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GEOLOGY OF THE BOISE CREEK AREA, MARQUETTE GREENSTONE BELT, MICHIGAN

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ABSTRACT

During the summer of 1989, a 12 mi^2 (31.1 km^2) area in the northern block of the Marquette Greenstone Belt was geologically mapped. The field area comprises sections 29, 30, 31, and 32 of T50N, R27W, and sections 4, 5, 6, 7, 8, 9, 16, and 17 of T49N, R27W.

The oldest rocks in the Boise Creek area are a succession of Archean volcanic pillowed and massive basalt lava flows referred to as the Lighthouse Point basalt. These basalts include an interflow pyroclastic member and a banded iron formation member. The volcanic pile has been intruded by sills of Archean gabbro and dikes of rhyolite.

Several different units of Archean plutonic rocks are distinguished on textural and compositional criteria, but their age relationships are less clear. Gneissic rocks, which crop out in the northern part of the area, range in composition from granite to diorite and are strongly to weakly foliated. The Rocking Chair Lakes granodiorite crops out in the southern part of the area. A number of granite intrusions have been mapped in the Boise Creek area. The granodiorite and gneiss are older than the granite.

The structure in the Boise Creek area is quite complex. The orientation of the iron formation and gabbroic sills outline a block scale Archean fold. Foliation measurements suggest that a planar foliation was folded, which would imply at least two deformational events in the area. Metamorphic grade, based on field and thin section data, varies in the Boise Creek area from amphibolite to greenschist facies. The higher grades of metamorphism in the volcanic rocks are typically located near the contact boundary with the Archean gneiss. This suggests that Archean metamorphism is related to the emplacement of the gneisses.

Alteration and gold mineralization is associated with iron sulfides and spatially with highly foliated rocks representing high strain zones. Of twenty-three samples from the Boise Creek area that were assayed for gold, nine contained gold concentrations greater than 10 parts per billion with the highest being 170 ppb. Alteration is retrograde after amphibolite metamorphic alteration indicating that it is post peak metamorphism.

Sediments of the Lower Proterozoic Michigamme Formation unconformably lie on top of the Archean. All of the Archean rocks have been cut by Lower Proterozoic and Keweenawan diabase dikes.

INTRODUCTION

This report describes the geology of a 12 mi^2 (31.1 km^2) area in the north-central part of the northern block of the Marquette Greenstone Belt (Fig. 1). The major rock units and geologic structures were mapped at a scale of 1:9000; in addition, several areas with higher potential for mineral resources were mapped at a scale of 1:1800. This project is east of previous geologic mapping by Small and Bornhorst (1989). Rock unit descriptions are supplemented with petrographic data in order to define metamorphic grade as well as alteration assemblages and their associated mineralization. This project was funded by the COGEOMAP program of the U.S. Geological Survey, the Geological Survey Division of the Michigan Department of Natural Resources, the Mineral Institute program administrated by the U.S. Bureau of Mines, and the Department of Geological Engineering, Geology and Geophysics at Michigan Technological University.

LOCATION AND ACCESSIBILITY

The Boise Creek map area is located approximately 15 miles northwest of Marquette, Michigan (latitude 46° 40' and longitude 87° 42'). It is completely within the Negaunee NW 7.5 minute quadrangle, and includes sections 29, 30, 31, and 32 of T50N., R27W, and sections 4, 5, 6, 7, 8, 9, 16, and 17 of T49N, R27W. Access to the eastern part of the field is excellent along County Road 510 (improved gravel), and the southern part of the area is directly accessible by means of the Red Road (gravel). The western and northern parts of the field area are accessed from an unimproved logging trail located one mile south of the hairpin curve on County Road 510. Old logging roads are abundant throughout the area and improve access by foot.

FIELD PROCEDURES

Field mapping was carried out during the summer of 1989. Geologic features were mapped on to 1:9000 enlargements of the topography taken directly from the Negaunee NW 7.5 minute quadrangle. In flat areas with little or no topography the pace-and-compass method was used along traverse lines, which were generally spaced 750 feet apart. Some outcrops are enlarged to show geologic relationships and others, typically along cliffs, were not fully mapped and are left open on the map. Where possible contacts were walked out, but in areas of sparse outcrop contacts were inferred.

ACKNOWLEDGEMENTS

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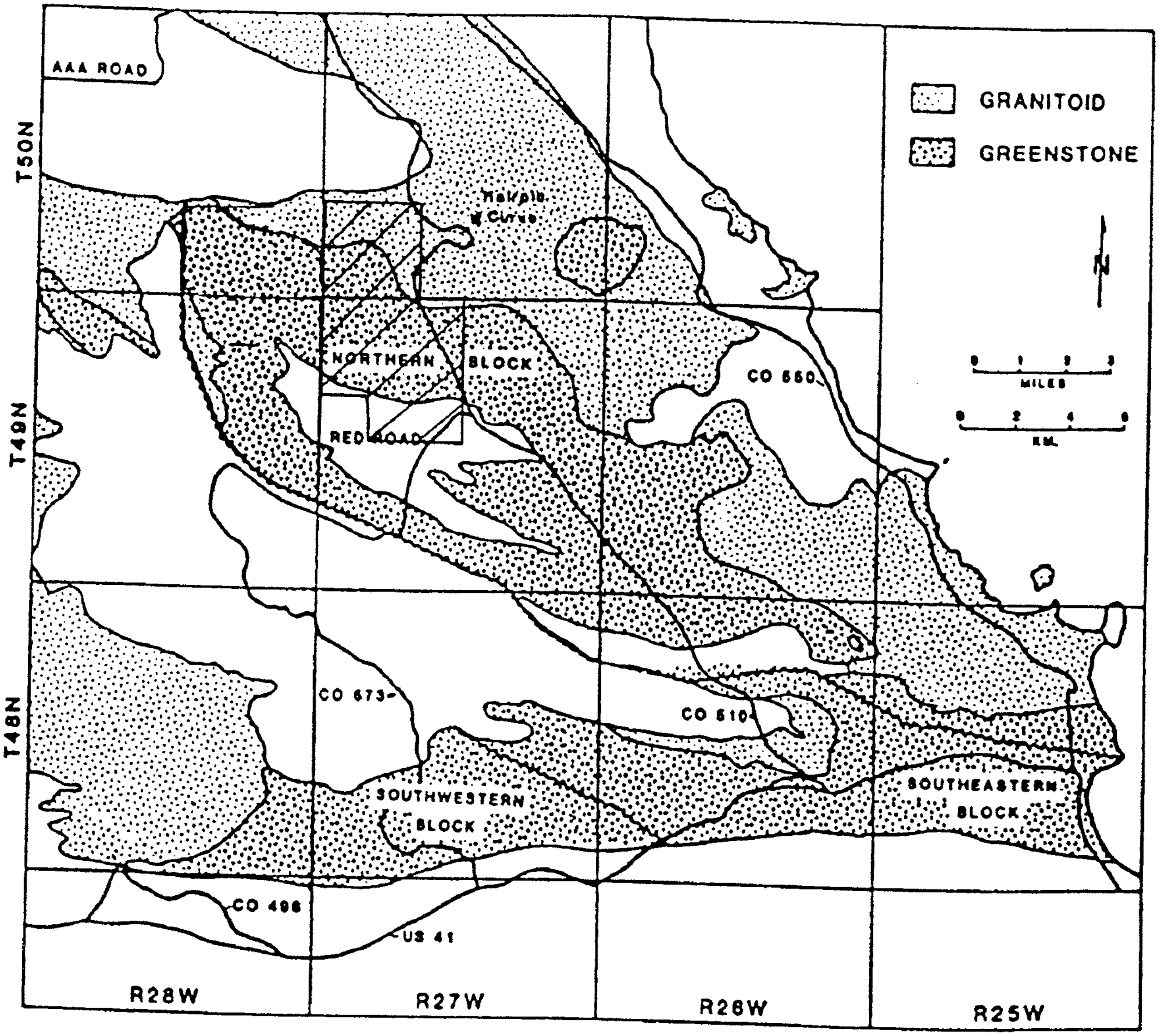

Figure 1. Location map of the Boise Creek area within the Marquette Greenstone Belt showing lithostratigraphic blocks (after Bornhorst, 1988).

Numerous discussions in the lab and office with Rodney Johnson improved the quality of this study. Bob McCarthy prepared thin sections and directed sample preparation.

PREVIOUS WORK

Bodwell (1972) examined the mineral potential of northern Marquette County on a regional scale (1:62,500). This is the only published geologic map for the Boise Creek area prior to this report. To the west of the area, detailed mapping has been carried out by Johnson et.al. (1987) and by Small and Bornhorst (1989). The geologic framework of the greenstone belt has recently been described by Bornhorst (1988). The Archean geology of the block is described by a concurrent study, Johnson and Bornhorst (in review).

GEOLOGIC SETTING

REGIONAL GEOLOGY

The Boise Creek area is located in the northern block of the Marquette Greenstone Belt (Bornhorst, 1988). The northern block is predominantly composed of a thick sequence of pillowed and massive basalt flows (Fig.2). In the northern block, volumetrically minor units include a single iron formation and two pyroclastic breccias which are stratigraphic interflow markers. The basalts and markers are intruded by sills of gabbro and, later, by rhyolite dikes and granitoid plugs and dikes. The northern block is bordered to the north and west by Archean granitoid gneisses. The southern border is buried by Lower Proterozoic sediments following the Dead River Storage Basin.

The metamorphic grade of the Archean rocks ranges from greenschist to amphibolite facies. Higher grades of

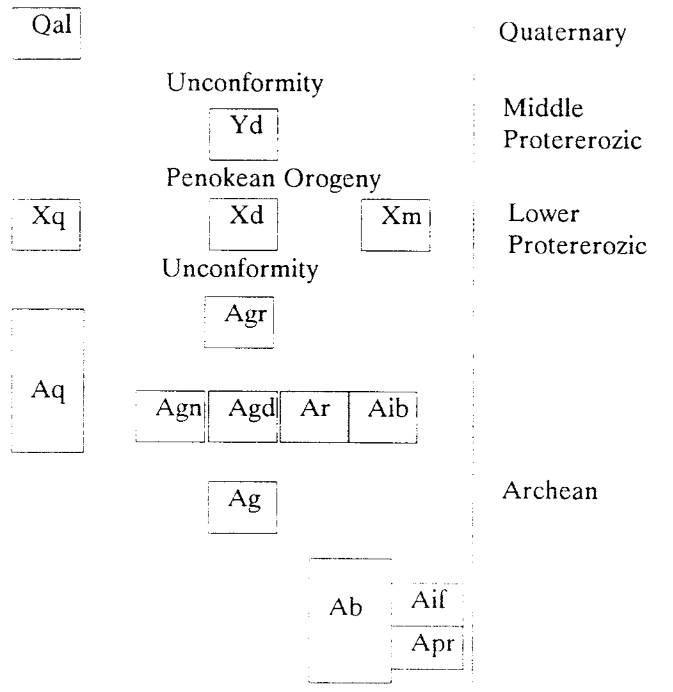

Figure 2A.
Correlation of map units within the Boise Creek area

LEGEND

Qal	Quaternary Alluvium
Yd	Keweenawan Diabase
Xd	Lower Proterozoic Diabase
Xm	Michigamme Formation
Xq	Quartz Veins
Aq	Archean Quartz Veins
Agr	Granite
Agd	Rocking Chair Lakes Granodiorite
Aib	Intrusive Breccia
Ar	Rhyolite Intrusive
Agn	Gneiss
Ag	Gabbro
Ab	Lighthouse Point Basalt
Aif	Fire Center Mine Iron Formation
Apr	Reany Lake Pyroclastic

Figure 2B.
Legend of map units within the Boise Creek area.

metamorphism are located, typically, near the contact with the gneisses. The major structural feature in the Boise Creek area is the continuation of the fold mapped to the west by Small and Bornhorst (1989). As in the area to the west, the strike of the gabbroic sills and the iron formation are subparallel to the limbs of the fold. The iron formation was first mapped in the southern limb of the northern block by Owens and Bornhorst (1985), and later in the northern limb by Small and Bornhorst (1989). Outcrops in several localities in the Boise Creek area suggest that it is a continuous unit (Plate 1). This is supported by an aeromagnetic anomaly which Johnson (1989) interpreted as corresponding to the iron formation, as well as ground based magnetometer surveys (Johnson, personal communication, 1989).

Lower Proterozoic diabase dikes cut across the Archean rock units. The center of the northern block is covered by Lower Proterozoic sediments of the Clark Creek Basin. Keweenawan diabase dikes cut across both Lower Proterozoic and Archean units.

ARCHEAN UNITS

INTRODUCTION

Rock unit descriptions are based on hand sample, thin section, and polished section analysis. The units have been named similar to Johnson and Bornhorst (in review). It should be noted that these rock unit names are different from those referred to by Owens and Bornhorst (1985), Johnson et.al. (1987), Baxter et.al. (1987), MacLellan and Bornhorst (1989), and Small and Bornhorst (1989).

LIGHTHOUSE POINT BASALT

The Lighthouse Point basalt is the name given to the dominant lithology in the Boise Creek area and the northern block as a whole. This formation is composed of Archean pillowed and massive basalt lava flows. The thickness is estimated to be near 3000 meters. An accurate estimate of the total thickness is difficult due to the paucity of interbedded sediments and the possibility of structural repetition due to folding and faulting.

The distinction between pillowed and massive flows is made based on grain size and the lack of pillow rind material in the massive basalt flows. Pillowed basalts are fine grained; massive basalts are fine to medium grained. These two rock types have been mapped as a single unit, however, an attempt to show an approximate distribution of the massive flows has been made in Figure 3.

Both types of basalt range in color from black to dark green and are typically foliated. However, due to their coarser grain size the massive basalt flows are often unfoliated. Pillow rinds are common in upper greenschist facies rocks but stratigraphic tops could rarely be determined. At amphibolite and epidote-amphibolite grade the pillow rinds are recognizable, but they are extremely deformed and often define ptygmatic folds.

The mineralogy of the basalts is dependent on the metamorphic grade. Amphibolite grade basalts contain green to yellow-brown nematoblastic hornblende and plagioclase, with minor sphene and pyrite. Epidote-amphibolite grade basalts are characterized by green pleochroic hornblende, oligoclase, epidote/clinozoisite, chlorite, and minor amounts of sericite, carbonate, and pyrite. Upper greenschist grade basalts are found in sporadic locations in the southern part of the area and are composed of pale green, weakly pleochroic ferro-actinolite, albite, chlorite, epidote/clinozoisite, and minor pyrite.

Altered varieties of basalt are shown on Plate 1. Altered basalt can be either highly foliated or more massive. When highly foliated, it is often found along fault zones or in narrow (1 meter) shear zones. These rocks are green,

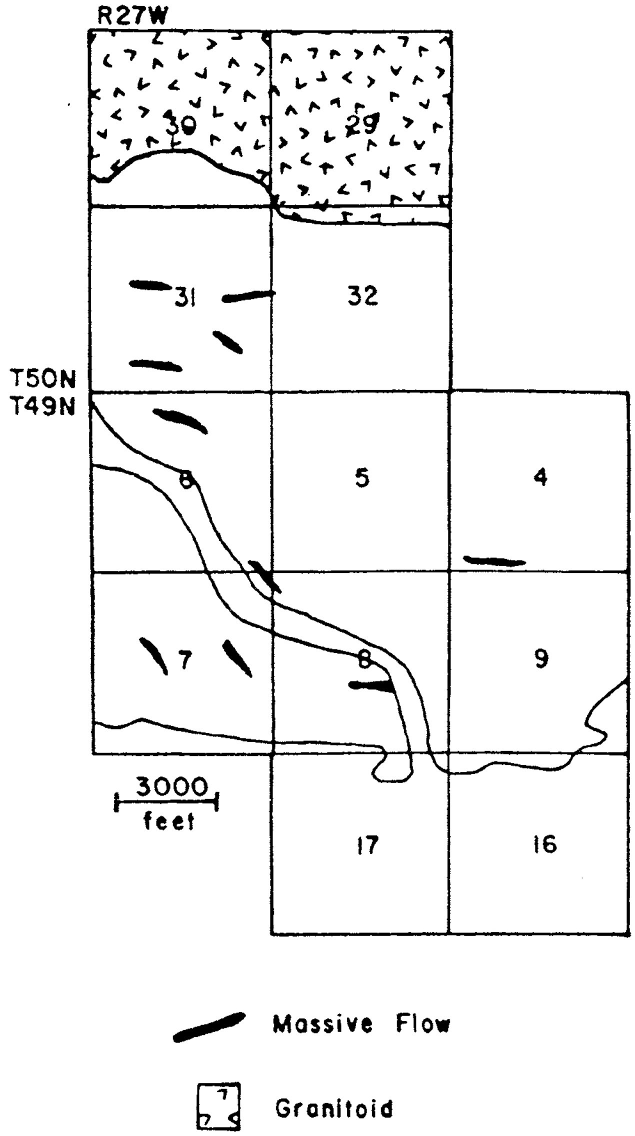

Figure 3. Approximate location of massive flows in the Boise Creek area.

chloritic phyllonites that often contain pods of quartz and occasionally calcite. In several localities

these phyllonites have up to 20% disseminated pyrite. All of these zones are too small to show at 1:9000, but one such area was mapped in detail (Plate 1, detail A). Another area, unmapped in detail, is located in the southeast corner of section 9, adjacent to rhyolite dikes shown on the map (Plate 1). When massive, the altered basalts are light green to gray and weakly foliated with the mineral assemblage epidote/clinozoisite, chlorite, calcite, clinopyroxene, and garnet. Pyrite, chalcopyrite, and pyrrhotite occur along fractures and in 1 to 3 millimeter wide veinlets. There is a gradation between unaltered epidote-amphibolite grade basalts to those cut by veins of epidote/clinozoisite and finally to more pervasive altered varieties. One such alteration zone is shown in Detail C, (Plate 1). This alteration zone is spatially associated with a northwest trending fault that truncates a large gabbroic sill. Probably, this fault acted as a conduit for hydrothermal fluids that produced the alteration.

Reany Lake Pyroclastic

The Reany Lake pyroclastic was originally mapped in the southern part of the northern block by Owens and Bornhorst (1985) and by Baxter et.al.(1987) as the Pyroclastic Member and the Mudflow Member of the Volcanics of Silver Mine Lakes, respectively. In the Boise Creek area the Reany Lake pyroclastic is a relatively thin unit (5-10 meters) and crops out in three localities in sections 31 and 32. Correlation of these rocks with those further south is difficult because of an intervening cover of Lower Proterozoic sediments and differences in the grade of metamorphism, amphibolite facies in the Boise Creek area versus greenschist in the south. However, its character and spatial association with iron formation gives high confidence to this correlation. This unit is bounded below by basalt and above by iron formation.

The Reany Lake pyroclastic consists of a quartz stringer horizon underlain by a massive lithic poor horizon. The quartz stringer horizon is characterized by a green to tan schistose matrix consisting of Fe-amphibole and chlorite, with common white to clear quartz stringers. This horizon contains disseminated pyrite and chalcopyrite in all outcrops. The massive horizon consists of a fine grained, light gray granular matrix with dispersed grains of amphibole and quartz.

Fire Center Mine Iron Formation

The Fire Center mine iron formation crops out in sections 31 and 32 in the Boise Creek area. It is never thicker than two meters in outcrop, and is bounded on the bottom by the Reany Lake pyroclastic and on the top by pillowed basalt flows of the Lighthouse Point basalt. This unit rarely crops out but magnetic anomalies confirm the more or less continuous presence of the iron formation. The banding in the iron formation strikes N70W and dips 82 to the south in the north part of section 31 where it is well exposed in a creek bed. In the Boise Creek area the iron formation is banded with .5 to 3 centimeter layers of magnetite and quartz plus epidote. There are also minor amounts of Fe-amphibole, pyrhottite and chalcopyrite.

This member was mapped to the west by Small and Bornhorst (1989) and can be traced via aeromagnetic data through the Boise Creek area. Based on sparse outcrops and magnetic data to the east of the Boise Creek area, the iron formation traces out the nose of a fold and even though it does not crop out it is inferred in the southeast corner of section 9. Magnetic data also support the existence of this iron formation beneath Lower Proterozoic sedimentary cover to the south and its correlation with an iron formation located in the southern part of the northern block (Johnson and Bornhorst, in review).

In one location the iron formation is diminished in iron content. This exposure in section 32 is composed of 1-5 cm. layers of quartz and chlorite and 1-3 cm layers of hornblende and chlorite. Pyrite is common throughout the layers and comprises 10% of the rock. Magnetite is not

Era	Subdivision	OWENS AND BORNHORST (1985)	BAXTER ET. AL. (1987)	MACLELLAN AND BORNHORST (1989)
Middle Proterozoic		Keweenawan Diabase	Keweenawan Diabase	Keweenawan Diabase
Early Proterozoic — Marquette Range Supergroup	Baraga Group	Michigamme Formation	Metadiabase; Michigamme Formation	Michigamme Formation
Early Proterozoic — Marquette Range Supergroup	Menominee Group			
Early Proterozoic — Marquette Range Supergroup	Chocolay Group	Slates of the Dead River Storage Basin		Reany Creek Formation
Archean		Breccia of Hoyoke Mine		
Archean				
Archean			Granodiorite of Rocking Chair Lakes	Granodiorite of the Dead River Pluton
Archean		Rhyolite Porphyry of Fire Center Mine	Rhyolite Intrusive of Fire Center Mine	Rhyolite Intrusive of Fire Center Mine
Archean		Metagabbro of Clark Creek	Metagabbro of Clark Creek	Gabbro of Clark Creek
Archean		Metavolcanics of Silver Mine Lakes	Metavolcanics of Silver Mine Lakes	Volcanics of Silver Mine Lakes

Figure 4A1.
Correlation chart for the rock units in the northern block

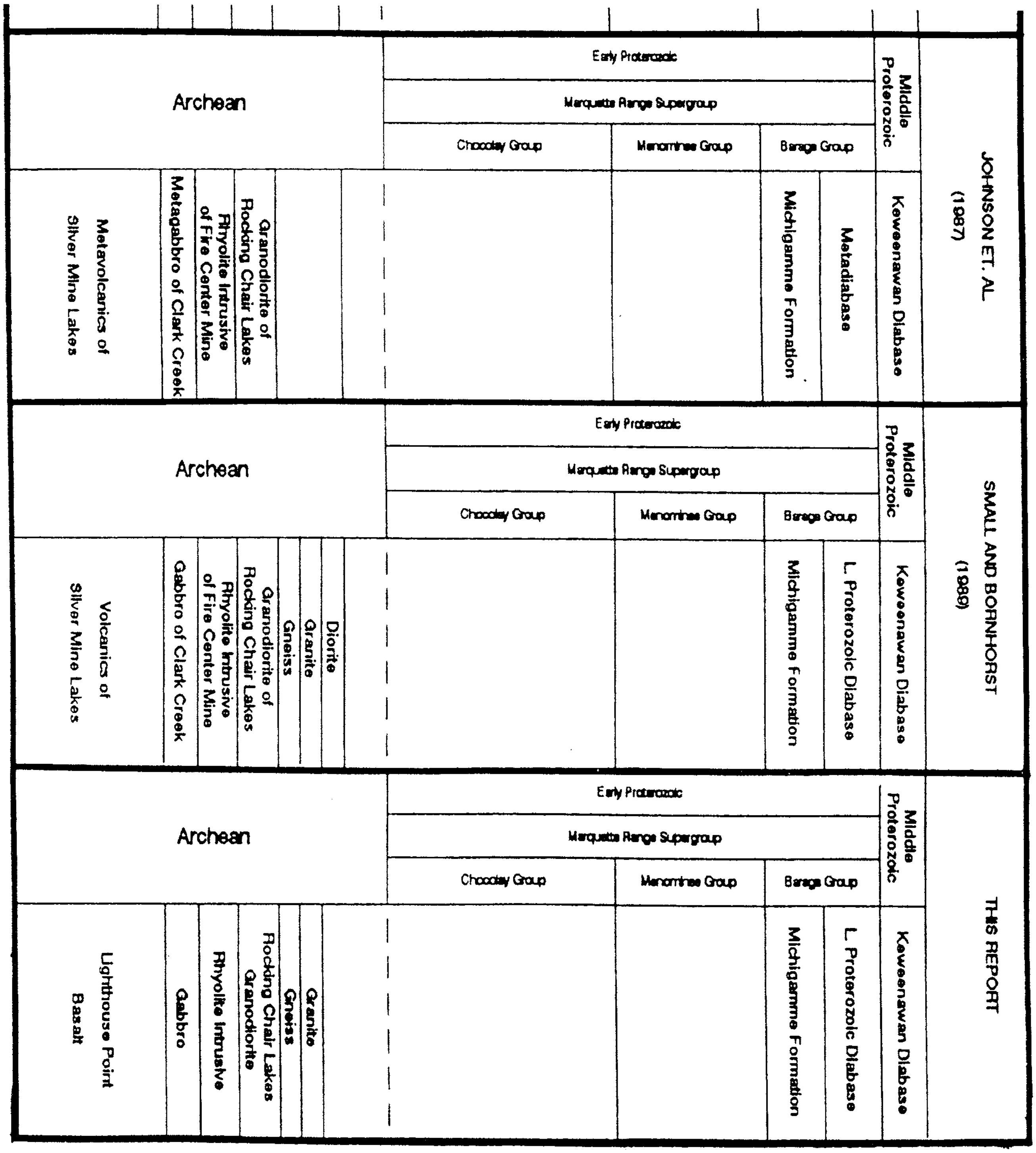

Figure 4A2.
Correlation chart for the rock units in the northern block

	OWENS AND BORNHORST (1985)	BAXTER ET. AL. (1987)	MACLELLAN AND BORNHORST (1989)	JOHNSON ET. AL. (1987)	SMALL AND BORNHORST (1989)	THIS REPORT
Archean	Pillowed Basalt	Upper Pillowed Basalt	Pillowed Basalt	Upper Pillowed Basalt	Pillowed Basalt	Lighthouse Point Basalt
	Laminated Schist			Hill's Lake Pyroclastic	Hill's Lake Pyroclastic	
					Pillowed Basalt	
	Iron Formation	Iron Formation	Iron Formation		Iron Formation	*Fire Center Mine* Iron Formation
	Pyroclastic	Mudflow Member	Breccia of Reany Lake			Reany Lake Pyroclastic
	Pillowed Basalt	Lower Pillowed Basalt	Breccia of Bismark Creek	Pillowed Basalt	Pillowed Basalt	Lighthouse Point Basalt
			Pillowed Basalt			

Figure 4B
Correlation chart for the members of the Lighthouse Point basalt.

present. This rock is considered to part of the Fire Center mine iron formation based on its banded character and its similar quartz-amphibole mineralogy. The amphibole layers suggest a depositional environment dominated by clastic sedimentation and may be more distal to exhalitive vent sources than the magnetite-rich iron formation. It may also represent a gradational contact between the iron formation and the underlying pyroclastic unit.

GABBRO

Johnson and Bornhorst (in review) recommend usage of gabbro for these rocks rather than the previous informal name Gabbro of Clark Creek. The Boise Creek area includes several bodies of coarse grained mafic rock that are referred to as gabbro. The distinction between gabbro and massive basalt flows is made on the criteria of grain size, and field relationships. Mafic rocks with a grain size coarser than about 4 millimeters have been mapped as gabbro. The continuity and lateral extent of true intrusive gabbro bodies is much clearer than the massive basaltic flows.

The gabbro intrusions are generally subparallel to the strike of bedding as indicated by the Fire Center mine iron formation. Where gabbros are in contact with basalts they take on a finer grain size which is reflective of chilled margins. In hand sample the gabbros have a distinct ophitic texture, and tend to be fairly rough. The average thickness of an individual intrusion is on the order of 250 meters.

The northernmost gabbro sill-like body crops out in section 31. This unit is an extension of the gabbro mapped by Small and Bornhorst (1989). The metamorphic grade of this body is amphibolite facies and it is composed of green-brown hornblende, calcic plagioclase, and minor amounts of sericite and pyrite. This gabbro appears to be at the same stratigraphic position as the one mapped in section 32. The gabbro mapped in sections 5 and 6 is at epidote-amphibolite facies and consists of green, pleochroic hornblende, plagioclase, chlorite, and minor amounts of epidote/clinozoiste, sericite, and pyrite.

Altered gabbro has been mapped in two different areas. In both areas the original gabbro has been epidotized. The altered gabbro in section 9 has been mapped in detail (Plate 1, detail C). In this area the gabbro has been truncated by a fault. It contains epidote/clinozoisite veins with minor amounts of calcite, pyrite, and chalcopyrite. Away from the veins the gabbro is relatively unaltered.

RHYOLITE INTRUSIVE

Johnson and Bornhorst (in review) recommend usage of Rhyolite Intrusive for these rocks rather than the previous informal name of Rhyolite Intrusive of Fire Center Mine. Rhyolite dikes are scattered throughout the Boise Creek area but are more common in the southern part of the area. The dikes range in thickness from .5 to 10 meters. Due to the scale of mapping in this project, none of these could be shown on plate 1; thus, a special symbol is used to show location and trend of some of these dikes. It should be noted that the width of these is exaggerated. Rhyolites are mapped in several detail sections (Plate 1, sections A, B, and D), and here the true exposure thickness is shown. The rhyolites are most common on the walls of ravines and on cliff faces.

Several different varieties of rhyolite occur in the Boise Creek area: porphyritic and aphyric. The porphyritic rhyolites have phenocrysts of quartz and albitic feldspar. Quartz porphyritic rhyolites are most common; but, there are also quartz-feldspar and feldspar porphyritic varieties. The porphyritic rhyolites are pink to gray in color with a groundmass of .05 mm diameter, equigranular quartz, and minor sericite and chlorite. The phenocrysts range in size from 1-5 mm. The aphyric rhyolites are also gray to pink in color and have a similar groundmass. Occasionally, rhyolite is tan in color and contains abundant sericite and disseminated pyrite e.g., in sections 7 and 8 (Plate 1, details A, and B).

ARCHEAN PLUTONIC UNITS

INTRODUCTION

The Boise Creek area contains several different kinds of Archean plutonic rocks that can be distinguished on textural and compositional criteria and may or may not be different in age. Gneissic rocks, which crop out in the northern part of the area, show a broad range of compositional types and are strongly to weakly foliated. The Rocking Chair Lakes granodiorite as named by Johnson and Bornhorst (in review) has been correlated with a granodiorite body in the Boise Creek area (Plate 1, detail D) and with granodiorite in the area to the west discussed by Small and Bornhorst (1989). Granite is the map unit used for plugs of granitic material that intrude the mafic rocks of the Boise Creek area.

GNEISS

Gneiss is the name given to medium to coarse grained foliated rocks that crop out in sections 29, 30, and 32. Small and Bornhorst (1989) mapped this unit in the Penny Lake area immediately to the west of the Boise Creek area. The gneiss is black to pink in color and is strongly to weakly foliated. It crops out infrequently, usually in steep ravines or on rounded knobs. The contact with the basalts is gradational and due to the outcrop density it can be difficult to locate. Amphibolitic xenoliths are common in the gneiss along the contact. Material resembling pillow rinds was observed in some of these xenoliths. In one outcrop 300 meters north of the mapped contact, a 20 meter long raft of pillowed basalt is engulfed in gneiss. These facts clearly indicate that the gneiss is intrusive into the Lighthouse Point basalt.

The composition of the gneiss ranges from diorite to granite based on the proportion of quartz and feldspar in thin sections. The mineralogy of the gneiss consists of

Greenschist	Epidote – Amphibolite	Amphibolite
Albite (An10–An17)	Oligoclase (An10–An30)	Ca–Plagioclase (An18–An100)
Actinolite	Hornblende	Hornblende
Chlorite	Chlorite	Epidote
Epidote	Epidote	

Figure 5. Mineral assembledges for individual metamorphic facies (after Miyashiro, 1961).

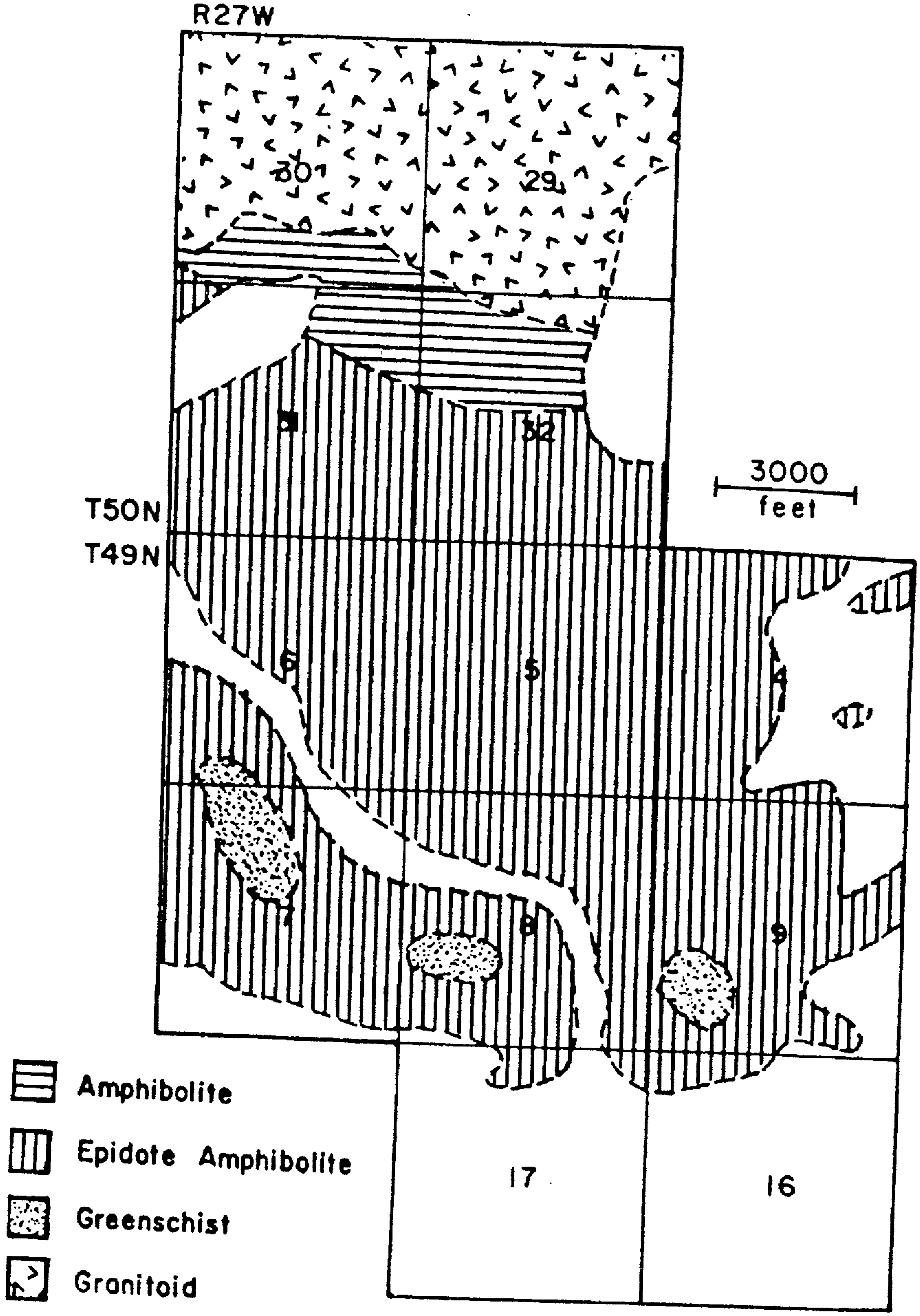

Figure 6. Location map of the metamorphic facies within the Boise Creek area.

varying amounts of quartz, plagioclase, orthoclase, microcline, and hornblende with minor amounts of sericite, biotite, and chlorite. Subdivision of the gneissic rocks awaits further study but this may prove to be difficult due to the large compositional variability at single outcrops.

ROCKING CHAIR LAKES GRANODIORITE

A massive granodioritic plug located in the southern part of the Boise Creek area (Plate 1, detail D) is correlated with the Rocking Chair Lakes granodiorite of Johnson and Bornhorst (in review). The plug is a gray, medium-grained, massive granodiorite which consists of quartz, andesine, orthoclase, and minor amounts of sericite and biotite that has been pseudomorphically replaced by chlorite. Several samples show strong carbonate alteration, and replacement of the feldspar by sericite. Hand samples of the altered variety show conspicuous red, earthy hematite that may be altered pyrite.

A peculiar intrusive breccia also crops out in detail D (Plate 1). This unit trends E-W, parallel to the contact between the granodiorite and a gabbro sill. This intrusive breccia contains fragments of pebble to boulder sized gabbro and basalt in a matrix of gray, medium-grained granodiorite. The breccia formed during the time the granodiorite was intruded and may have been injected forcefully as there is a considerable amount of breakup in the gabbro.

GRANITE

Granite is the map name used for a number of plugs and stock-like bodies that occur in the Boise Creek area. Granite has been mapped in sections 4, 5, 6, 8 and 9. The outcrop pattern of these bodies is generally elliptical to arcuate in shape. The granite plugs intrude the Lighthouse Point basalt and the gabbro. Often associated with the plugs are .5 to 5 meter thick granitic dikes that extend into the surrounding rocks. None of these dikes have been shown on the map due to scale. Granitic dikes were often observed cutting the gneiss and Small and Bornhorst (1989) noted that granitic dikes cut the Rocking Chair Lakes granodiorite. This suggests that the granite intrusions may be the youngest plutonic event.

The granite is pink to white in color, and consists of equigranular quartz, orthoclase, microcline, plagioclase, and lesser amounts of sericite, biotite, and chlorite. Thin (.5-1 meter) aplitic and pegmatitic dikes are common in the Boise Creek area, but, it is unclear whether these are related to the granitic plugs.

QUARTZ VEINS

Both Archean and Lower Proterozoic quartz veins are present in the Boise Creek area. Quartz veins are common, but they are thin: 1 millimeter to 4 meters, so most of them have not been mapped. Two quartz veins are shown on the map in detail sections B and D representing Archean and Lower Proterozoic veins respectively. Three samples of vein quartz were analyzed for gold content and none of these yielded anomalous concentrations.

Archean quartz veins are white to dark gray in color and occasionally have a reddish color due to hematite staining. The quartz vein mapped in detail B is a massive gray vein with 1-4 millimeter cubes of pyrite. This quartz vein shows a close spatial relationship with a rhyolite dike. Other Archean quartz veins contain minor amounts of pyrite, chalcopyrite, and occasionally sphalerite. Unless evidence to the contrary exists all quartz veins cutting Archean rocks were assumed to be Archean in age.

The vein mapped in detail section D is a thin, milky white, crystalline quartz vein with no visible sulfides. It unequivocally postdates the Archean as it cuts across the Michigamme Formation of Early Proterozoic age.

PROTEROZOIC UNITS

MICHIGAMME FORMATION

The Michigamme Formation of Early Proterozoic age (Clark, et.al., 1975 and Sims, et.al., 1984), crops out in section 17 of the Boise Creek area.

In detail D (Plate 1) the Michigamme Formation consists of light green to tan quartz pebble conglomerate which contains pebble to cobble sized clasts of quartz, basalt, and rhyolite in a fine-grained schistose matrix. In this locality there is also a light gray, medium-grained quartzite and a black slate. Distinctions between these lithologies is not made on Plate 1. The quartzite in this locality contains earthy red hematite similar to that noted in the Rocking Chair Lakes granodiorite. Thus, this type of alteration is Proterozoic in age. The outcrops in the southern most part of section 17 are composed of a fine-grained, thinly bedded graywacke.

LOWER PROTEROZOIC DIABASE

Several Lower Proterozoic diabases were mapped in the Boise Creek area with both east-west and north-south trends. In the northern part of the area, especially within the gneiss, the dikes are more likely to trend east-west, whereas in the southern part they typically trend north-south. This may correspond to differing types of fracture systems in the gneisses and basalts. These dikes range in thickness from 1 to 15 meters and cut all Archean rock units.

In hand sample, the dikes are green in color with a diabasic texture. Their mineralogy consists of actinolite and plagioclase (often altered to sericite), chlorite, and minor amounts of opaques and carbonate; these are indicative of greenschist facies metamorphism.

KEWEENAWAN DIABASE

Keweenawan diabase is the name given to relatively unaltered, brown to black, medium grained diabase dikes that crop out in the Boise Creek area. These dikes are composed of plagioclase, clinopyroxene, and minor amounts of olivine and opaques. The maximum thickness of these dikes is 40 meters. They are considered to be Middle Proterozoic in age because of the lack of metamorphic alteration (Gair and Thaden, 1968, Puffett, 1974, and Clark, et.al., 1975). They are related to the development of the mid-continent rift system.

CORRELATION OF MAP UNITS

The stratigraphic correlation of map units within the Boise Creek area compared to those of Owens and Bornhorst (1985), Johnson, et.al. (1987), Baxter et. al.

(1987), MacLellan and Bornhorst (1989), and Small and Bornhorst (1989) is shown in Figure 4. The nomenclature used in this report is similar to the formalized recommendations of Johnson and Bornhorst (in review).

In this report Archean aged basalt is referred to as the Lighthouse Point basalt. Two interflow sedimentary units were mapped in the Boise Creek area and are referred to as the Fire Center mine iron formation and the Reany Lake pyroclastic. Gabbro sills which intrude the mafic volcanics are named gabbro and rhyolite dikes are referred to as rhyolite intrusive. Three Archean aged plutonic units in the Boise Creek area are named: Rocking Chair Lakes granodiorite, gneiss, and granite.

The Lower Proterozoic Michigamme Formation and diabase dikes, and Middle Proterozoic Keweenawan diabase of the Boise Creek area, all correlate to those units mapped elsewhere.

METAMORPHISM

The grade of metamorphism was estimated during field mapping. Amphibolite facies and epidote-amphibolite facies were the dominant grades of metamorphism. These grades are suggested by black to dark green coloration, and the presence of aligned crystals of hornblende. Greenschist facies is indicated by a light green to green color and the presence of chlorite, but is lesser in abundance in the Boise Creek area.

Subsequently, thin section data were used to supplement field observations in determining the metamorphic grade. In thin section, amphibolite facies is recognized based upon the presence of hornblende, whereas greenschist facies is indicated by the presence of actinolite (Winkler, 1979). However, there is a difficulty in distinguishing these two minerals, especially when the actinolite contains a significant amount of iron. Therefore, the distinction between these two facies is also based on Ca content of the plagioclase made by comparing the refractive index of the plagioclase with that of the balsam mounting medium. Figure 5 outlines the criteria used in determining the metamorphic grade and Figure 6 shows the distribution of metamorphic facies in the Boise Creek area.

STRUCTURE

ATTITUDE OF BEDDING

Due to the paucity of interbedded sediments within the Archean layered rocks an extensive study of bedding orientations is not possible. In the Boise Creek area bedding orientation has been measured in several outcrops of the Fire Center mine iron formation and the Reany Lake pyroclastic. The iron formation is seen dipping 82S in section 31. Further to the east beds within the Reany Lake pyroclastic dip to the south at a lower angle (45). To the west the iron formation dips at 71S. This data suggests that the Archean layered units in the Boise Creek area are at a high angle to horizontal. However, there is a shallowing of units to the east.

Bedding within the Lower Proterozoic Michigamme Formation in the southern part of section 17 strikes N60W and dips 50N. In detail D, the bedding in the Michigamme Formation is nearly horizontal.

GENERAL STRUCTURE

Sill-like bodies of gabbro and the trace of the Fire Center mine iron formation outline the northern limb of a synformal fold. Johnson and Bornhorst (in review) suggest that this represents a separate fold than the one mapped by Small and Bornhorst (1989). Based on an interpretation from magnetic data, the iron formation continues through section 32 and to the east of the Boise Creek area where it forms the nose of a fold. The strike of the iron formation changes from northwest to northeast in the nose, and the unit returns into the Boise Creek area in section 9, where it is covered by Quaternary alluvium. The buried section has been confirmed by ground magnetic surveys. Figure 7 shows the fold as outlined by the iron formation and several of the major gabbroic sills. Several granite plugs seem to parallel the fold axis. This fold represents the third Archean deformational event (D3) after a complex prior history (Johnson and Bornhorst, in review).

FOLIATIONS

Metamorphic fabric in the Archean rocks are defined by nematoblastic hornblende in amphibolite facies and epidote-amphibolite facies rocks, and by lepidoblastic chlorite in greenschist facies rocks. The poles to these planar features are plotted on a stereonet in Figure 8. It can be seen that the foliations have been folded. So, a total of at least two deformational events have occurred in the Archean rocks of the Boise Creek area.

Poles of foliation planes for the Lower Proterozoic sediments have been plotted on a stereonet shown in Figure 9. This cluster of poles is not related to those of the Archean rocks, which implies that the Penokean Orogeny had little effect on the Archean rocks. However, the difference in rock competency between the Archean and Lower Proterozoic rocks complicates this interpretation.

FAULTS

The recognition of faults in the Boise Creek area was made on the following criteria: truncation of mapped units, presence of highly foliated rocks, presence of brecciated rocks, and topographic lineaments.

Figure 10 shows all of the faults mapped on Plate 1. Faults are more abundant in the southern part of the area compared to the north. In part, this may reflect a lower density of outcrop in the northern part of the area due to extensive alluvium.

In the Boise Creek area rare east-west trending faults appear to be the oldest. They are truncated by N-S to NE-SW trending faults which are in turn truncated by NW-SE faults. NW-SE trends are the most common in the southern part of the area and are commonly associated with highly foliated rocks and rhyolite dikes.

MINERALIZATION

INTRODUCTION

A total of twenty-three samples were analyzed for gold from the Boise Creek area. Concentration of gold was determined by fire assay and neutron activation to a detection limit of 1 part per billion (Activation Laboratories LTD Ancastor, Ontario). Gold values

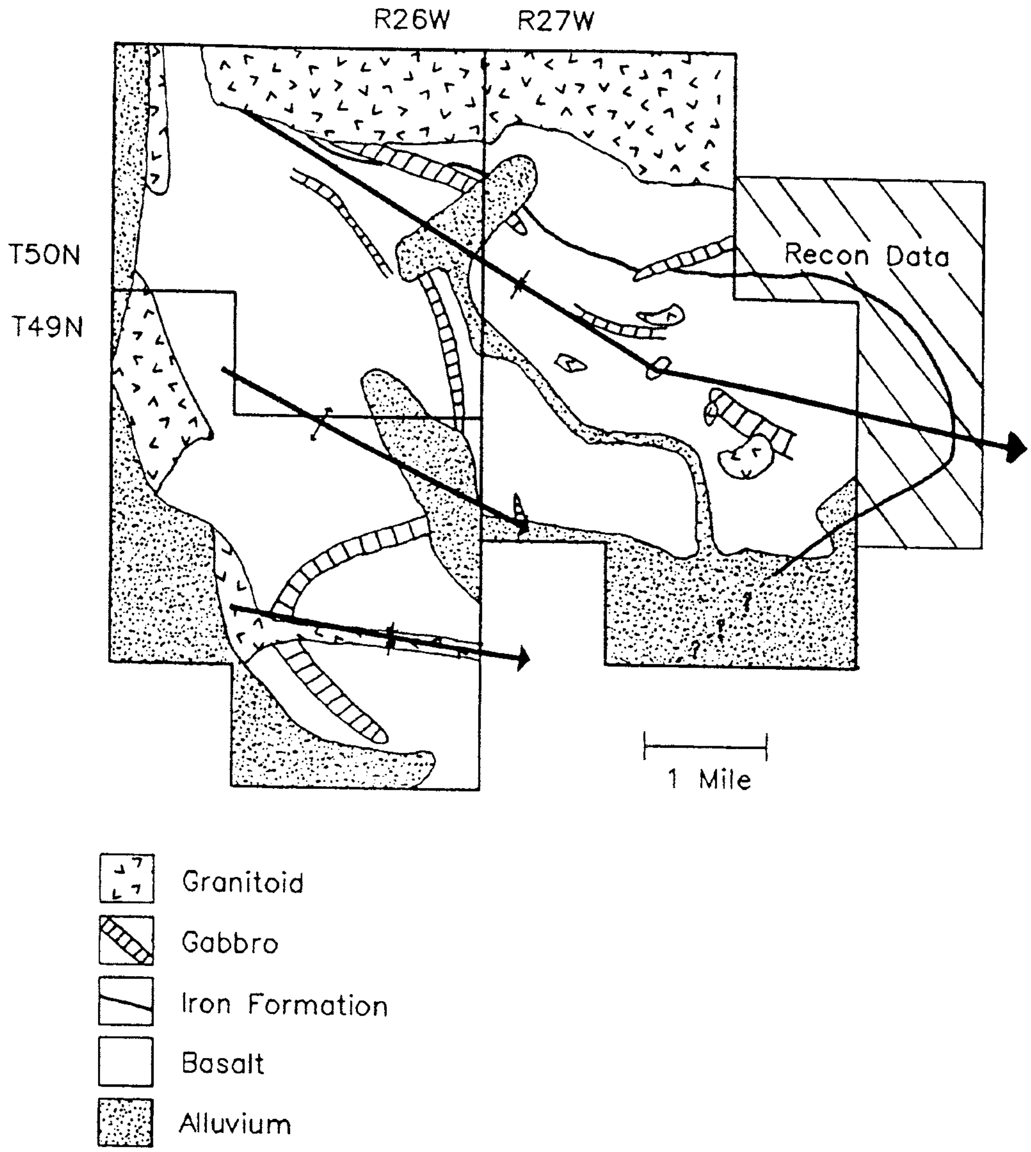

Figure 7. Geologic map showing the Boise Creek area and areas to the east studied by Small & Bornhorst, (1989) and Johnson, et al (1987).

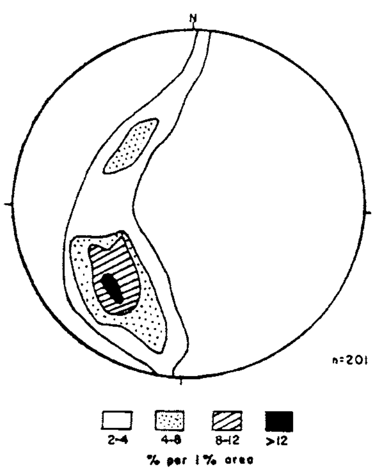

Figure 8. Plot of poles to foliations in Archean rocks, contoured using the method of Regan, (1985)

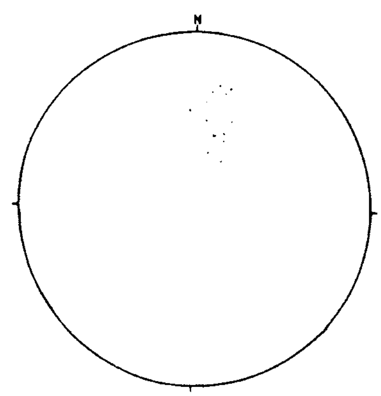

Figure 9. Plot of poles to cleavage planes in Lower Proterozoic sediments.

greater than 10 parts per billion are considered to be anomalous (Kwong and Crocket, 1978).

Table 1 gives descriptions of all samples with background values of gold and Table 2 describes those with anomalous values. Since only a very limited number of samples were assayed for gold (Fig. 11) from the Boise Creek area, they may not adequately represent the potential for gold resources in this area.

NATURE OF MINERALIZATION

The majority of samples with anomalous gold values are from areas either in or nearby faults. An example of one such fault is located in detail A (Plate 1). This locality yielded three anomalous samples with concentrations ranging from 12-170 ppb. In this area highly foliated basalt is localized along a narrow stream valley. Foliation measurements show a change from dominantly NW-SE strikes outside of the stream valley to near N-S strikes within the valley, confirming this as a shear zone. In several outcrops, brecciated and silicified rocks were observed. A rhyolite dike intruded this zone, and is spatially associated with the mineralization. The samples which contain anomalous gold values from this area also show a strong correlation with the presence of iron sulfides, commonly pyrite. These rocks are composed of up to 30% sulfides. The sulfide bearing rocks were only in the shear zone. In reflected light, samples from this area show pyrite and minor amounts of pyrhottite, chalcopyrite, and covellite followed by sphalerite.

In the SE corner of section 9, a similar mineralized shear zone has been identified. Highly foliated rocks occur along a topographic low, and are associated with rhyolite dikes. Rocks from this area contain up to 15% pyrite, but samples analyzed from this area did not show anomalous concentrations of gold.

The largest areas of alteration are shown on Plate 1 and on the detailed maps by a black dotted pattern. Two dominant types of alteration are: quartz-sericite-chlorite and epidote/clinozoisite-chlorite. Carbonate is ubiquitous in these assemblages. Detail A (Plate 1), and the previously mentioned area in the SE corner of section 9, both are characterized by quartz-sericite-chlorite alteration with minor amounts of carbonate. Epidote/clinozoisite-chlorite-carbonate alteration characterizes detail C (Plate 1) in the NW corner of section 31. Although pyrite, pyrhottite, and chalcopyrite are common sulfide minerals in this area, the few analyzed samples did not have anomalous gold. This alteration zone is associated with a NE trending fault.

The rocks in detail D (Plate 1) show a variety of alteration types. The Lighthouse Point basalt has been chloritized and cut by 1-3 mm. veinlets of pyrite and epidote. On weathered surfaces the basalt is highly bleached and shows iron staining along fractures. The basalt in this area yielded one anomalous gold concentration. The alteration may have occurred at the time the Rocking Chair Lakes granodiorite was emplaced, thus being Archean in age. In this area the granodiorite and sediments of the Michigamme Formation show a different type of alteration. These rocks have been carbonitized and contain earthy red hematite which may be altered pyrite. The presence of this alteration in the Michigamme Formation indicates that it occurred during the Early Proterozoic. None of the rocks analyzed with this type of alteration contained gold mineralization. The Proterozoic alteration may be overprinted on the Archean alteration in the form of intense iron staining along fractures.

Detail B (Plate 1) was mapped after 1:9000 scale mapping revealed an abundance of rhyolite intrusives associated with a pyrite bearing quartz vein. The quartz vein in this area did not contain anomalous gold, nor did any other quartz vein analyzed in this study. Rhyolite intrusives from this area yielded two anomalous samples. Both of these rhyolites contained disseminated, euhedral pyrite and are sericitized.

Alteration and associated gold mineralization appears to be sparse in the Boise Creek area although areas found in this study deserve further attention. Where found it is associated with faults or shear zones, rhyolite dikes and sulfide minerals. The alteration assemblages are retrograde after amphibolite facies metamorphic minerals indicating that alteration is post peak metamorphism.

TABLE 1

Background gold analyses from the Boise Creek area.

Sample Number	Rock Type	Au (PPB)
9SE17	Ab	4
6NW14	Ab	6
17NW4	Aq	1
9SE11	Aq	4
810	Aq	< 1
6NE6	Agr	1
31NE10	Ab	1
32SE11	Apr	3
32NW8	Agr	5
177	Agd	< 1
31SE28	Apr	< 1
94	Agr	6
97C	Ab	2
1713	Ar	< 1

Sample Descriptions

9SE17 Highly foliated basalt, quartz-sericite- chlorite altered with 15% pyrite.

6NW14 Fine grained, epidote-amphibolite facies basalt. No visible sulfides.

17NW4 Massive, white quartz vein, with a hematite staining. Includes chlorite stringers and minor amounts of .5-1 mm cubes of pyrite.

9SE11 Iron stained quartz vein, with minor amounts of disseminated pyrite.

810 Massive, gray quartz vein with abundant .5-2 mm cubes of pyrite.

6NE6 Coarse grained, chlorite altered granitic dike, with abundant .5-3 mm cubes of pyrite.

31NE10 Fine grained, amphibolite facies basalt, with visible pyrite and chalcopyrite, and a 1 cm wide quartz vein.

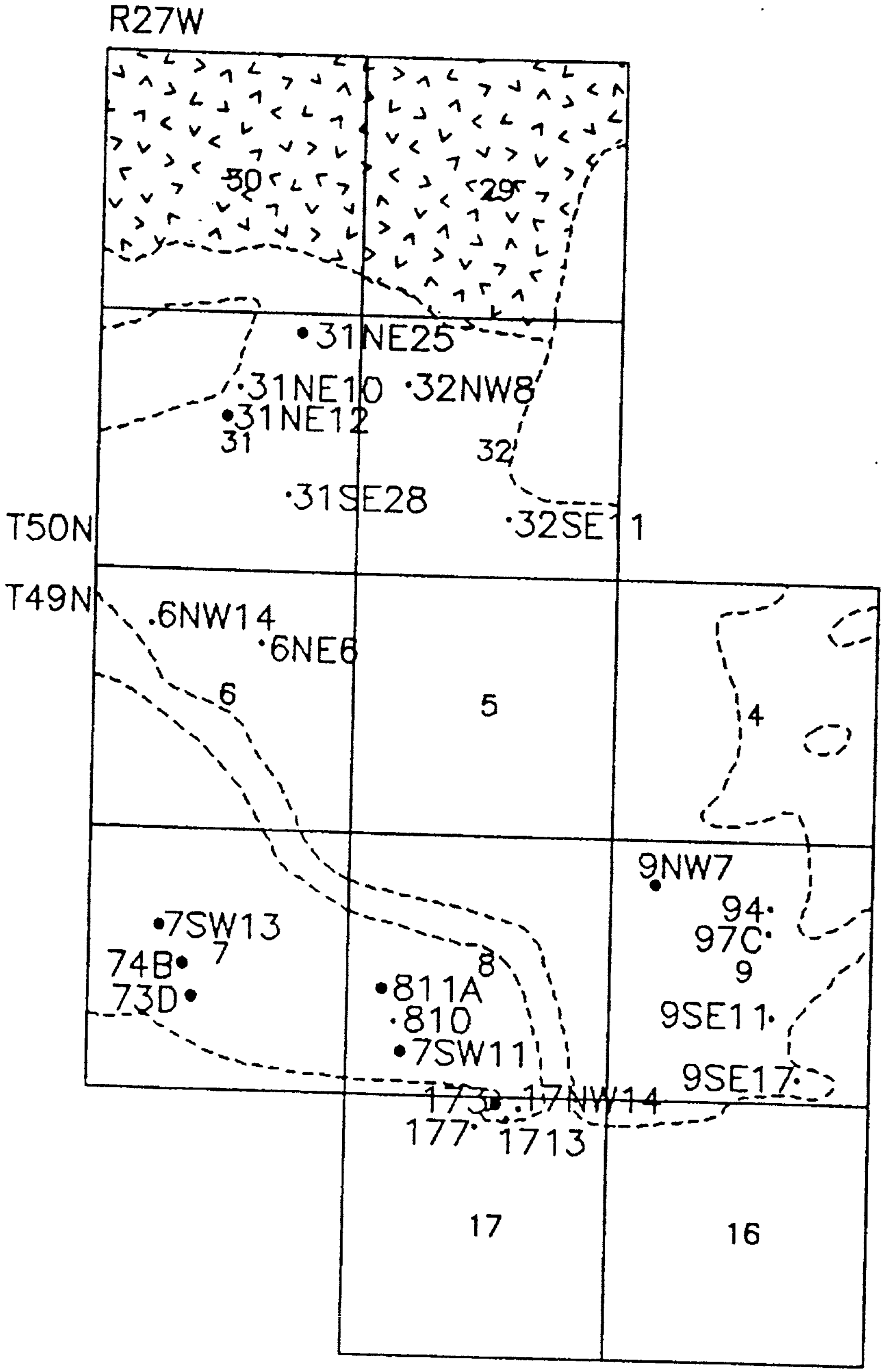

Figure 11. Map showing the location of assay values from the Boise Creek area.

32SE11 Layered iron formation, includes bands of massive Fe-amphibole and quartz-chlorite. Minor pyrite and chalcopyrite.

32NW8 Granitic dike cut by 1-3 cm thick quartz vein. Chloritized with abundant 1-2 mm pyrite cubes.

177 Massive, medium grained granodiorite, heavy limonitic alteration.

31SE28 Iron stained pyroclastic, cut by a pegmatitic dike.

94 Granitic dike with abundant disseminated pyrite.

97C Highly epidotized basalt with common pyrite, chalcopyrite, and calcite.

1713 Rhyolite intrusive with a reddish hematitic staining.

TABLE 2

Anomalous gold values from the Boise Creek area.

Sample Number	Rock Type	Au (PPB)
7SW11	Ar	45
73D	Ab	26
7SW13	Ab	12
173	Ab	25
811A	Ar	10
9NW7	Ag	15
74B	Ab	170
31NE25	Ab	45
31NE12	Aif	10

Sample Descriptions

7SW11 Highly foliated, quartz-sericite altered rhyolite, cut by 1 cm wide quartz vienlets. Abundant disseminated pyrite.

73D Brecciated basalt with stringers of quartz. Highly silicified with 1-2 mm euhedral pyrite.

7SW13 Highly foliated, quartz-sericite altered basalt with 10% pyrite + pyrhottite.

173 Chlorite-carbonate altered basalt with 2- 5% fine grained pyrite.

811A Gray, quartz porphyry rhyolite intrusive with common disseminated euhedral pyrite.

9NW7 Coarse grained, chlorite altered gabbro with no visible sulfides.

74B Foliated, sericite altered basalt, veined by quartz with .5-2 mm euhedral pyrite.

31NE25 Highly foliated and chloritized basalt, with pods of calcite. No visible sulfides.

31NE12 Banded, 1-4 cm quartz-epidote and magnetite layered iron formation with minor amounts of pyrhottite.

GEOLOGIC HISTORY

The earliest known event recorded in the rocks of the Boise Creek area is the extrusion of subaqueous pillowed and massive basalt lava flows. Thurston and Chivers (1989) have suggested that massive flows are characteristic of mafic plain volcanism, which is defined as having effusion rates intermediate between high-volume flood basalts and low- volume Hawaiian type volcanism. Mafic plain sequences are typified by 1-5 meter thick flows which cover up to several hundred km2. The flows ideally have massive interiors and thinner pillowed tops. The Lighthouse Point basalt fits the mafic plain sequence as defined by Thurston and Chivers (1986) except for the apparent paucity of massive flows. The lesser abundance of massive flows in the Lighthouse Point basalt as compared to Thurston's mafic plain volcanism may be due to lower effusion rates.

During a time of relative quiescence a subaqueous pyroclastic deposit and an exhalitive banded iron formation were deposited. Mafic volcanism continued after the deposition of these sediments. The age of the basalts is around 2.7 Ga Trow (1979). The volcanic pile was then intruded by dikes and sills of gabbro.

During an extended orogenic event the mafic rocks were deformed and metamorphosed and plutonic rocks and rhyolite dikes were emplaced. The emplacement of the granite plugs and dikes occurred near the end of this orogenic event, possibly along with the alteration and mineralization.

The area was then subjected to uplift and erosion, followed by the deposition of conglomerates, quartzites, slates, and graywackes of the Lower Proterozoic Michigamme Formation (1.9-2.1 Ga), and the intrusion of Lower Proterozoic diabase dikes. The Boise Creek area was again subjected to a deformational event, the Penokean Orogeny (1.83-1.89 Ga), which deformed and metamorphosed the Lower Proterozoic rocks. Archean faults may have been reactivated, but overall the Archean rocks are not greatly effected by the Penokean Orogeny.

During the Middle Proterozoic, the area was intruded by Keweenawan diabase dikes associated with the mid-continent rift.

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