLOMERATE

Colorless, .1 to 1 mm, xenoblastic carbonate (ankerite?), replacement of matrix;colorless, 2 cm to .1 mm, subangular quartz clasts, composed of many individual undulose grains; colorless, .01 mm, subidioblastic sericite; light green, .01 mm, subidioblastic chlorite; red-black, .05 mm, idioblastic to subidioblastic opaques(rutile?).

MINERALOGY CLASTS:

quartz 100% MATRIX:
carbonate 85%
quartz 12%
sericite 2%
chlorite tr
opaques tr
(estimated)

TABLE 24

Petrographic descriptions of representative samples from the Lower Proterozoic diabase.

SAMPLE 26-28 DIABASE (greenschist facies)

Green, 1 mm, subidioblastic actinolite (Z C 15), replacing pyroxene; clear, .75 mm, subhedral andesine, altered to epidote/clinozoisite and sericite; light yellow, .01 mm, xenoblastic epidote; .2 mm, anhedral opaques (magnetite?); green, .01 mm, subidioblastic chlorite, in actinolite; colorless, .01 mm, subidioblastic sericite, in plagioclase; brown, .1 mm, xenoblastic sphene.

MINERALOGY

actinolite 45%
andesine 35%
epidote 10%
opaques 8%
chlorite tr
sericite tr
sphene tr
(estimated)

SAMPLE 26-9 DIABASE (greenschist facies)

Green-blue, .8 mm, subidioblastic actinolite (Z C 15), altered from pyroxene;colorless, .6 mm, subhedral andesine, epidote and sericite altered; light yellow, .05 mm, xenoblastic epidote/ clinozoisite;.2 mm, anhedral opaques (magnetite?), skeletal; green, .01 mm, subidioblastic chlorite, in amphiboles; colorless, .01 mm, subidioblastic sericite, in plagioclase; brown, .1 mm, xenoblastic sphene, with magnetite.

MINERALOGY

actinolite 45%
andesine 35%
epi/cz 13%
sphene 5%
opaques 2%
chlorite tr
sericite tr
(estimated)

TABLE 25

Petrographic descriptions of selected samples of the north-south trending Lower Proterozoic Diabase.

SAMPLE 26-26 DIABASE (greenschist, N-S trending)

Light green, 2 mm, idioblastic actinolite, commonly twinned, relatively fresh;colorless, 1.5 mm, subhedral oligoclase, highly altered to sericite and epidote; light yellow, .02 mm, xenoblastic epidote/clinozoisite; colorless, .01 mm, subidioblastic sericite;brown, .5 mm, anhedral, sphene, skeletal (from magnetite); green, .05 mm, subidioblastic chlorite, intersitital.

MINERALOGY

actinolite 40%
epi/cz 25%
oligioclase 10%
sericite 10%
sphene 10%
chlorite 5%
(estimated)

SAMPLE 26-18 DIABASE (greenschist, N-S trending)

Colorless, 1.5 mm, subhedral oligoclase, sericite and epidote alteration;light green, .75 mm, subidioblastic actinolite, relict pyroxene;green, .2 mm, subidioblastic chlorite, in amphibole; brown, .5 mm, xenoblastic sphene, from magnetite; colorless, .01 mm, subidioblastic sericite; light yellow, .02 mm, xenoblastic epidote/clinozoisite; colorless, .01 mm, xenoblastic carbonate.

MINERALOGY

oligioclase 40%
actinolite 35%
chlorite 10%
sphene 10%
sericite 2%
epi/cz 2%
carbonate tr
(estimated)

TABLE 27

Petrographic description of a selected sample from the east-west trending Keweenawan Diabase.

SAMPLE 36-23 UNALTERED DIABASE

Colorless, 1 mm, euhedral labradorite laths, unaltered; light grey, .75 mm, subhedral clinopyroxene, commonly twinned; 1.5 mm, anhedral opaques(magnetite?), skeletal; light yellow, .5 mm, anhedral olivine, fractured; green, .05 mm, xenoblastic chlorite. @TABLE = MINERALOGY

labradorite 55%
clinopyroxene 30%
opaques 10%
olivine 5%
chlorite tr
(estimated)

TABLE 28

Background gold assay values from the Penny Lake Area.

Sample Number	Rock Type	Au (ppb)
SE25-8	Aq	6
26-3	Agn	9
26-4	bAif	2
27-2	Ab	3
34-6	Agn	6
34-17	Ab	9
34-31	Aq	7
35-14	Aba	2
35-29	Aq	7
36-14	Aq	8
36-17	Aba	3
36-22	Ab	4

SAMPLE Descriptions-

SE25- - Colorless to milky green quartz vein, adjacent to chlorite altered basalt. Somewhat granular with no visible sulfides.

26-3 - Typical tonalite gneiss sample with pegmatitic granite vein. No visible sulfides.

26-4b - Iron Formation Member with magnetite and epidote bands. Minor pyrite

27-2 - Amphibolite facies basalt with .5 to 2 mm chalcopyrite and pyrite. Highly foliated sample, near contact with Gneiss.

34-6 - Highly foliated sample from north end of Granodior ite of Rocking Chair Lakes. Contains up to 20 percent euhedral, medium grained pyrite.

34-17 - Foliated basalt and rhyolite with quartz and gra niteveins. Some veins contain hematite, and basalts are highly altered to epidote.

34-31 - Quartz vein in basalt, 15 cm wide. Vein contains up to 10 percent sulfides, including; pyrite, chalcopyrite, and sphalerite.

35-14 - Chlorite and muscovite rich rock near contact with smallgranitoid pluton. Possibly highly foliated Hill's Lakes Pyroclastic, contains no sulfides.

35-29 - Milky white quartz vein with highly foliated gabbro fragments. Euhedral, 2 to 3 mm, pyrite within both gabbro and quartz.

36-14 - Quartz vein breccia with basalt fragments. Epidote and silicic alteration, no visible sulfides.

36-17 - Highly silicified basalt with quartz pods and minor chlorite alteration. Contains up to 2 percent euhedral pyrite.

36-22 - Typical epidote-amphibolite facies basalt, minor silicic alteration.

TABLE 29

Anomalous gold assay values from the Penny Lake Area.

Sample Rock Au