Geology and Precious Metal Mineralization of the Fire Center and Holyoke Mines Area, Marquette County, Michigan

by
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ABSTRACT

The bedrock geology of the Fire Center and Holyoke Mines area (about 3 km^2) was mapped at a scale of 1:2,400 during the summer of 1984. The oldest rocks in the area consist of a succession of steeply dipping Archean metavolcanic rocks, named here the Metavolcanics of Silver Mine Lakes. From oldest to youngest, the members comprising this succession are: the Pillowed Basalt Member, the Pyroclastic Member and the overlying Iron Formation Member, and the Laminated Schist Member. The metavolcanics are intruded by Archean gabbroic dikes and Archean(?) rhyolite porphyry dikes which are roughly concordant. Field evidence indicates the gabbroic dikes to be older than the rhyolite porphyry. The Metavolcanics of Silver Mine Lakes is in fault contact with the Breccia of Holyoke Mine. The Breccia of Holyoke Mine is a deformed, tectonized, polymictic breccia, with interbedded, boudined banded iron formation. The Breccia of Holyoke Mine is in fault contact on the south with the Slates of the Dead River Storage Basin. The breccia and the slates may be Archean or Lower Proterozoic in age. Quartzite of the Lower Proterozoic Michigamme Formation are in fault contact with the Metavolcanics of Silver Mine Lakes along the northern portion of the study area. East-west striking Middle Proterozoic (Keweenawan) diabase dikes cross cut the older rock units and structure.

All pre-Keweenawan rocks have been metamorphosed to greenschist facies. Metamorphism occurred both at the end of the Archean, about 2,500-2,600 Ma, and at the end of the Lower Proterozoic, during the Penokean Orogeny, about 1,800-1,900 Ma. Bedding, foliation, and lithologic contacts typically strike N60°W to N70°W and dip 65° to near vertical to the northeast and southwest. Shear zones and faults appear to be of three ages: 1) older (Archean ?) shear zones, striking about N50°W to N70°W, 2) approximately north-trending faults, and 3) youngest east-west trending faults.

Mineralization in the area consists primarily of epigenetic veins and altered country rock, mostly associated with shear zones and banded iron formation. The dominant gangue mineral in the veins is quartz, typically with minor amounts of sericite and carbonate. Locally, sericite and chlorite are present in major amounts. The main sulfide mineral is pyrite, with local high concentrations of galena and sphalerite, and minor chalcopyrite. Gold and silver analyses yielded anomalous values for both metals in several samples. Additional sampling should be taken to further evaluate the economic potential of this area.

TABLE OF CONTENTS

Abstract 1
Table of Contents 1
List of Figures 2
List of Tables 2
Introduction 3
- Location, Definition, and Accessibility 3
- Work Methods 3
- Acknowledgements 3
- Previous Work 3
- Bedrock Geologic Setting 4

Unit Descriptions 4
- Archean Rocks 4
  - Metavolcanics of Silver Mine Lakes 4
    - Pillowed Basalt Member 4
    - Pyroclastic Member 5
    - Iron Formation Member 6
    - Laminated Schist Member 6
    - Age and Origin of the Metavolcanics of Silver Mine Lakes 7
  - Metagabbro of Clark Creek 8
    - Age and Origin of the Metagabbro of Clark Creek 8
- Archean or Lower Proterozoic Rocks 8
  - Rhyolite Porphyry of Fire Center Mine 8
    - Age and Origin of the Rhyolite Porphyry of Fire Center Mine 9
  - Breccia of Holyoke Mine 9
    - Age and Origin of the Breccia of Holyoke Mine 10
  - Slates of the Dead River Storage Basin 10
    - Age and Origin of the Slates of the Dead River Storage Basin 12
- Lower Proterozoic Rocks 12
  - Michigamme Formation 12
    - Age and Origin of the Michigamme Formation 12
- Middle Proterozoic Rocks 12
  - Diabase of Keweenawan Age 12
    - Age and Origin of the Keweenawan Diabase Dikes 12

Correlation of Rock Units 13
Summary.....13
Details of Correlative Units 13
Metamorphism..... 14
Structure..... 14
Bedding.....14
Foliation 14
Folds 15
Faults and Shear Zones 15
Geologic History..... 15
Mineralization 16
Historical Activity.....16
Character of Mineralization.....16
Vein Mineralization.....16
Altered Country Rock. 17
Paragenesis. 17
Age and Genesis.....17
Gold and Silver Assay Data.....17
Description of Prospects.....18
The Fire Center Prospect.....18
The Holyoke Prospect.....19
Unnamed Prospects.....21
Prospects in the Banded Iron Formation. 21
Other Prospects 22
Economic Potential 22
Appendix A 23

LIST OF FIGURES

FIGURE 1. Regional Geology and Location Map of the Fire Center and Holyoke Mines Area.....3
FIGURE 2. Stratigraphic column of the metavolcanic and metasedimentary units in the Fire Center and Holyoke Mines Area. 5
FIGURE 3. Pillow structure in the Pillowed Basalt Member (MSML).....5
FIGURE 4. Quartz stringers in the Pyroclastic Member (MSML).....6
FIGURE 5. Close-up of the Pyroclastic Member, containing lenses of darker material interpreted to be sheared pumice fragments.. 6
FIGURE 6. Close-up of the Laminated Schist Member (MSML), showing contorted layering. 7
FIGURE 7. Simplified geologic map of the contact between the Breccia of Holyoke Mine and the Slates of the Dead River Storage Basin.....9
FIGURE 8. Lenses of slate within the schistose matrix of the Breccia of Holyoke Mine.....10
FIGURE 9. Broken and oriented clasts in the Breccia of Holyoke Mine.....11
FIGURE 10. Banded iron formation boudin within the Breccia of Holyoke Mine. 11
FIGURE 11. Correlation chart for the rocks within the Fire Center and Holyoke Mines Area. 13
FIGURE 12. Past exploration and mining activity.....16
FIGURE 13. Location of samples taken for gold and silver assays. 17
FIGURE 14. Detailed geology across the contact between the Metagabbro of Clark Creek and the Rhyolite Porphyry of Fire Center Mine 19
FIGURE 15. Geologic map of the Holyoke Mine.....20
FIGURE 16. Cross section of the geology near the Holyoke Mine 20
FIGURE 17. Close-up of the banded iron formation taken from the Holyoke Mine dump.....20

LIST OF TABLES

TABLE 1. Background gold and silver analyses for some rocks in sections 35 and 2 17
TABLE 2. Gold and silver analyses from the Fire Center Mine dump and associated rocks.....19
TABLE 3. Gold and silver analyses from the Holyoke Mine dump, the dump near the shafts to the northeast of the Holyoke Mine, and related rocks 20
TABLE 4. Gold and silver analyses from the Iron Formation Member 22
TABLE 5. Gold and silver analyses from miscellaneous samples in sections 35 and 2 22
TABLE A1. Log for drill hole #1 23
TABLE A2. Log for drill hole #2 23
TABLE A3. Log for drill hole #3 24
TABLE A4. Log for drill hole #4 24
TABLE A5. Log for drill hole #7 24
TABLE A6. Log for drill hole #8 25
TABLE A7. Log for drill hole #9 25
TABLE A8. Log for drill hole #10 26
TABLE A9. Log for drill hole #11 26
TABLE A10. Log for drill hole #12 26
TABLE A11. Log for drill hole #13 27

INTRODUCTION

The area around the Fire Center Prospect and Holyoke Prospect was mapped as part of a cooperative project between the Geological Survey Division of the Department of Natural Resources and the Department of Geology and Geological Engineering at Michigan Technological University. The purpose of this project is to provide fundamental geologic data on a precious metal occurrence in Michigan, and was designed to provide geologic information as a base for industrial exploration.

LOCATION, DEFINITION, AND ACCESSIBILITY

The Fire Center and Holyoke Prospects Area is located on the northern shoreline of the Dead River Storage Basin in Marquette County, Michigan (latitude 87°37'30" and longitude 46°37'30"), about 19 km northwest of the city of Marquette (Fig. 1). The area is within the NE quarter of the Negaunee SW 7-1/2' quadrangle and consists of section 35, T49N, R27W, and the northern portion of section 2, T48N, R27W. Access to the area is made by driving approximately 7 km north on County Road 510 from the junction with U.S. Highway 41, and then heading west on North Basin Drive about 5 km.

WORK METHODS

The Fire Center and Holyoke Prospects Area was geologically mapped in detail at a scale of 1 inch equals 200 feet (1 cm = 24.25 m). The boundaries of sections 35 and 2 were surveyed and flagged at one hundred foot intervals using compass and tape. Outcrop mapping was performed on generally N-S traverses by compass and pace methods. Contacts were followed directly when density of outcrop permitted. In areas of rocks with high magnetic susceptibilities, triangulation methods from base stations outside the area of high magnetic variability were used. After mapping was completed/ data was transferred to a topographic base which consists of an enlargement of a portion of the Negaunee SW 7-1/2' topographic quadrangle.

All known outcrops are shown on the geologic map (Plate 1). Some very small outcrops are enlarged in order to show necessary geological relationships/ and some clusters of small outcrops are shown as single large outcrops. All rock units are mapped to scale. Rocks were identified megascopically in the field, and volume estimates of mineralogy was performed with the hand lens. Field magnetic susceptibility measurements were made on a Gisco G-816 Portable Proton Magnetometer in order to trace an iron formation unit in the area. Gold and silver analyses were made by Nuclear Activation Services Limited of Hamilton, Ontario, Canada.

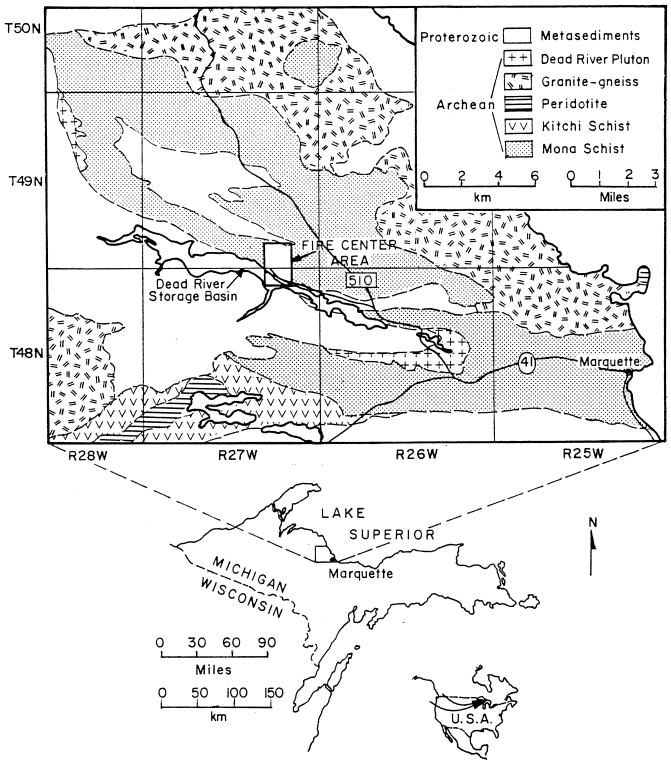

FIGURE 1. Regional geology and location map of the Fire Center and Holyoke Mines Area -- section 35, T49N, R27W and the northern portion of section 2, T48N, R27W (modified from Morgan and DeCristoforo, 1980).

ACKNOWLEDGEMENTS

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PREVIOUS WORK

Regional geologic studies of the area have been undertaken by several workers. The earliest works include Van Hise and Bayley (1895), which defined many of the rock units, including the Mona Schist and Kitchi Schist. Van Hise and Bayley (1897) compiled an extensive bibliography of the geologic knowledge to that date. Van Hise and Leith (1911) continued the regional geologic work in the area, adding data collected by themselves and A.E. Seaman. James (1955) described

the regional metamorphism of the western Upper Peninsula. Recent regional geologic work has emphasized the tectonic aspects of the Archean and Proterozoic of the southern Canadian Shield (Sims, 1980; Sims et. al., 1981; Klasner et. al., 1982), while the geologic history of the Ishpeming Greenstone Belt was described by Morgan and DeCristoforo (1980). Sims (1976) discussed the relationship of mineral deposits to Precambrian tectonics in the Lake Superior region, and Bodwell (1972) reviewed the mineral potential of the western Upper Peninsula of Michigan.

Gair and Thaden (1968) geologically mapped the Marquette and Sands Quadrangles and delineated several members of the Mona Schist in the vicinity of Marquette, in addition to describing and defining other formations of Archean and Proterozoic ages. Puffett (1974) mapped the geology of the Negaunee Quadrangle, extending the detailed geology of Gair and Thaden (1968) to the west and further delineating members of the Mona Schist. Clark, et. al. (1975), mapped the Negaunee SW 7-1/2' quadrangle, in which the Fire Center area is located, and correlated many of the units with Puffett (1974), including members of the Mona Schist and Kitchi Schist. On a more local scale, a series of unpublished maps and reports were produced by Norgan Gold Mining Company (Kelly, 1936) as part of their exploration of the region for gold. These reports contain a geologic map of a part of the Fire Center area at a scale of 1"=50' (1 cm = 6.06 m), logs of 12 drill holes, and a map of the Holyoke Mine.

BEDROCK GEOLOGIC SETTING

The Fire Center Area is located on the steeply dipping north limb of a regional WNW trending synform comprised of Archean and Lower Proterozoic rocks (Fig. 1). Archean metavolcanic rocks are unconformably overlain by, or in fault contact with, metasediments of Archean or Lower Proterozoic age (see also Gair and Thaden, 1968, and Puffet, 1974). The Archean rocks consist of a sequence of metavolcanic rocks originally mapped as part of the Mona Schist (Clark, et. al., 1975). The metavolcanic rocks have been intruded by Archean metagabbro and Archean(?) rhyolite porphyry dikes (Clark et. al., 1975). All Archean rocks were then probably weakly deformed and metamorphosed during the Algoman Orogeny about 2,500-2,600 Ma.

Within the study area, the near vertical Archean or Lower Proterozoic metasediments are in fault contact with the Archean rocks and consist of breccia and slate with interbedded conglomerate and arkose, which were originally mapped as part of the Reany Creek Formation (Clark et. al., 1975). To the north of, and also in fault contact with, the Archean rocks is the Lower Proterozoic Michigamme Formation. The Archean and Lower Proterozoic rocks were then folded, faulted, and metamorphosed to chlorite-level greenschist facies, during the Penokean Orogeny about 1,800-1,900 Ma. East-west striking Keweenawan diabase dikes intruded all units about 1,100 Ma.

UNIT DESCRIPTIONS

ARCHEAN ROCKS

METAVOLCANICS OF SILVER MINE LAKES (MSML)

The Metavolcanics of Silver Mine Lakes (MSML) is named for a succession of Archean metavolcanic deposits underlying the area around Silver Mine Lakes (Section 35, T49N, R27W and the northern part of section 2, T48N, R27W -- See Plate 1 and Clark et. al., 1975). The succession is subdivided into four distinct members, from the oldest to youngest: Pillowed Basalt Member, Pyroclastic Member, Iron Formation Member, and Laminated Schist Member. This succession was originally mapped as part of the Mona Schist (Wmm) by Clark et. al. (1975).

The four steeply-dipping members of the Metavolcanics of Silver Mine Lakes are the dominant lithologies in section 35 and in the northern part of section 2. The total thickness of the succession is about lf160 m in this area (Fig. 2). This is an approximate thickness because the contacts between the metavolcanics and adjacent units are fault bounded. In addition, the Laminated Schist Member is highly contorted making thickness estimates for that unit difficult.

The northern boundary of the Metavolcanics of Silver Mine Lakes is interpreted to be a fault contact between the Pillowed Basalt Member (MSML) and the Lower Proterozoic Michigamme Formation, which is consistent with Clark et. al. (1975). The southern contact is also a fault contact, between the Laminated Schist Member and the Archean(?) Breccia of Holoyoke Mine (Plates 1 and 2). The volcanic succession has been intruded by at least three different ages of dikes, frequently along the contacts between the members.

The four members strike in a N55 W to a N70 W direction. Bedding and foliation typically strike parallel to one another and dip is near vertical. Relative age of the members is based on pillow structure in the Pillowed Basalt Member, which indicate stratigraphic top to the south.

Pillowed Basalt Member

The Pillowed Basalt Member is the oldest and thickest member of the Metavolcanics of Silver Mine Lakes. This member consists of a relatively homogeneous pile of subaqueous pillowed basalt flows with an approximate cumulative thickness about 900 m, and underlies most of the northern half of section 35 (Plate 1). Thick, massive basalt flows are lacking in the study area, as are interflow sediments. Schistose to massive basalts located in the extreme northeast corner of Plate 1 are included with this unit. These massive to schistose basalts are in fault contact with the Lower Proterozoic Michigamme Formation, and their exact relationship to the Pillowed Basalt Member is unclear.

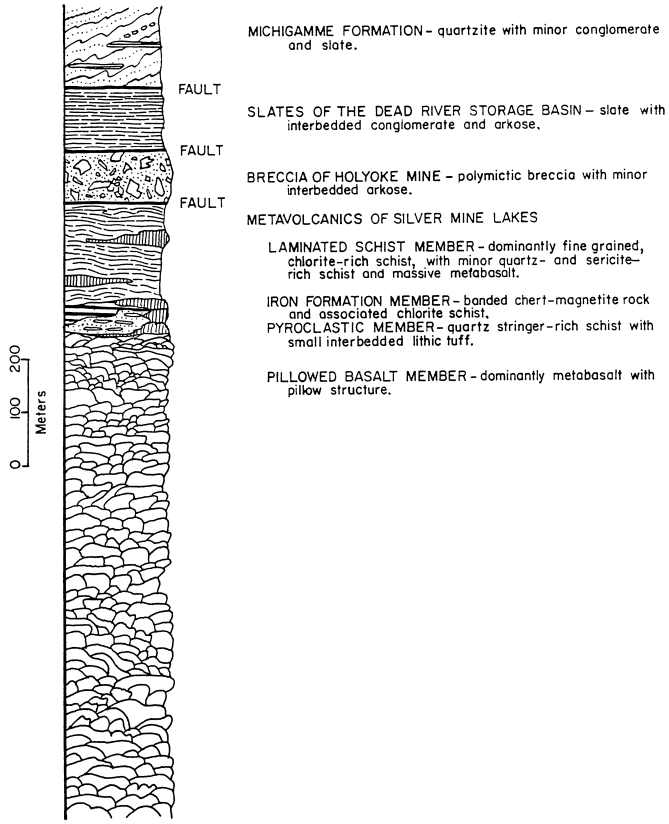


FIGURE 2. Stratigraphic column of the metavolcanic and metasedimentary units in the Fire Center and Holyoke Mines Area.

The northern boundary of the Pillowed Basalt Member is inferred to be a fault contact with the lower Proterozoic Michigamme Formation (see Clark et. al., 1975). This contact strikes approximately N70°W. The southern boundary is apparently near vertical, and is characterized by interfingering with the discontinuous Pyroclastic Member. The basalt near this contact lacks pillow structures; it is massive to schistose. Toward the east edge of the map area (e.g. east of the N-S trending Keweenawan Diabase Dike on Plate 1) the pyroclastic horizon pinches out and the Pillowed Basalt Member grades southward into the massive and schistose rocks of the Laminated Schist Member.

Outcrop size ranges from small rounded knobs to large northwest trending ridges. Pillow structures are most easily visible on cliff faces. The pillow structures are revealed by preferential weathering and parting along the rims of the pillows. Many forms occur, but the pillows are commonly elongate, and range in size from less than 15 cm to more than 3 m in the maximum dimension. Although only approximate, attitudes of pillows strike N60°W to N75°W and dip 65° to vertical, both to the northeast and to the southwest. Pillow tops are difficult to determine, but rare examples indicate that stratigraphic top is to the south (Fig. 3).

The basalt is massive, dark greenish gray and aphanitic. The groundmass contains abundant fine grained, green amphibole, chlorite and minor sericite. Plagioclase phenocrysts are rare overall, but one specimen revealed small (less than 1 mm), white plagioclase laths on the cut surface, which comprise about 2% of the rock. The rock contains trace amounts of disseminated, fine grained pyrite, and both pyrite and sericite are more abundant in the southern extent of this unit. Randomly oriented, elongate vesicles make up less than 1-2% of the rock, and are concentrated near the rims of the pillows. White quartz and very light tan carbonate fill interpillow voids and small cross-cutting veinlets.

The schistose to massive basalts in the extreme northeast corner of section are similar lithologically to the Pillowed Basalt Member, but lack pillow structures. They are very fine grained, greenish gray rocks, rich in chlorite and lacking phenocrysts. They reveal zones of intensely sheared rock, commonly with quartz and carbonate veinlets present parallel to the schistosity.

FIGURE 3. Pillow structure in the Pillowed Basalt Member (MSML). North is to the left; stratigraphic top is indicated to be to the south.

Pyroclastic Member

The Pyroclastic Member is a relatively thin, discontinuous unit trending approximately N55°W to N60°W across the center of the mapped area, where the unit crops out in topographic lows (Plate 1). This unit is tabular to lenticular and varies in thickness, to a maximum of 50 m. It pinches out toward the east edge of section 35.

This member is a sheared rock comprised of two lithologies: a quartz-stringer horizon, which is the dominant lithology, and a small, localized lithic tuff horizon (maximum dimensions being 16 m by 125 m). Both horizons weather to a light tan-gray color. The lithic tuff horizon is characterized by oblong, subrounded relict lithic fragments up to 1.5 cm in length, which are easily visible on the weathered surface. The quartz-stringer horizon is characterized by tabular to sausage-shaped quartz pods and stringers, ranging in size from less than 2.5 cm in length up to 10 cm wide and 30 cm in length (Fig. 4). These stringers are interpreted to be boudined quartz veins or layers. The contact between the two horizons is gradational over a maximum distance of 10 m: the quartz pods gradually increase from zero

percent in the lithic tuff horizon to as much as 50% in the quartz-stringer horizon.

FIGURE 4. Quartz stringers in the Pyroclastic Member (MSML). The stringers are interpreted to be boudined quartz veins.

The quartz stringer horizon is a medium greenish gray rock on the fresh surface. It consists of a highly schistose, chlorite-quartz groundmass surrounding the white to light gray quartz stringers. Locally the horizon is a breccia, consisting of angular clasts of microcrystalline quartz up to 8 cm in diameter set in the schistose groundmass. These make up approximately 50% of the rock. Lensoidal wisps of dark brown material up to 10 cm long are visible on the weathered surface, and are interpreted to represent sheared pumice fragments (Fig. 5). The groundmass consists primarily of fine to medium grained chlorite and quartz. Quartz phenocrysts, less than 2 mm in diameter, were observed at one location in the field. Disseminated pyrite is common in amounts less than 1%, but locally occurs as thin stringers, masses, and pods making up 2 to 3% of the rock. Chalcopyrite was observed as small grains in trace amounts, and malachite occurs locally on fractures in minor amounts.

On the fresh surface, the lithic tuff horizon is light to medium gray. It consists primarily of a fine grained, schistose groundmass of quartz, muscovite, and feldspar. The lapilli-sized lithic fragments, which are very fine grained quartz (and feldspar?), are elongate parallel to the schistosity and make up 10% of the rock. These are interpreted to be relict pumice fragments. Subhedral, clear, gray quartz phenocrysts, and clear, subhedral K-feldspar phenocrysts, both up to 2 mm in diameter, each make up about 5% of the rock. Disseminated pyrite, as small cubic crystals, commonly occurs in trace amounts.

Iron Formation Member

The Pyroclastic Member is overlain to the south by the Iron Formation Member. The Iron Formation Member is a very thin and discontinuous layer, tabular to lenticular, and highly magnetic. This unit varies in thickness, attaining a maximum of 25 m and pinching out to the northwest and the southeast (Plate 1). Magnetic data from Puffett (1974) and drill hole data (unpublished drill hole logs, Humble Oil Company, 1970), however, indicate that this horizon is continuous on a more regional scale to the east, and it probably continues to the west as well. Exposures of this unit are very poor and there are essentially no outcrops of iron formation except where trenches have been dug by past workers. Contacts are never seen, but the unit is spatially bound by the Pyroclastic Member on the north and primarily by the Metagabbro of Clark Creek on the south. At one location chert-magnetite layering strikes N53°W and dips 86° to the northeast.

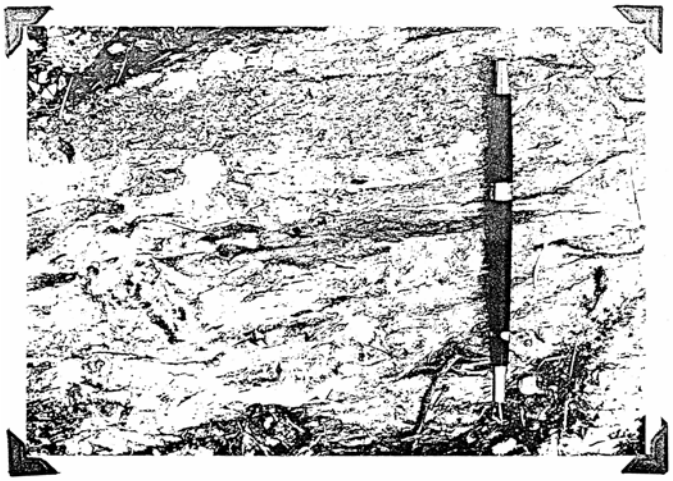


FIGURE 5. Close-up of the Pyroclastic Member (MSML), containing lenses of darker material interpreted to be sheared pumice fragments. Note pods of quartz.

The Iron Formation Member consists of evenly laminated, quartz-magnetite rock and associated chlorite-rich schist. The quartz layers in the banded horizon are generally 1 cm to 3 cm thick and alternate with magnetite bands which are generally less than 1.5 cm thick. The quartz layers consist of very fine grained, massive, light to medium gray, cherty quartz containing less than 1% fine grained, disseminated magnetite. The magnetite layers are comprised essentially of fine grained, dark gray to black, magnetite grains. There is typically very little pyrite contained within the laminated chert-magnetite rock.

The chlorite-rich schist is a highly contorted, schistose rock as indicated by tightly folded pyrite layers. This rock is comprised mostly of medium to fine grained, green chlorite and fine grained quartz (and feldspar?). It commonly contains thin pods and layers of pyrite less than 5 mm thick.

Laminated Schist Member

This member consists of a variety of schists, slates, phyllites, and massive to schistose metabasalt which underlie the southern region of the mapped area (Plate 1). The map thickness is about 185 m, but true thickness has not been determined due to the highly deformed nature of this unit. Outcrops of this unit are generally very small and low lying and the best

exposures of this unit occur along the northern shoreline of the Dead River Storage Basin.

Like the other units, contacts are generally not visible, but the lower (northern) contact with the Iron Formation Member and with the Pillowed Basalt Member is considered to be conformable. The southern contact between this unit and the Breccia of the Holyoke Mine is interpreted to be a fault contact due to the deformed nature of the rocks on both sides of the contact. Where exposure of the units is good along the shoreline, the contact between the Laminated Schist Member and the Breccia of Holyoke Mine can be placed within 2 m.

The Laminated Schist Member is characterized primarily by chlorite-quartz schist, which is a medium to dark green-gray, generally very fine grained, schistose rock and weathers to a light green-gray. Banding is visible on the weathered surface of some outcrops, but are most easily seen on the surfaces of cut slabs. The layers are highly contorted (Fig. 6). Transposed and folded quartz veins are also present.

The banding is represented by alternating light to dark green layers and dark gray layers. The light green to tan layers range in thickness from 2 mm to 2.5 cm. The thicker layers consist of light green to tan laminations alternating with darker green layers, generally 1 mm to 5 mm thick. They are very fine grained and mineral identification in the field is extremely difficult, but are probably a mixture of chlorite, sericite, quartz and feldspar. The dark gray layers within the schist range in thickness from 5 mm to 2.5 cm and consist of a massive, fine grained, dark gray matrix surrounding angular fragments of quartz and feldspar. Quartz fragments are white to gray, and comprise about 15% of the layer and white feldspar fragments make up about 10% of the layer. The fragments are generally less than 2 mm in size.

The Laminated Schist Member also includes massive to schistose metabasalt, which occurs as lenses and layers less than 60 m long to over 300 m long. These metabasalts are similar in appearance to the basalts of the Pillowed Basalt Member, but lack the pillow structure. These rocks are dark green-gray and aphanitic on the fresh surface and weather to a light greenish-gray. The schistose variety is comprised primarily of fine grained chlorite whereas the massive variety consists of a mixture of fine grained chlorite and green amphibole. Minor sericite is also present. Fine, disseminated pyrite commonly occurs in trace amounts. Phenocrysts were not observed.

Lenses of chlorite-quartz-sericite schist, quartz-muscovite schist, chlorite-rich slates and phyllites are also included in the Laminated Schist Member. These occur as lenses and bands scattered throughout the unit, and can be up to several tens of meters long. The schists are fine grained and vary in mineralogy, grading from quartz-rich to muscovite-rich types. Chlorite content ranges from nearly 0% to 10% in these schists. The slates are generally very fine grained, dark green-gray rocks comprised of a mixture of chlorite, quartz, feldspar, and sericite. The phyllites range from a chlorite-rich variety to a quartz-sericite rich variety. These phyllites locally contain clots of chlorite up to 5 mm in diameter, which may represent a retrograde reaction from an earlier metamorphic biotite or amphibole.

FIGURE 6. Close-up of the Laminated Schist Member (MSML), showing contorted layering.

Age and Origin of the Metavolcanics of Silver Mine Lakes

The Metavolcanics of Silver Mine Lakes are the oldest rocks in the area, and are considered to be of Archean age based upon correlation with rock units in surrounding areas (Clark et. al., 1975, Puffett, 1974, and Gair and Thaden, 1968). The absolute age of the assemblage is probably around 2,700 Ma. This is based on an U-Pb age date of 2,700 +/- 15 Ma from a porphyritic metarhyolite tuff from within the Mona Schist (Trow, 1979; located in the Clark Creek Basin approximately 5 km northwest of the Fire Center and Holyoke Mines Area), and from a Rb/Sr date of about 2,750 Ma, also in the Mona Schist (Morgan and DeCristoforo, 1980; located in Section 9, T50N, R27W).

The metavolcanic succession represents a changing environment from earlier basaltic flows to later more explosive volcanism. The Pillowed Basalt Member is interpreted to be a subaqueously deposited succession of basalt flows. Subaqueous volcanism continued with

the deposition of the Pyroclastic Member, which is considered to represent one or more ash-flow tuffs. The Iron Formation Member was then deposited as an exhalite. Overlying the Iron Formation Member is the Laminated Schist Member, which may represent interbedded tuffs (later reworked?), with basalt flows and volcaniclastic sediments deposited either in a subaqueous or subaerial environment.

METAGABBRO OF CLARK CREEK

The Metagabbro of Clark Creek is named for coarse grained, metamorphosed gabbroic dikes of Archean age exposed in the study area (Plate 1). This unit is the same as the metagabbro of Clark et. al. (1975), and is named for the exposures which occur near Clark Creek about 3 km west of the Fire Center Area. They also continue east of the study area. Exposures of this unit commonly form the larger outcrops in the area. Outcrops form ridges, hills and large knobs elongate parallel to the strike of the dikes.

The dikes are near-vertical, continuous, tabular intrusive bodies, ranging from less than 15 m wide up to 275 m wide. They strike in a direction subparallel to the regional structure and have commonly intruded along the contacts between the different members of the Metavolcanics of Silver Mine Lakes. At the local scale contacts may be parallel to bedding or cross-cut bedding at a high angle. One contact, for instance, between a metagabbro dike and the Pillowed Basalt Member has a strike of N25°W, which is considerably different than the strike of the pillows (approximately N65°W). The contacts are typically sharp, and the metagabbro shows a grain size decrease at some contacts with the Metavolcanics of Silver Mine Lakes, which is suggestive of chilled margins.

On the fresh surface, the metagabbro is medium greenish gray, and weathers to a light greenish gray. Megascopically, textures range from massive to schistose, from medium grained to very coarse grained, and from hypidiomorphic to subophitic. All variations can be found within a single large oucrop. The metagabbro consists of 40% to 50% green amphibole, generally less than 5 mm in length, approximately 40% light gray plagioclase less than 3 mm long, and minor opaque minerals and chlorite. The schistose varieties have about 55% feldspar and 45% chlorite. Disseminated pyrite occurs in trace amounts.

Age and Origin of the Metagabbro of Clark Creek

The age of this unit is considered to be Archean. The Metagabbro of Clark Creek cross cuts, and is therefore younger than, the Metavolcanics of Silver Mine Lakes, and is older than the Rhyolite Porphyry of Fire Center Mine, which cross cuts the metagabbro. The Metagabbro of Clark Creek is equivalent to the metagabbro mapped as Archean by Clark et. al. (1975). Although no evidence was found to show the relative age, the Metagabbro of Clark Creek is probably older than the Breccia of Holyoke Mine.

The Metagabbro of Clark Creek is an intrusive rock. The dikes may have been related to the magmatism which produced the Metavolcanics of Silver Mine Lakes, or may be significantly later than the volcanism. Some of the metagabbro could represent the slower cooling interiors of basalt flows, but this view is not favored here due to the fact that the vast majority of the basalt volcanism in the area is represented by thin, pillowed flows rather than thick, massive flows.

ARCHEAN OR LOWER PROTEROZOIC ROCKS

RHYOLITE PORPHYRY OF FIRE CENTER MINE

The Rhyolite Porphyry of Fire Center Mine is named for numerous small felsic dikes striking N50°W to N70°W in the study area. The unit is named for the two prominent rhyolite dikes located at the Fire Center Mine near the center of section 35, T49N, R27W. The dikes continue to the northwest and southeast (see Clark et. al., 1975, and Puffett, 1974). They were originally mapped by Clark et. al. (1975) as felsic intrusive rocks of Archean or Lower Proterozoic age.

Outcrops tend to be elongate in the direction of the trend of the dike. The width of the outcrop probably reflects the width of the dikes fairly closely as this is one of the more resistant units. The dikes are tabular to lenticular and vary in thickness from less than 3 m to 100 m; most are less than 30 m thick. The larger dikes are relatively continuous but many of the smaller ones are not/ and instead tend to occur as subparallel dikes too small to be mapped as such. Many of the dikes intrude along contacts between the older units, suggesting at least some structural control.

Contacts between the Rhyolite Porphyry of Fire Center Mine and the other rock units are sharp. They vary from smooth planar contacts parallel to the strike of the body to very irregular contacts consisting of tongues of rhyolite porphyry intruding into the country rock. The contacts are steep, usually dipping greater than 70° to the northeast and southwest, and strike N50°W to N70°W. Some contacts consist of shear zones. Notable among the sheared contacts are those contacts at the Fire Center Mine between a rhyolite porphyry dike and the Metagabbro of Clark Creek and between the same rhyolite porphyry dike and Pillowed Basalt Member (MSML -- see Plate 1). The contact with Metagabbro of Clark Creek is exposed in trenches which reveal a locally silicified and mineralized shear zone a minimum of 5 m wide (Fig. 14).

The color of the Rhyolite Porphyry of Fire Center Mine on the fresh surface is a very light gray to tan-gray, and on the weathered surface is a very light tan. The rock is massive to schistose and varies from crystal-poor quartz porphyry to crystal-rich quartz-feldspar porphyry. Equidimensional, clear, gray quartz phenocrysts (1 to 2 mm) and clear, pink to gray, subhedral feldspar phenocrysts (1 to 2 mm) are embedded in a very fine

grained light gray groundmass. Quartz phenocrysts make up from 5% to 15% of the rock whereas feldspar phenocrysts comprise from less than 1% to 30% of the rock. The groundmass is composed primarily of quartz and sericite. In some of the crystal-poor varieties, sericite becomes a major component, imparting a cherty look to the rock. Finely disseminated pyrite commonly occurs throughout many of the dikes, particularly in the more intensely sericitized varieties. Locally, disseminated chlorite makes up 5% of the rock, but typically makes up much less than 1% of the porphyry.

Age and Origin of the Rhyolite Porphyry of Fire Center Mine

The Rhyolite Porphyry of Fire Center Mine was originally mapped as felsic intrusive rocks of Archean and/or Lower Proterozoic age (Clark et. al.f 1975). Dikes of the Rhyolite Porphyry of Fire Center Mine cross cut and are therefore younger than the Metagabbro of Clark Creek. The upper age boundary is limited by the deformation, metamorphism, and mineralization contained within the rhyolite porphyry. The Rhyolite Porphyry of Fire Center Mine is thought to be related to the granitic rocks found in the region, which are considered to be 2,500 Ma to 2,600 Ma and therefore Archean in age -- either the Dead River Pluton or the Compeau Creek Gneiss (See Puffett, 1974, and Morgan and DeCristoforo, 1981).

The rhyolite porphyry dikes are hypabyssal intrusives, interpreted to be the shallower level manifestation of the granitic rocks found in the region. Certain features suggest that the intrusions of the dikes are related to tectonic activity in the area, possibly at the end of the Archean. Contacts between the dikes and the Archean country rocks at the Fire Center Mine, for example, are sheared, whereas along strike on the same contact the rhyolite porphyry dike may cross cut shearing.

BRECCIA OF HOLYOKE MINE

The Breccia of Holyoke Mine is named for the tectonized breccia located near the Holyoke Mine, just north of the shoreline of the Dead River Storage Basin where it occurs as a continuous layer trending in a N65°W direction (Plate 1). This unit was mapped in this area as part of the Reany Creek Formation by Clark et. al. (1975), which was originally defined by Puffett (1969) as a sequence of Lower Proterozoic metasediments located to the east of the area covered by this report. In this study area, this succession of rocks is given separate designation because the age is equivocal; this unit may be Archean in age rather than Lower Proterozoic as would be suggested by designation as the Reany Creek Formation. This unit is fairly resistant and much of it crops out at the top of the steep slope that leads down into the Dead River Storage Basin. Although good exposures can be found near the top of the slope, the best exposures occur on the shoreline and in the stream valley near the shoreline at the center of the map.

The breccia varies in width from about 30 m to 100 m. Its northern and southern contacts are inferred fault contacts. The evidence for this at the northern contact between the breccia and the Laminated Schist Member is the contorted, tectonized nature of the rocks on both sides of the contact. The contact between the breccia and the Slates of the Dead River Storage Basin, however, is marked by a zone, generally 6 m to 7 m wide, consisting of a spotted schist (Fig. 7). This zone is consistent throughout the length of the contact mapped in the area and marks a structural change across the contact from slate to spotted schist to the contorted and boudined schist of the breccia. This is also inferred to represent a fault contact. In addition, previous mapping of the Holyoke Mine indicates a sheared contact between the breccia and slates (Fig. 15).

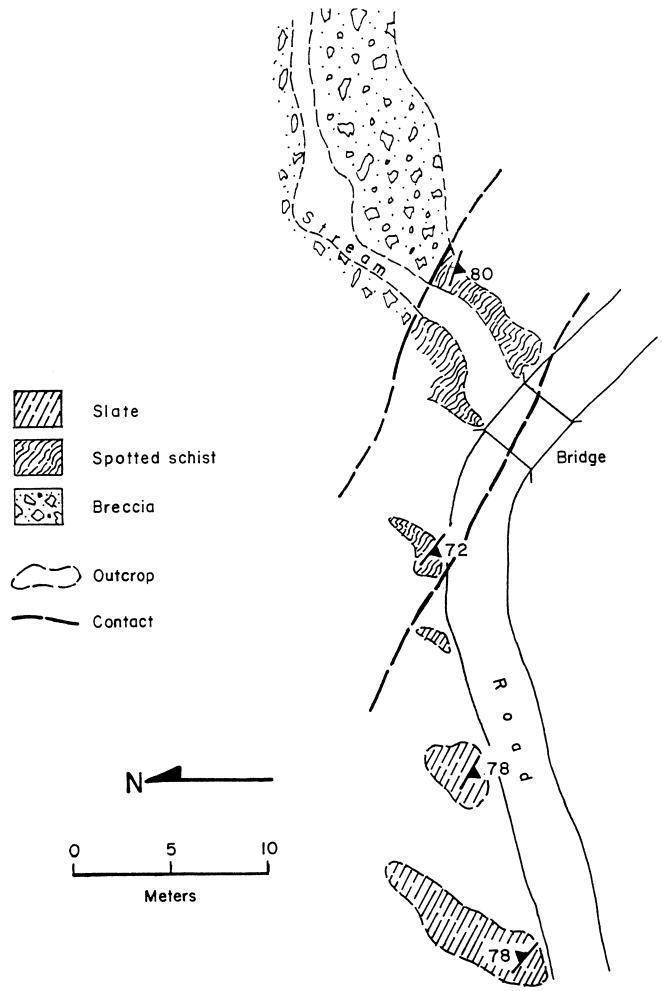


FIGURE 7. Simplified geologic map of the contact between the Breccia of Holyoke Mine and the Slates of the Dead River Storage Basin, showing the zone of spotted schist that separates the two. Location is at 600 m west and 580 m south of the SE corner, section 35.

The rock is medium to dark greenish gray on the fresh surface and weathers to a light greenish gray. It is poorly sorted, matrix-supported, with subangular to subrounded clasts which range in size from less than 2.5 cm to over 3 m. Clast shape ranges from semi-spherical to rectangular in form, and many clasts are quite slender. The clasts include coarse grained granites, fine grained, dark gray metavolcanics, banded iron

formation, felsic porphyry, and slate. The matrix is primarily a fine to medium grained schist, consisting of 50% feldspar, 20% quartz, 20% chlorite, and 10% sericite. Locally the matrix is a mixture of irregular, wispy to lensoidal pods of schist and pods of slate (Fig. 8).

The unit is an intensely deformed rock as shown by well developed schistsity, commonly with anastomosing chlorite-rich layering; broken clasts; boudined dikes, layers and quartz veins; and cataclastic features such as mortar and phacoidal structures (Fig. 9). The spotted schist zone at the southern contact between the breccia and Slates of the Dead River Storage Basin contains elongate aggregates of chlorite, giving the rock a lineation. The aggregates of chlorite may be the result of retrograde metamorphism of previous amphibole or biotite.

A zone of boudined banded iron formation occurs within the Breccia of Holyoke Mine, near the northern contact with the Laminated Schist Member (MSML). It is a relatively thin, continuous zone, ranging in thickness from 1 m to 7 m. This zone is lithologically similar to the rest of the breccia and is distinguishable only because a significant proportion of clasts is banded iron formation. The characteristics of the banded iron formation clasts found in this zone are very similar to the characteristics of banded iron formation found in the Iron Formation Member (MSML). It is comprised of alternating bands of medium to dark gray chert and dark gray magnetite. The chert bands range in thickness from 1 cm to 3 cm, while the magnetite layers are somewat thinner, ranging in thickness from 0.5 cm to 1 cm. The fragments of banded iron formation in this zone are subrounded to angular. The clasts range in size from 15 cm to 5 m in length; their shapes vary from relatively equidimensional forms to slender rectangular forms (Fig. 10). Where the clasts are rectangular, their long axes are parallel to the schistosity and trend of the breccia; the chert-magnetite laminations parallel the long axes of the clasts. Where the clasts are more equidimensional, the laminations in the clasts are oriented in random directions, and are commonly folded. The clasts of banded iron formation are interpreted to represent boudins of an originally continuous layer of iron formation that was deposited as part of the parent rocks of the Breccia of Holoyoke Mine.

Near the northern contact between the Breccia of Holyoke Mine and the Laminated Schist Member (MSML) there are interbedded deformed arkose beds. They are light pink-gray on the fresh and weathered surfaces. They exhibit massive, medium-grained, granoblastic texture and consist primarily of quartz and feldspar. The layers pinch and swell, but are generally less than 1 m thick. They dip steeply to the northeast and southwest.

Age and Origin of the Breccia of Holyoke Mine

The absolute age of the Breccia of Holyoke Mine is inconclusive. It could be Archean or Lower Proterozoic in age. The lower age boundary is represented by the granites and metavolcanics which are contained as clasts within the breccia. The upper age boundary is constrained by metamorphism which occurred during the Penokean Orogeny. The presence of laminated chert-magnetite banded iron formation which is mineralogically similar to the Archean Iron Formation Member (MSML), favors an Archean age for the breccia.

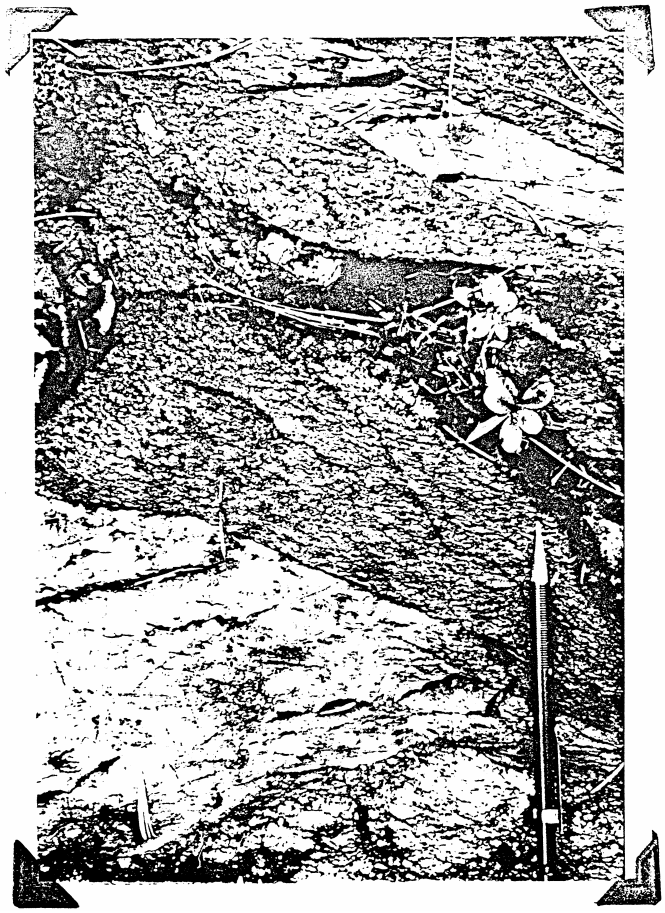


FIGURE 8. Lenses of slate within the schistose matrix of the Breccia of Holyoke Mine. Note granitic clast at the bottom of the picture.

The Breccia of Holyoke Mine is interpreted to be tectonic in origin, based on the extreme deformation that characterizes this unit. The presence of features such as boudins, broken clasts, cataciastic textures, and the mixture of irregularly shaped pods of slate and schist support this interpretation. The presence of subrounded to angular clasts of granite, rhyolite porphyry, metavolcanics and slates suggests a pretectonized clastic sedimentary origin as the dominant process of deposition. The banded iron formation was probably deposited in a quiet, subaqueous, exhalative environment,

SLATES OF THE DEAD RIVER STORAGE BASIN

This unit is named the Slates of the Dead River Storage Basin for the exposure along the shoreline of the reservoir of the same name (Plate 1). It was originally mapped as part of the Reany Creek Formation by Clark et. al. (1975). The strike of this unit, like the units to the

north, is about N60°W to N70°W. Only a minimum thickness of 125 m can be determined since the top of the unit is covered by water of the reservoir. The northern contact with the Breccia of Holyoke Mine is characterized by a 6 m to 7 m zone of spotted schist (Fig, 7). This is interpreted as a fault contact.

FIGURE 9. Broken and oriented clasts in the Breccia of Holyoke Mine, the result of deformation.

FIGURE 10. Banded iron formation boudin within the Breccia of Holyoke Mine. Laminations are parallel to the schistosity of the host rock.

The unit consists predominantly of very fine grained slates, which are locally phyllitic. The rock is a dark green-gray on the fresh surface and a light green gray on the weathered surface. The very fine grained nature of the rock renders megascopic identification of minerals difficult, but the green tint to the rock indicates chlorite is abundant. The rock also contains a very fine grained mixture of quartz, feldspar, and, locally, sericite.

The slates contain small clast-rich horizons and lone, sub-rounded granitic clasts. The lone granitic clasts occur sporadically throughout the unit. They range in size from 5 cm to 20 cm. Clasts such as these have in the past been interpreted to be of glacial origin (Puffett, 1974). The clast-rich horizons strike about N60°W to N70°W. They are up to 2.5 m in width but are usually thinner. Commonly, the matrix-supported clasts in these horizons comprise up to 30% of the rock. The clasts in these zones are predominantly granitic, but also include felsic porphyry, arkose, banded iron formation, and slate. The matrix is usually indistinguishable from the slates, although in some locations it is schistose owing apparently to preferential shearing in these horizons.

A one meter thick horizon containing banded iron formation clasts is interbedded with the slate. The clasts are sub-rounded to sub-angular, up to 1 m in diameter, and consist of chert and magnetite laminations. The clasts are randomly oriented as revealed by folded laminations. The lateral extent of this horizon is unknown but it extends at least 15 m. This is interpreted as originally being a thin interbedded banded iron formation layer, similar to that found within the Breccia of Holyoke Mine, which has subsequently been boudined.

A small conglomerate layer and numerous arkose beds are also interbedded with the slates and crop out along the far southeastern shoreline. Contacts between the slate and these layers are typically near vertical. The conglomerate layer is about 2.5 m thick and consists of matrix-supported clasts comprising about 25% of the rock, in a fine grained, schistose matrix. The clasts are subrounded and are dominantly less than 2.5 cm in diameter. They are primarily granitic clasts, but also include felsic porphyry and slate fragments. The matrix consists primarily of light gray, equidimensional quartz, and white, anhedral feldspar in subequal amounts, and 10-15% muscovite.

The arkose layers are generally less than 1 m wide, although one attains a thickness of 2 m to 3 m. The beds generally pinch out at a maximum length of 30 m. The arkose is a massive, very light tan rock and is comprised of approximately equal amounts of recrystallized, equidimensional, white to gray quartz and light gray to pink, anhedral feldspar. Veinlets of massive, white quartz are present within the arkose layers, oriented perpendicular to the strike of the layer. The veinlets are less than 7 cm wide and end abruptly at the contact between the arkose and the slates; they are interpreted as gash veins.

Age and Origin of the Slates of the Dead River Storage Basin

The age of the Slates of the Dead River Storage Basin is obscure; the unit may be Archean or Lower Proterozoic in age. Like the Breccia of Holyoke Mine, the Slates of the Dead River Storage Basin were originally mapped as part of the Lower Proterozoic Reany Creek Formation (Clark et. al., 1975). However, the presence of a small layer of boudined banded iron formation, lithologically similar to that found in the Archean Metavolcanics of Silver Mine Lakes, may suggest an Archean age.

The presence of sporadic, lone granitic clasts embedded within the slates has led past workers to envision a glacial origin for this type of deposit (Puffett, 1974). However, it has also been suggested that the Reany Creek Formation is a mass-flow deposit (Mattson and Cambray, 1983). The banded iron formation can be interpreted as an exhalative horizon, and as such may have been deposited between a series of mass debris flows. Interbedded conglomerate, which contains angular grains of quartz and feldspar, represents deposition from a closer, more rapidly eroding source, and the interbedded arkose layers represent a more sandy facies within the dominantly pelitic succession.

LOWER PROTEROZOIC ROCKS

MICHIGAMME FORMATION

The Lower Proterozoic Michigamme Formation crops out in the extreme northern portion of Plate 1 and probably underlies the topographic low that trends N60°W to N70°W along the northern border of section 35. According to Clark et. al. (1975), the Michigamme Formation extends several miles west of the study area and is in fault contact with the older Archean units. Although no contacts are visible in section 35, discordance of bedding attitudes between the Michigamme Formation and the Pillowed Basalt Member (MSML) and the presence of intensely sheared Archean metabasalt in the extreme northeast corner of the study area support the existence of fault contacts.

This unit is poorly exposed and accurate bedding attitudes were not found, but approximate bedding attitudes were found and they appeared to be dipping shallowly to the north-northeast. These bedding attitudes are consistent with previous work in the area (Clark, et. al.,1975). The minimum thickness of the unit is 150 m.

The unit consists primarily of light gray, massive quartzite, which is interbedded small lenses of conglomerate. Megascopicaily, the quartzite is comprised primarily of medium grained (1 to 2 mm in diameter), gray granoblastic quartz. Fine to medium grained light gray to white feldspar makes up less than 5% of the rock. Trace to 3% of the rock consists of disseminated pyrite, as small cubic crystals.

Conglomerate lenses are generally 5 cm to 15 cm thick and up to several feet in length. The clasts are sub-angular to sub-rounded, generally range in size from 6 mm to 7 cm, and are typically matrix supported. The clasts are dominantly fine grained, dark brownish-gray volcanic rocks and medium to coarse grained granitic rocks. The matrix is texturally and mineralogically similar to the quartzite.

Age and Origin of the Michigamme Formation

The age of the Michigamme Formation is considered to be Lower Proterozoic in age (see Clark, et. al., 1975, and Sims, et. al., 1984). Age relationships within the Fire Center Area are indeterminant, however, due to faulting. The formation in this area, primarily quartzites, is interpreted to represent near shore beach deposits.

MIDDLE PROTEROZOIC ROCKS

DIABASE OF KEWEENAWAN AGE

Diabase of Keweenawan Age refers to coarse grained, relatively unaltered, magnetic diabase dikes which strike predominantly east-west on Plate 1. Their typically east-west trend and relatively unaltered mineralogy, along with paleomagnetic studies, indicate a Keweenawan Age for these dikes. Outcrops vary in size, forming both large cliffs and ridges and underlying stream valleys. The dikes are generally tabular, discordant bodies, although one intrusive body is ellipsoidal with dimensions of 100 m by 200 m. The dikes range in width from less than 4 m to 60 m. Length varies from 250 m to greater than 1.5 km (the width of the mapped area). They are apparently near vertical, as indicated by the lack of topographic control. Contacts, where visible, are typically sharp.

The diabase is medium brown-gray on the fresh surface and weathers to a light gray. It is a massive, medium to coarse grained, generally equigranular rock, with grain sizes typically less than 3 mm. In the hand specimen there is about 40% to 45% gray, subhedral plagioclase laths, 40% anhedral, blocky pyroxene grains, 10% to 15% brown, anhedral olivine and about 5% opaque oxides, primarily magnetite.

There is a north-south trending dike in the southeast edge of Plate 1 which has been interpreted to be Keweenawan in age. Field relationships reveal that it is cut off by the east-west trending Keweenawan dikes. The north-south dike is therefore older than the east-west dikes, and is suggested to be older Keweenawan. It is a fine grained schistose to massive rock which has been weakly chloritized. Results of paleomagnetic data collected by students under the direction of S. Beske-Diehl (unpublished data) are consistent with an older Keweenawan Age.

Age and Origin of the Keweenawan Diabase Dikes

The Keweenawan Diabase dikes cross are correlated with dikes of the same age elsewhere in the region

(Clark et. al., 1975, Puffet, 1974, and Gair and Thaden, 1968). Within the Fire Center Area they are relatively unaltered, and they were observed to cross cut all Archean rock units. Results of paleomagnetic studies on the dikes are consistent with Keweenawan Age. The dikes are considered to represent deeper levels of magmatism related to rifting and volcanism during Keweenawan times.

CORRELATION OF ROCK UNITS

SUMMARY

Fig, 11 shows the stratigraphic correlation between the units mapped in this report and the formations delineated by Gair and Thaden (1968), Puffet (1974), and Clark et. al. (1975). A more complete historical development of stratigraphic nomenclature and correlation can be found in James (1958) , Puffett (1974) , and Gair (1975). The Metavolcanics of Silver Mine Lakes are interpreted to be of similar age as the Lower Member of the Mona Schist (Gair and Thadenf 1968f and Puffett, 1974), The Metaggabbro of Clark Creek and the Rhyolite Porphyry of Fire Center Mine are equivalent to the metagabbro (Wmm) and felsic intrusive (fi), respectively, of Clark et. al. (1975). The Breccia of Holyoke Mine and the Slates of the Dead River Storage Basin were originally mapped as part of the Lower Proterozic Reany Creek Formation (Clark et. al., 1975). These two units are considered as separate units here due to the ambiguity of the age of them. They may be correlative with the Reany Creek Formation, but both may be either Archean or Lower Proterozoic in age. The Michigamme Formation and the Diabase of Keweenawan Age are both the same as respective units mapped by Clark et. al. (1975), Puffett (1974), and Gair and Thaden (1968).

DETAILS OF CORRELATIVE UNITS

The Metavolcanics of Silver Mine Lakes is age correlative with the Lower Member of the Mona Schist (Puffet, 1974, and Gair and Thaden, 1968). This is based upon lithology, age, and location of the former unit in the study area. The lithology consists primarily of pillowed metabasalts, overlain by pyroclastic rocks, banded iron formation, and chlorite schist. The age is presumed to be similar to the metavolcanics elsewhere in the region, and the location of the units on the north limb of a WNW trending synform indicates a lateral continuity of the metavolcanics to those present on the south limb of the same structure.

The Metagabbro of Clark Creek is equivalent to the metagabbro (Wmm) of Clark et. al. (1975), which was mapped as Archean in age. These rocks apparently extend eastward into the Negaunee 7-1/2' quadrangle, where they were, at least in part, mapped by Puffett (1974) as metadiabase (md) of uncertain age. Gair and Thaden (1968) mapped metadiabase and metagabbro (md) of uncertain age which are also probably similar in age to the Metagabbro of Clark Creek.

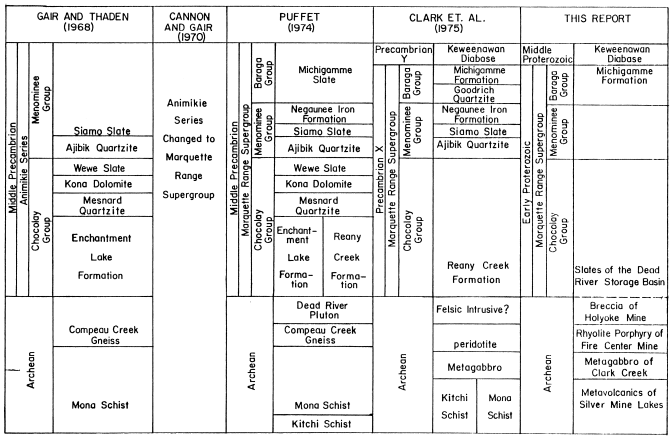


FIGURE 11. Correlation chart for the rocks within the Fire Center and Holyoke Mines Area.

The Rhyolite Porphyry of Fire Center Mine is equivalent with the felsic intrusive (fi) of Clark et. al. (1975), which were mapped as Lower Proterozoic and/or Archean. On a more regional scale, Puffett (1974) suggests that felsic intrusive rocks be included in the felsic metavolcanic unit (f), and Gair and Thaden (1968) describe felsic porphyry dikes of uncertain age (fp) similar to the rhyolite porphyry of this study area. The Rhyolite Porphyry of Fire Center Mine is interpreted to be of Archean age because they were not observed to cut Lower Proterozoic Rocks, and because they may be related to the Archean granitic rocks found in the region.

The Breccia of Holyoke Mine was originally mapped in this study area as part of the Reany Creek Formation by Clark et. al. (1975). The Reany Creek Formation was first defined to the east of this study area by Puffett (1969) for a sequence of metasedimentary rocks interpreted to be of Lower Proterozoic age. The Breccia of Holyoke Mine and the Slates of the Bead River Storage Basin are named here because the age of the units is not clear: they could be Archean.

The Slates of the Dead River Basin, like the Breccia of Holyoke Mine, were originally mapped as part of the Reany Creek Formation (Clark et. al., 1975), and both units were considered part of the same sedimentary sequence as the Reany Creek Formation. Evidence in this study area indicates there is a tectonized contact betweeen the slates and the breccia which has clouded any original contact that may have existed prior to shearing. The Slates of the Dead River Storage Basin may be Lower Proterozoic or Archean in age.

The Michigamme Formation was originally mapped by Clark, et. al. (1975) and is retained here as such. Diabase Dikes of Keweenawan Age are equivalent to those of Gair and Thaden (1968) and Puffett (1974).

METAMORPHISM

All pre-Keweenawan rocks in the Fire Center and Holyoke Mines Area have undergone at least one period of metamorphism, and the Archean rocks have probably undergone multiple periods of metamorphism. The first metamorphic event, marked by weak metamorphism of the rocks in the study area, would have occurred during the Algoman Orogeny at the end of the Archean (about 2,500 Ma). The existence of this event is shown by amphibolite facies metamorphism in the Mona Schist within the Negaunee 7-1/2' Quadrangle (Puffett, 1974) and the Marquette 7-1/2' Quadrangle (Gair and Thaden, 1968). However, metamorphism was probably relatively low grade within the Fire Center and Holyoke Mines Area during this Archean event, as revealed by relict primary igneous textures and structures in the Archean rocks. Microlites of plagioclase reveal relict felty texture in the Pillowed Basalt Member (MSML), and relict subophitic texture is present in the Metagabbro of Clark Creek.

This late Archean event was overprinted by higher grade metamorphic changes which occurred during the Penokean Orogeny (about 1,800-1,900 Ma). James (1955) delineated 3 regional metamorphic nodes of Penokean Age in the western Upper Peninsula. These nodes represent zones of metamorphic intensity ranging from relatively low grade chlorite level greenschist facies metamorphism in the periphery to sillimanite level metamorphism at the nodes. The Fire Center and Holyoke Mines Area lies within the chlorite level, on the northeast flank of the Republic metamorphic node.

The highest grade of metamorphism found in the study area is the chlorite-amphibole (actinolitic hornblende?) level of greenschist facies, and is most easily visible in the mafic rocks. The metabasalts in the Metavolcanics of Silver Mine Lakes and the Metagabbro of Clark Creek are made up of fibrous, green amphibole, which James (1955) termed an actinolitic hornblende. Chlorite is typically present in lower amounts and becomes the dominant mafic mineral in the schistose mafic rocks; epidote is also commonly found as a minor constituent. Regional metamorphic effects in the felsic rocks are less obvious than in the mafic rocks, but is revealed in textural readjustment and mineralogic changes. The quartzite of the Michigamme Formation consists primarily of recrystallized, granoblastic quartz, as do the arkose layers within the Breccia of Holyoke Mine and the Slates of the Dead River Storage Basin. The Rhyolite Porphyry of Fire Center Mine contains recrystallized quartz with sutured grain boundaries or mosaic textures. These felsic dikes also contain major amounts of sericite, feldspar, and minor amounts of chlorite. The sericite is particularly abundant replacing both K-feldspar and plagioclase. Both sericite and chlorite may reflect local hydrothermal alteration rather than regional metamorphism.

STRUCTURE

The study area is located on the north limb of a regional syncline comprised of Archean and Lower Proterozoic rocks (See Bodwell, 1972, Clark et. al., 1975, and Puffett, 1974). The syncline trends about N70°W and plunges to the west-northwest. Many of the features observed in the study area can be attributed to this syncline. The pre-Michigamme rocks in the study area typically strike N60°W to N70°W and generally dip greater than 65° to vertical to the southwest and northeast. Lithologic contacts and foliations also strike and dip in this direction.

Massive rocks dominate the northern half of the study area, whereas schistose and slaty rocks dominate the southern half. Schistosity, in general, strikes N55°W to N70°W and dips steeply to the southwest and northeast, and typically occurs in linear belts and zones throughout the study area which strike roughly in the same direction. These zones and belts vary in width from less than 1 m to 400 m thick.

There is a graben-like structure in the extreme northern portion of the study area (Clark et. al., 1975; see also Plates 1 and 2). The structure strikes about N70°W. It apparently consists of a block of shallow dipping Michigamme Formation juxtaposed against steeply dipping rocks of the Metavolcanics of Silver Mine Lakes.

BEDDING

Bedding is exhibited by pillow structure in the Pillowed Basalt Member (MSML), by chert-magnetite layering in the Iron Formation Member (MSML), by interbedded arkose and breccia in the Breccia of the Holyoke Mine, and by interbedded arkose, conglomerate, and slate within the Slates of the Dead River Storage Basin. Bedding in the Iron Formation Member (MSML) strikes N53°W and dips 88° to the NE. Bedding within the Breccia of Holyoke Mine strikes N60°W and dips 86°SW, and bedding found within the Slates of the Dead River Storage Basin strikes N75°W and dips 78°SW. Bedding could not be accurately measured in the Pillowed Basalt Member due to the irregular nature of pillow formation. However, the direction of elongation of the pillows was invariably striking about N50°W to N70°W and dipping near vertical where observed.

Bedding in the Michigamme Formation in the northern portion of the study area is revealed by conglomerate lenses within quartzite. This was not measured accurately due to poor exposure. However, the unit appeared to strike in a northwest direction and dip shallowly to the northeast, which is consistent with Clark et. al. (1975).

FOLIATION

Slaty and phyllitic cleavages and schistosity define the foliation. In most cases, the cleavages and schistosity strike N60°W to N80°W and dip 65° to 90° to the southwest and northeast. There are, however, local

aberrations. About 150 m north of the SE corner of section 35 the foliation strikes about due north. A similar situation occurs about 980 m west of the southeast corner of section 35 where the strikes are approximately N35°W. Both anomalies are thought to be related to drag along an east-west fault located here (Plate 1).

FOLDS

All the folds observed in the area are small scale features. The size of the folds are typically on the order of a few centimeters of wavelength, although one folded rhyolite porphyry dike was found with a wavelength of 1 m. The primary features exhibiting folds were transposed quartz hooks and folded laminations within the Laminated Schist Member (MSML), and folded layering in the boudins of banded iron formation within the Breccia of Holyoke Mine and the Slates of the Dead River Storage Basin. The folds are, in general, assymmetric, and some ptygmatic folding was observed. The fold axes of the folded quartz veins plunged about N60 W to N70°W. No measurements were obtained on any of the other folds.

FAULTS AND SHEAR ZONES

Faults in this area can be separated into at least three ages: 1) older shear zones striking sub-parallel to the regional foliation, 2) generally north-south striking faults, and 3) younger east-west striking faults. The older shear zones are relatively thin, linear bands of well developed schistosity. The north-south faults, where visible, are similarly revealed by schistosity, but are mainly defined by offset layers. The east-west faults are defined by brecciation in some of the smaller zones, and by offset units and discordant foliations.

The shear zones strike approximately N60°W and dip steeply to the SW and NE, and range in size from less than a meter to probably more than 30 m wide. Because they are generally parallel to the regional structure, and define it in part, they are commonly difficult to trace for extended distances. Where shear zones form the contact between different lithologies they can be traced more easily. Notable among these is the contact between the Breccia of Holyoke Mine and the Laminated Schist Member (MSML). In addition, the contacts between many dikes of the Rhyolite Porphyry of Fire Center Mine and the country rocks similarly show well developed schistosity indicative of high strain. The age of the shear zones is unknown, but they are suspected to be Archean in age and perhaps reactivated during the Penokean Orogeny.

There are also north-south trending faults with apparent left-lateral movement in the study area. One such fault cross cuts the N60°W shear zones and is exposed in the center of the northern half of section 35, where a prospect has been sunk on a mineralized quartz vein in the fault. A sheared zone with a minimum thickness of 3 m defines the fault. Contacts are offset from 15 to 50 m. The age of this fault is uncertain, but is later than the Archean rocks it offsets and older than the Kewenawan dikes which cross cut it.

At least one east-west trending fault is revealed by offset rock units and discordant foliation. Right-lateral movement is indicated by the offset of the Pyroclastic Member of the Silver Mine Lakes Metavolcanics. A Keweenawan dike has intruded along this fault (Plate 1). The age of this fault is uncertain but, because of its spatial association with the Keweenawan Diabase, and because minor zones of brecciation are present in the dikes, it may be of similar age.

GEOLOGIC HISTORY

The earliest recorded geologic event in the study area was the volcanism which formed the rocks of the Metavolcanics of Silver Mine Lakes during Archean time/ about 2,700 Ma. This period is dominated by subaqueous extrusion of pillowed basalts, and followed with deposition of a subaqueous ash-flow tuff and exhalative oxide-facies banded iron formation in a relatively shallow water environment. Volcanism continued with the deposition and reworking of mafic tuffs of the Laminated Schist Member. The volcanic pile was then intruded by the gabbroic dikes and sills of the Metagabbro of Clark Creek.

The order of the next set of events is speculative due to the lack of conclusive field data. It is suggested that during the Algoman Orogeny, at about 2,500-2,600 Ma, several overlapping events occurred. Sedimentary deposition of the parent rocks of the Breccia of Holyoke Mine may have occurred, including interbedded banded iron formation, prior to any major folding and tilting of the metavolcanic rocks. All Archean units were intruded by dikes of the Rhyolite Porphyry of Fire Center Mine. Deformation and shearing probably occurred at a similar time as intrusion of the rhyolite porphyry dikes, and the rocks were subjected to low grade metamorphism. Gold, and possibly silver, mineralization, occurred near the end of this event. The Breccia of Holyoke Mine may have been brought into contact with the metavolcanics at this time.

Deposition of the Slates of the Dead River Storage Basin may have occurred prior to or after the Algoman Orogenic event, or after, in a dominantly quiet water regime. Subsequently, after a period of erosion or non-deposition, quartzose sands which yielded quartzites of the Michigamme Formation were deposited in a near shore environment. All rocks were then folded, faulted and metamorphosed to greenschist facies during the Penokean Orogeny, at about 1,800-1,900 ma. Previous Archean mineralization was remobilized and speculatively additional precious metal mineralization occurred during this orogeny.

The Penokean Orogeny was followed by a period of quiescence marked by erosion and/or non-deposition. The rocks in the area were then intruded by Keweenawan diabase dikes, associated with rifting to

the west and north about 1,100 Ma. Pleistocene to recent unconsolidated surficial deposits sporadically cover the area.

MINERALIZATION

HISTORICAL ACTIVITY

There has been sporadic mining and exploration activity in the study area since the mid-1800's, and the location of mines and prospects, together with trenches and drill holes from Norgan Mining Co, exploration, are shown on Figure 12, The first known mining activity occurred at the Holyoke Mine, which was mined for silver in the 1860fs. During the late 1800's, the Fire Center shafts were sunk on gold-bearing quartz veins, which are associated with rhyolite porphyry dikes (Bodwell, 1972). Total production of gold from these shafts amounted to about 100 ounces. Known activity in the area ceased until the mid-1930's when Norgan Gold Mining Co. explored the area extensively. At this time geologic mapping of the region was undertaken. Sampling, trenching, and the drilling of 12 holes were also included in the exploration program, primarily to test the continuity of gold mineralization in and around the rhyolite porphyry dikes. Sampling of the Holyoke Mine for gold also occurred at this time. Exploration apparently ceased until 1970 when Humble Oil drilled 4 holes in nearby areas, and during the summer of 1984 when Nicor Minerals of Denver carried out a drilling program within the study area.

CHARACTER OF MINERALIZATION

Mineralization in the area can be characterized by two styles: sulfides hosted within quartz veins (vein type) and altered country rock (disseminated type). Host rocks for the veins include sheared and silicified varieties of all members of the Metavolcanics of Silver Mine Lakes, the Metagabbro of Clark Creek, Rhyolite Porphyry of Fire Center Mine, and the Breccia of Holyoke Mine. Disseminated type mineralization is found in all the above units and in the Slates of the Dead River Storage Basin. As Figure 12 shows, however, most of the past exploration and mining activity has centered around the rhyolite porphyry or banded iron formation. Within the Breccia of Holyoke Mine and the Slates of the Dead River Storage Basin mineralization may be restricted to clasts and boudins of banded iron formation. These clasts and boudins of banded iron formation are notable for containing sulfides, but commonly lacking significant secondary silica associated with the sulfides. In all cases observed, cross cutting relationships show mineralization to be epigenetic.

Vein Mineralization.

The quartz veins are associated typically with sheared and altered country rock, in shear zones which strike predominantly N50°W to N70°W. Due to poor surface exposure, lateral continuity of veins is often difficult to establish. Drill hole data from Norgan Gold Mining Co. work in the 1930fs indicates wide variability in the continuity of veining and mineralization (See Appendix I). Typically, the veins are tabular to lensoidal with widths ranging from a few cm to more than 1 m. The veins are massive to banded, with the banding being most visible where sulfides are relatively abundant. No open-space textures were seen in the veins.

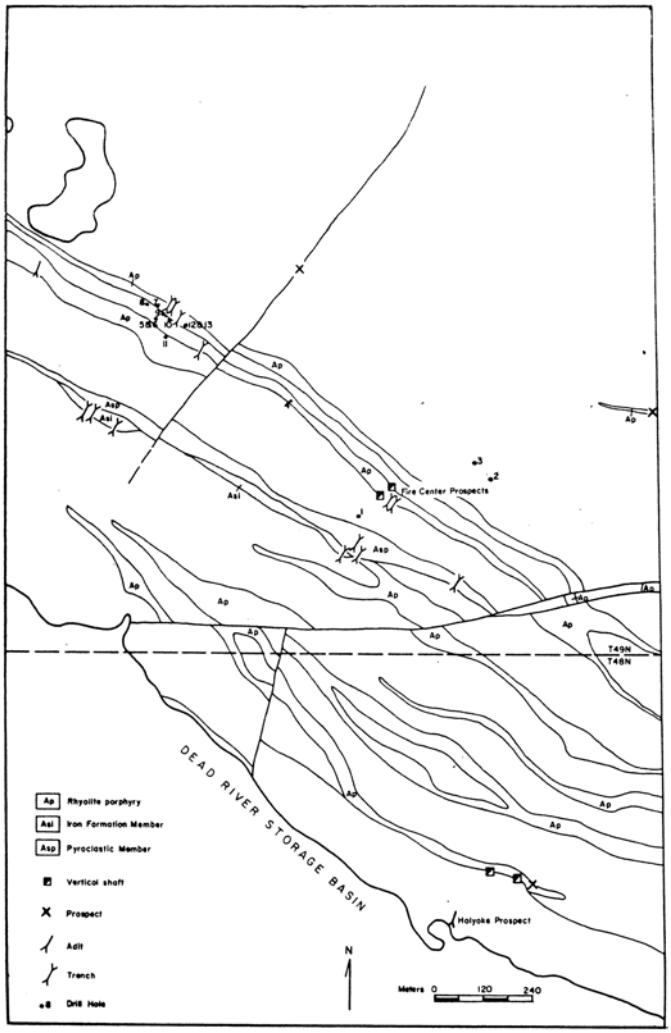


FIGURE 12. Past exploration and mining activity, and their relationship to the Rhyolite Porphyry of Fire Center Mine and the Iron Formation Member (MSML). Keweenawan dikes have been omitted for brevity.

The veins are predominantly interlocking coarse, white, and anhedral quartz or very fine grained, cherty-looking, light gray grains. Sericite and chlorite are commonly present in varying amounts, but are generally less than 10% of the vein material. Biotite was found in trace amounts as coarse, platy grains (up to 2 mm) within the vein quartz at the Fire Center Mine.

Sulfides (+/- limonite) generally make up less than 5% of the vein, but occasionally comprise up to 30% of the vein. The sulfides are enclosed within the quartz, occurring as individual, euhedral grains, as repetitive bands generally less than 1 cm thick, or as small irregularly shaped pods generally less than 1.5 cm thick.

Pyrite is the primary sulfide, and is commonly the only visible sulfide. Chalcopyrite and galena are locally the dominant sulfide, the latter occurring in significant amounts at the Holyoke Mine dump. Sphalerite occurs locally in minor amounts, and arsenopyrite was not found, although it is noted on some of the core logs of Norgan Gold Mining Company (Appendix I).

Carbonate occurs with quartz in thin veinlets which are typically less than 2 cm wide. The carbonate is light tan-pink on the fresh surface and weathers to a medium orange brown, occurring as anhedral grains generally less than 5 mm in diameter. The mineralogy of these veinlets generally consists of sub-equal amounts of quartz and carbonate, with locally high concentrations of sericite, and minor chlorite. These quartz-carbonate veinlets are late stage and cut the quartz-sulfide veins.

Altered Country Rock.

Altered country rock is schistose and occurs in zones striking generally N60°W, parallel to the quartz veins. The zones most commonly, but not exclusively, occur in close proximity to the quartz veins. The width of these zones is difficult to establish due to poor exposure, but they appear to vary from less than a one m to greater than 5 m. They are interpreted as shear zones.

The alteration mineralogy is primarily quartz, sericite, and carbonate. The quartz is very fine grained and light to medium gray. White to light tan sericite occurs in all the rock types but is most prevalent in the Rhyolite Porphyry of Fire Center Mine. Sericite content ranges from less than 5% to more than 50% of a rock. Chlorite is probably the next most common alteration mineral, particularly in the mafic rocks. The origin of chlorite, however, could be due to either regional metamorphism or hydrothermal alteration, and at this time is equivocal. The only sulfide found in these alteration zones is pyrite, which generally comprises trace to 1% of these rocks. Pyrite commonly occurs as disseminated, euhedral cubes less than 1 mm in size. Galena is visible as disseminated grains in sheared country rock near galena-bearing veins.

Paragenesis.

Field data regarding the paragenesis of mineralization reveals, in general terms, that quartz is early, probably accompanied by sericitization of the country rock. Sulfides deposition began later as they are located along grain boundaries of the quartz: pyrite appears to be followed in no particular order by chalcopyrite, galena, and sphalerite. Late stage quartz-carbonate veining took place after most of the pyrite deposition as indicated by cross cutting relationships. At the Holyoke Mine, dump material shows galena to be hosted within these late stage veinlets. Galena is therefore interpreted to be late as well.

Age and Genesis.

The age of mineralization is not conclusively known, but is interpreted to be Archean. It is younger than the Rhyolite Porphyry of Fire Center Mine which host the veins. Cursory examination of thin sections reveal metamorphic textures in the late stage quartz-carbonate veinlets, which indicates that the veinlets are pre-Penokean. Mineralizing fluids possibly arose late during the Algoman Orogeny, at about 2,500-2,600 ma.

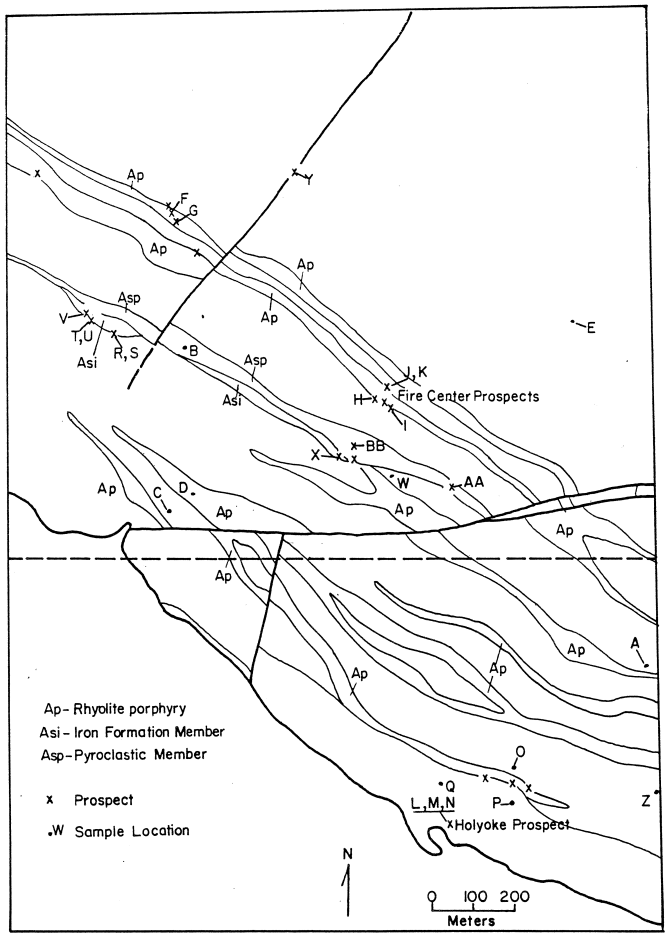


FIGURE 13. Location of samples taken for gold and silver assays. Letters correspond to sample numbers in Tables 1 to 5.

TABLE 1

Background gold and silver analyses for some rocks in sections 35 and 2. Detection limit for gold is 0.001 ppm and for silver is 0.5 ppm. Letters before sample numbers refer to the sample location on Figure 13. All samples are rock chip samples.

SPECIMEN	GOLD (PPM)	SILVER (PPM)	
(A) 6115	<0.001		Metagabbro of Clark Creek
(B) 8221	<0.001		Pyroclastic Member (MSML)
(C) 9181	0.004		Chlorite schist from the Laminated Schist Member (MSML)
(D) 9183	0.001	<0.5	Rhyolite Porphyry of Fire Center Mine
(E) 10113	0.001	<0.5	Pillowed Basalt Member (MSML)

GOLD AND SILVER ASSAY DATA.

Several samples were analyzed for gold and silver content as a part of this study. The results are listed in Tables 1 to 5 (detection limits of 0.001 ppm for gold and

0.5 ppm for silver), and the locations of the samples can be found on Figure 13. Table 1 lists background gold and silver values for the rocks in the study area. Values of gold and silver in all background samples but one are below the detection limits of the analysis methods used for this study. Banded iron formation is not included in this table, but according to Boyle (1979), typical values in Algoman-type banded iron formation are generally less than 0.031 ppm. More detailed features of the samples follow in the descriptions of prospects, but the following statements can be made from the assay data:

1.) In general, the highest values of gold are from quartz vein material: samples 92015, 92019, 10109 (Table 2), 10117 and 91910 (Table 3). Sericitized rhyolite porphyry also yielded relatively high Au values (Sample 92020 -- Table 2). Most of the assays from banded iron formation showed anomalous values, but the banded iron formation from within the Breccia of Holyoke Mine (Sample 92024) yielded the highest value at 2.1 ppm (see Tables 3 and 4). A chlorite schist associated with the Iron Formation Member (MSML) also yielded relatively high gold values (Sample 92011). In addition, an anomalous Au value came from a pyritized shear zone within the Metagabbro of Clark Creek (Sample 6112).

2.) The highest values of silver occurred in quartz vein material taken from the Holyoke dump and from the dump near the shafts to the northeast of the Holyoke Mine: samples 10117, 10118, and 91910 (Table 3). Banded iron fromation from within the Breccia of Holyoke Mine also yielded anomalous values of silver: samples 10116 and 92024 (Table 3).

3.) Anomalous gold values are found in the Iron Formation Member (MSML), and anomalous gold and silver values are, found in the banded iron formation boudins in the Breccia of Holyoke Mine (See Tables 3 and 4).

4.) In general, anomalous gold and silver values can be said to be associated with shear zones.

5.) There appears to be, in general, a correlation between the concentration of sulfides and the concentration of gold and silver. Since pyrite is the dominant sulfide, in some cases the only sulfide, it is suggested that gold is related to pyrite. Due to the low number of samples assayed for silver, relationships with particular sulfides are harder to discern than for gold. However, silver is apparently related to the galena content, as the highest silver values were found in those samples with highest galena concentrations.

DESCRIPTION OF PROSPECTS.

The Fire Center Prospect.

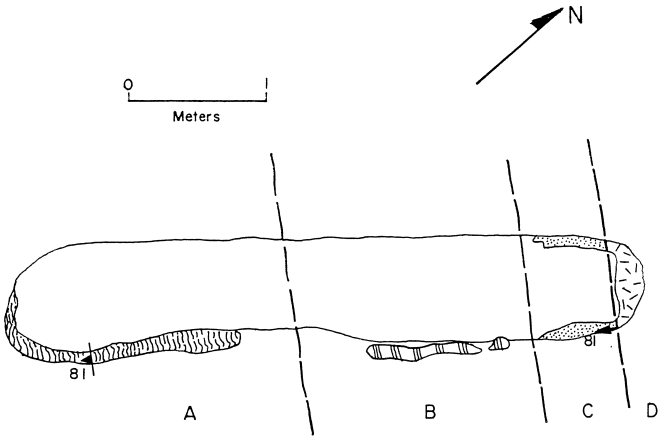
This prospect has been a target of exploration in the past. It consists of two vertical shafts which are now covered and filled, and are shown on Fig. 12. One shaft was sunk along the contact between a rhyolite porphyry dike and sheared metagabbro (south shaft), and the other shaft was sunk along the contact between the same rhyolite porphyry dike and sheared metabasalt (north shaft) of the Pillowed Basalt Member (MSML). Also, trenches have been dug along these contacts and within the rhyolite porphyry dikes and holes were drilled during the 1930's by Norgan Gold Mining Company. (See Appendix I for logs and cross sections of the drill holes).

The south shaft is located on the contact between a dike of the Rhyolite Porphyry of Fire Center Mine and the Metagabbro of Clark Creek. The contact is marked by intense shearing and silicification of the metagabbro near the contact, and strikes N68°W and dips 81° to the southwest. A trench located about 17 m SE of the shaft reveals the zone of shearing to be a minimum of 5 m wide. As Figure 14 shows, the most distal zone (Zone A) visible within the trench is occuppied by schistose metagabbro, a fine grained, chlorite- and carbonate-rich sheared rock. The schistosity in this rock extends well beyond the length of the trench to the south. The schistose metagabbro of Zone A is in contact with the alternating bands of quartz and silicified metagabbro of Zone B, slightly more than 1 m thick. The quartz bands consist of alternating dark gray laminations (less than 2 mm thick) and light gray layers of very fine grained quartz (less than 5 mm thick). The rock in Zone B is in contact with the most intensely silicified rock of the shear zone: the quartz-suifide vein of Zone C. Zone C consists of alternating bands of quartz and pyrite (+/- limonite) 0.5 cm to 1 cm thick. Sausage-shaped pods of quartz are present parallel to the banding. These pods are interpreted to be boudins of quartz, which suggest post mineralization shearing. Locally pyrite (+/- limonite) make up 25% of the vein. About 350 feet to the southeast of the shaft the metagabbro at the contact is sheared and silicified, but the contact lacks the quartz veining and sulfide content that the Fire Center Prospect contains.

Coarse, white quartz vein material, and, fine grained gray quartz are present in dump material around the south shaft. Pyrite is the dominant sulfide, ranging from trace to 15% of the rock. It occurs as veinlets, as massive, amoeboid pods, and as disseminated grains. Chalcopyrite, galena, and sphalerite were found only in trace amounts, associated with the coarse, white vein quartz. Light pink-tan to white carbonate occurs as veinlets and pods, and as the matrix of brecciated quartz. The carbonate is late stage, cross cutting quartz and pyrite veins. Intensely sericitized rock was also found in the dump material, and is interpreted to be altered country rock rather than an actual part of the vein material.

The location of the northern shaft is somewhat obscure. It is inferred to be located on the contact between the same rhyolite porphyry dike mentioned above and sheared metabasalt (Fig. 12). Dump material from the northern shaft suggests that the character of mineralization is similar to that found at the southern

shaft. However, there is much less vein quartz, and more sericitized country rock at the north shaft dump than at the south shaft dump. Pyrite, as disseminated grains and stringers, comprises up to 5% of the sericite schist.



UNIT A - Foliated to schistose metagabbro.

UNIT B - Sheared metagabbro with light gray, cherty quartz stringers. Stringers comprise 60% of the rock; 1% disseminated pyrite.

UNIT C - Banded quartz vein: anastomosing layers of quartz, pyrite, and limonite. 70% quartz, 30% limonite and pyrite.

UNIT D - Schistose rhyolite porphyry.

FIGURE 14. Detailed geology across the contact between the Metagabbro of Clark Creek and the Rhyolite Porphyry of Fire Center Mine, located about 17 m southeast of the Fire Center south dump.

Gold and silver analyses taken from this area are shown in Table 2. Sample 92015 (H, Fig. 13) is a dump grab of quartz vein material with 5% or more pyrite. It was taken from the south shaft dump and recorded an average gold concentration from two analyses of 0.450 oz/ton (15.5 ppm) and a silver concentration of 0.116 oz/ton (4.0 ppm). Sample 92016(1, Fig. 13), quartz vein material with pyrite and limonite, yielded a gold content of 0.0019 oz/ton (0.065 ppm) and a silver concentration less than 0.0145 oz/ton (less than 0.5 ppm). Samples 92019 and 92020 (J and K, Fig. 13) are essentially sericite schist with 1-5% disseminated to stringer pyrite taken from the north shaft, contain gold concentrations of 0.0142 and 0.0067 (0.490 ppm and 0.230 ppm), respectively.

Numerous trenches exist in the rhyolite porphyry dikes (Fig. 12). They expose mineralized quartz veins and silicified shear zones within the dikes and at the contacts between the dikes and the metabasalt or metagabbro. They commonly strike N55°W to N65°W and dip 65°, or greater, to the southwest. Most appear to be less than 5 to 10 feet wide. The lateral and vertical continuity of these veins is uncertain. Style of mineralization found in the trenches is similar to that found at the Fire Center dumps. Two gold analyses from trenches within the dikes are shown in Table 2. Samples 10108 and 10109 (F and G, Fig. 13) yielded 0.0028 oz Au/ton (0.098 ppm) and 0.0061 oz Au/ton (0.210 ppm), respectively.

TABLE 2

Gold and silver analyses from the Fire Center mine dump and associated rocks.

	GOLD		SILVER	
SPECIMEN	PPM	OZ/TON	PPM	OZ/TON
(F) 10108	0.098	0.0028		
(G) 10109	0.210	0.0061		
(H) 92015	15.00 16.00	0.435 0.464	4.0	0.116
(I) 92016	0.065	0.0019	<0.5	<0.0145
(J) 92019	0.490	0.0142		
(K) 92020	0.230	0.0067		

10108 Rock chip across sheared, silicified contact between rhyolite porphyry and metabasalt; sample is vein quartz with 3% pyrite overall as bands and pods parallel to foliation in shear zone.

10109 Rock chip of 3 foot wide shear zone with quartz vein within rhyolite porphyry; massive white vein quartz with trace pyrite, although pyrite is locally 25%.

92015 Fire Center South dump grab: sample restricted to material containing more than 5% pyrite as veins, massive, disseminated grains; milky-white to light gray quartz is the dominant gangue mineral, but sericite, carbonate and minor coarse chlorite are present; trace chalcopyrite, galena, and sphalerite.

92016 Rock chip sample of silicified contact between rhyolite porphyry and sheared metagabbro; light gray to white quartz with 5-10% pyrite, locally to 25%; high content of orange-brown limonite.

92019 Fire Center North dump grab: essentially quartz-sericite schist--altered basalt(?); 1-5% pyrite as stringers.

92020 Fire Center North dump grab: intensely sericitized, schistose rhyolite porphyry(?); trace to 5% pyrite.

Appendix I contains drill hole logs, selected assays, and cross sections produced during the 1930's by workers of Norgan Gold Mining Co. (Kelly, 1936). Locations of the drill holes can be found on Fig. 12. Correlation of surface geology and drill hole data is shown on some of the cross sections. Apparent continuity of mineralization is revealed in some holes such as drill hole #4: a surface trench yielded 0.22 oz. Au/ton and was correlated with a shear zone in the hole which yielded 0.08 oz. Au/ton. Similarly, drill hole #7 yields similar correlations between surface geology and depth: surface assays yielded 0.57 and 0.84 oz. Au/ton and were correlated with a 0.6f quartz vein in the drill hole containing 0.20 oz. Au/ton.

The Holyoke Prospect.

The Holyoke Prospect was originally a silver mine which was active during the 1860's. No production statistics for the mine are known. The tunnel extended 636f in a N17°E direction. In the 1930's, Norgan Gold Mining Co. mapped the Holyoke tunnel and sampled it for gold. Their map provides a detailed cross section of the rocks in that area (Fig. 15). The structural trends are dominantly N65°W. The tunnel mouth is located in slates which are in fault contact with a unit to the north

termed greenstone which is cherty in places. The tunnel traverses various units of greenstone, which have been intruded by porphyry dikes and a red feldspar gabbro dike. Interpretation and correlation of these rock units with the units of this report delineated by surface geology are shown on Fig. 16. Numerous shear zones, quartz veins and carbonate veins were delineated by Norgan Gold Mining Co. geologists. Gold analyses by Norgan Gold Mining Co. during the 1930's are also shown on Fig. 16. The highest value found was 0.03 oz Au/ton from a quartz vein within tuffaceous greenstone. It does not appear that any banded iron formation was sampled and analyzed for gold.

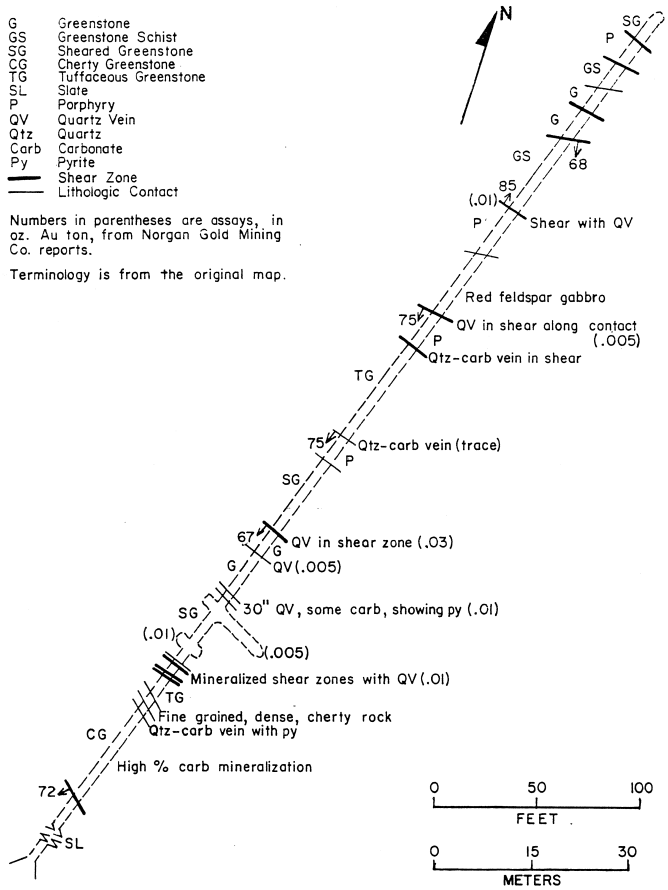


FIGURE 15. Geologic map of the Holyoke Mine (modified from Norgan Gold Mining Company data; Kelly, 1936).

Material collected during this study from the dump reveals visible mineralization associated with banded iron formation and chlorite schist. The banded iron formation found in the dump is similar to that which crops out as boudins in the Breccia of Holyoke Mine. The dark gray rock consists of chert bands about 1 cm to 2.5 cm thick interlayered with magnetite bands less than 0.5 cm thick. Pyrite is the dominant secondary mineral, occurring as veinlets parallel to, and cross cutting, the chert-magnetite bands. Where it occurs parallel to the banding, pyrite selectively replaces the chert. Pyrite comprises up to 15% of the rock. Late stage veinlets, generally less than 1 cm thick, consist of white quartz and light pink-tan carbonate, cross cutting the banding and the pyrite veinlets (Fig. 17). Sample 10116 (L, Fig. 13), banded iron formation from the Holyoke dump (Table 3) yielded 0.0032 oz Au/ton (0.110 ppm) and 0.0102 oz Ag/ton (3.5 ppm). Samples 9196 and 92024 (P and Q, Fig. 13), samples of banded iron formation taken from the Breccia of Holyoke Mine (Table 4), yielded 0.009 oz Au/ton (0.3-10 ppm) and 0.061 oz Au/ton (2.100 ppm), respectively. In addition, sample 92024 contained 0.029 oz Ag/ton (1.000 ppm).

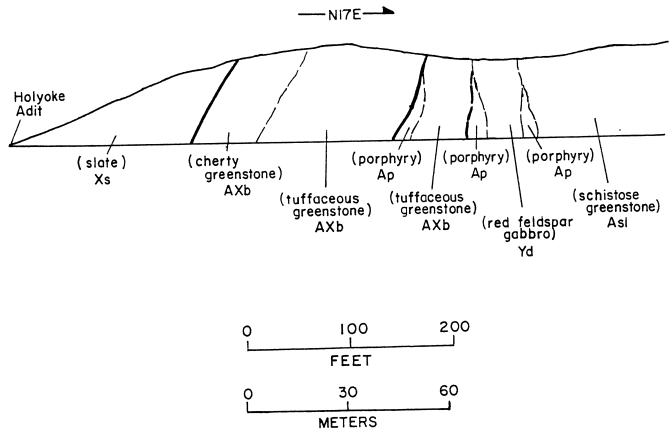


FIGURE 16. Cross section of the geology near the Holyoke Mine correlating the geology of the Holyoke Mine (data from Norgan Gold Mining Company comprises the base of this section) with the surface geologic data from this report. Unit symbols are from this report, and rock names shown in parentheses are from the mine map taken from Kelly (1936).

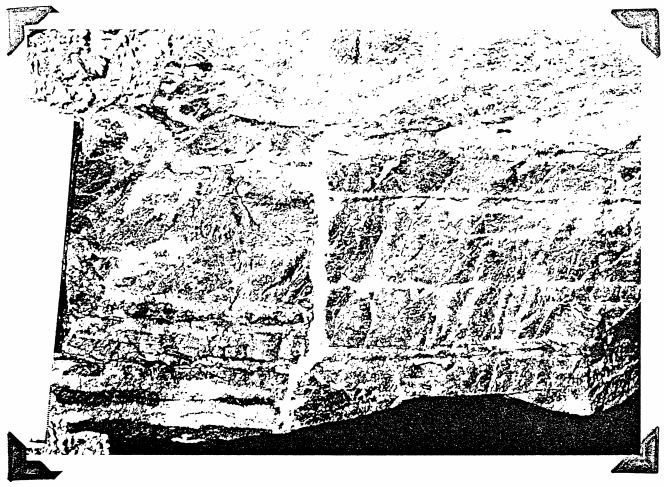


FIGURE 17. Close-up of the banded iron formation taken from the Holyoke Mine dump. Veinlets and pods of pyrite are parallel to and cross cut the laminations; late stage quartz-carbonate veinlets cross cut earlier pyrite.

TABLE 3

Gold and silver analyses from the Holyoke Mine dump, the dump near the shafts to the northeast of the Holyoke Mine, and related rocks.

	GOLD		SILVER	
SPECIMEN	PPM	OZ/TON	PPM	OZ/TON
(L) 10116	0.110	0.0032	3.5	0.1015
(M) 10117	0.410	0.0119	3.5	0.1015
(N) 10118	0.043 0.068	0.0012 0.0020	17	0.493
(O) 91910	0.410	0.0119	35	1.015
(P) 9196	0.310	0.0090		
(Q) 92024	2.100	0.0609	1.0	0.029

10116 Holyoke dump grab; laminated chert-magnetite banded iron formation, with trace to 5% pyrite and little or no secondary quartz and carbonate.

10117 Holyoke dump grab: silicified chlorite schist with sericite, quartz and carbonate as veinlets and pods; 1-3% sulfides, mostly galena and pyrite.

10118 Holyoke dump grab: silicified chlorite schist with late carbonate veins; quartz occurs as veins or as widespread replacement of schist (flooding); with 5-8% sulfides, primarily pyrite and galena, with minor sphalerite and chalcopyrite.

91910 Dump grab: milky white vein quartz in chlorite schist, with 3-5% sulfides, primarily galena and pyrite, and minor sphalerite and chalcopyrite; pyrite frequently concentrated at the contacts between the veins and the schist; late barren quartz-carbonate veinlets.

9196 Rock chip sample of laminated chert-magnetite banded iron formation from boudins within Breccia of Holyoke Mine, with trace to 5% pyrite as stringers and disseminated grains.

92024 Rock chip sample of laminated chert-magnetite banded iron formation from boudins within Breccia of Holyoke Mine, with 5-10% sulfides, mostly pyrite and chalcopyrite.

The chlorite schist found on the dump is a fine grained chlorite-sericite rock characterized by silicification in two forms: 1) discrete veinlets of white to light gray quartz, and 2) extensive replacement of the rock by very fine grained, light gray quartz. Late stage pods and veinlets of quartz and carbonate cross cut the earlier quartz and some sulfides. Total sulfide content is generally less than 5%, although it may locally be higher. Galena and pyrite are the dominant sulfides; galena is commonly associated with late stage quartz-carbonate veinlets, but is not restricted to them, and pyrite is most likely associated with the earlier silicification. Chalcopyrite and sphalerite are found sporadically, occasionally making up a significant amount of the sulfides. Sample 10117 (M, Fig. 13), silicified chlorite schist with less than 1% sulfides, contains 0.0119 oz Au/ton (0.410 ppm) and 0.1015 oz Ag/ton (3.5ppm). A higher value for silver occurred in sample 10118 (N, Fig. 13), which is also silicified chlorite schist collected from the Holyoke dump, with sulfides approaching 8%. Galena is the dominant sulfide, followed by pyrite, with minor sphalerite and chalcopyrite. Silver concentration is 0.493 oz/ton (17 ppm), while the average gold content of two analyses of the same sample is 0.0161 oz/ton (0.055 ppm).

Unnamed Prospects.

Two fenced-off, vertical shafts are located on the,shear zone marking the contact between the Breccia of Holyoke Mine and rhyolite porphyry (Fig. 12). A nearby dump assumed to contain material from one or both of these shafts reveals chlorite schist which has been invaded by veins of milky white, massive quartz. Sulfides occur as massive, amorphous pods, as disseminated grains, and as fracture coatings. Sulfide concentration can range up to 5% of the vein, but is typically trace to 1%. The dominant sulfide is either galena or pyrite; they tend to be mutually exclusive. Commonly, pyrite is concentrated at the edge of the vein and is in contact with the chlorite schist. Chalcopyrite is the next most prominent sulfide, followed by sphalerite, both of which are more closely associated with galena than with pyrite. Late stage quartz-carbonate veins and pods cross cut earlier quartz veins and appear to be barren. Sample 91910 (0, Fig. 13) was taken from the dump, and consists of vein quartz with 3-5% sulfides, mostly galena and pyrite. The silver analysis yielded 1.015 oz/ton (35 ppm) while the gold analysis yielded 0.0119 oz/ton (0.410 ppm -- Table 3).

Prospects in the Iron Formation Member (MSML).

Several trenches have been excavated in the Iron Formation Member (MSML) as shown in Figure 12. These trenches, and their dump material, reveal locally intense silicification in the form of massive white quartz veins and very fine grained, light gray cherty-looking quartz. This is very similar to the silicification found at the Fire Center dumps. A quartz vein was observed to be parallel to the banding in the iron formation as exposed in one trench (at R and S on Fig. 13), but lithologic relationships are poorly known due to lack of exposure of the unit. In this trench, there is a vein of massive white quartz, which contains up to 50% pyrite (+/- limonite), and trends parallel to the chert-magnetite banding within the banded iron formation.

The dominant sulfide found within the iron formation is pyrite, although chalcopyrite was significant at two locations, and bornite was observed at one location. No galena or sphalerite were observed. Within silicified iron formation and quartz veins, sulfides occur as small disseminated grains, as irregular-shaped pods, and as suifide-rich layers up to 5 mm wide. In the chlorite schist which is associated with the iron formation, pyrite occurs as thin layers, less than 2 mm thick, parallel to the schistosity.

Carbonate occurs as veinlets, as pods, and as the matrix surrounding iron formation and quartz fragments in brecciated iron formation. It typically weathers to a light red-brown; on the fresh surface it is white to light tan. The veinlets commonly contain some quartz intergrown with the carbonate. The quartz-carbonate veining in the BIF was the latest stage of hydrothermal alteration. In one location the paragenetic sequence is as follows,

from oldest to youngest: quartz, pyrite (+chalcopyrite and bornite?), quartz + carbonate.

Gold analyses in the BIF show slight relative enrichment in the quartz vein material and chlorite schist, and a relative depletion in the laminated chert-magnetite rock (Table 4). The lowest values were obtained from laminated chert-magnetite iron formation and the quartz veins associated with them. All samples but one registered less than 0.01 oz Au/ton. Vein quartz varied from 0% in sample 10103 to greater than 90% in sample 92011, and pyrite content ranged from trace amounts in sample 10103 to 30% in 7261. Two samples of chlorite schist, 10102 and 92011, have gold concentrations of 0.0041 oz/ton (0.140 ppm) and 0.0113 oz/ton (0.390 ppm), respectively. Pyrite in both of these samples was approximately 5%.

TABLE 4

Gold and silver analyses of banded iron formation from the Iron Formation Member (MSML) and associated rocks.

SPECIMEN	GOLD PPM	GOLD OZ/TON	SILVER PPM	SILVER OZ/TON
(R) 7261	0.039	0.0011		
(S) 7262	0.042	0.0012	< 0.5	<0.0145
(T) 10102	0.120 0.160	0.0035 0.0046		
(U) 10103	0.033	0.0010		
(V) 10106	0.160	0.0046		
(W) 92011	0.390	0.0113		
(X) 92012	0.330	0.0096		

7261 Rock chip sample of highly fractured vein quartz with 30% orange-brown limonite and pyrite; pyrite occurs in the fractures, as massive grains in the limonite, and as disseminated grains; with late quartz-carbonate veinlets.

7262 Rock chip sample of highly fractured vein quartz with up to 70% orange-brown limonite; trace to 1% pyrite.

10102 Dump grab of cherty quartz with minor chlorite schist and magnetite; quartz is very fine grained and light gray; 10% pyrite as pods and veinlets; late carbonate veinlets.

10103 Dump grab of laminated chert-magnetite banded iron formation: trace to 3% pyrite, mostly associated with the chert.

10106 Dump grab of massive, light gray, cherty quartz with 10% pyrite in pods; orange-brown limonite on fractures; with minor carbonate.

92011 Rock chip sample of chlorite schist with cherty quartz; 8-10% pyrite as massive to veinlets parallel to the foliation.

92012 Dump grab from trench in banded iron formation: cherty quartz with trace to 2% pyrite and chalcopyrite.

Other Prospects

The other prospects in the area are few in number and diverse in their geological setting. They include: 1) trenches in the Pyroclastic Member (MSML), which may be related to the Iron Formation Member (MSML), 2) a prospect which consists of a small near-vertical shaft located on the NNE trending fault (location Y, Fig. 13), and 3) a number of very small pits located within the rhyolite porphyry dikes throughout the area.

Trenches in the pyroclastic horizon did not reveal any quartz veins or highly mineralized shear zones. Samples were taken from two trenches where the samples contained up to 2% to 3% sulfides, mostly pyrite. The sulfides occurred as small stringers and pods parallel to the foliation. Both trenches were located near the southern contact of the unit with the banded BIF. Table 5 indicates anomalous values for gold in both samples 9207 and 92014 (AA and BB, Fig. 13): 0.0004 oz/ton (0.015 ppm) and 0.0064 oz/ton (0.220 ppm), respectively.

The vertical shaft located at Y on Fig. 13 has been dug on a mineralized quartz vein following a fault which strikes N15 E. The shaft is approximately 10 m deep and dips 86° to the NW. The vein material consists of massive white quartz with trace sulfides filling the fractures. The primary sulfide is chalcopyrite with minor pyrite. Minor orange-brown limonite and malachite line the fractures. Sample 1010-A was taken from this location and contained 0.0002 oz Au/ton (0.007 ppm).

TABLE 5

Gold and silver analyses of miscellaneous samples from sections 35 and 2.

SPECIMEN	GOLD PPM	GOLD OZ/TON
(Y) 1010A	0.007	0.0002
(Z) 6112	0.380	0.0110
(AA) 9207	0.015	0.0004
(BB) 92014	0.220	0.0064

1010A Dump grab: massive white vein quartz with trace disseminated chalcopyrite and pyrite; trace malachite on fractures.

6112 Rock chip sample of schistose, silicified metagabbro from a mineralized shear zone within the Metagabbro of Clark Creek; silicification occurs as small veinlets of quartz and as flooding; 2-3% pyrite as euhedral disseminated grains up to 1/8" in diameter.

9207 Rock chip sample from trench within Pyroclastic Member(MSML); 2-3% pyrite overall, as podsf thin stringers and seams.

92014 Rock chip sample of Pyroclastic Member (MSML); chlorite schist with cherty quartz; trace pyrite as stringers parallel to foliation.

Table 5 shows a gold assay for sample 6112 (Z, Fig. 13), a rock chip sample taken from a shear zone within the Metagabbro of Clark Creek and is not associated with any prospect(Fig. --). The sample consists of schistose and silicified metagabbro, with 3-5% disseminated euhedral pyrite cubes up to 3 mm in size. The sample contained 0.0110 oz Au/ton (0.380 ppm).

ECONOMIC POTENTIAL

The following statements provide an indication of the economic potential in this area:

1). The geology of the study area is favorable to host gold mineralization as it is similar to numerous Canadian gold deposits (See Hodgson and MacGeehan, 1982): the age of the host rocks is Archean; there is favorable structural control with pervasive shearing and the presence of iron rich rocks (See Phillips et. al., 1984, and Colvine et. al. 1984); there are numerous hypabyssal felsic rocks (rhyolite porphyry) which have intruded into a dominantly mafic terrain (metabasalt and metagabbro); there is banded iron formation; and there is the presence of sulfides, together with characteristic quartz, sericite and carbonate alteration.

2). Assay data from this study and past work show anomalously high values for both silver and gold in the study area.

3). Gold and silver have been produced from the area in the past. Although mining has been nonexistent for nearly a century, exploration has been sporadic but persistent.

APPENDIX A

The drill logs, cross sections and assays presented within this appendix are redrafted from Norgan Gold Mining Co, reports (Kelly, 1936). These data are provided in this report for public record. First, the log of the drill hole, showing depth, lithology, and the assay with its appropriate interval is given. This is followed by a general cross section of the hole. Terminology, wording and geology are taken from the original reports for the most part, and has been modified only where necessary. Data on gold assays throughout this report which are taken from the Norgan Gold Mining Company reports are presumed to be in oz. Au/ton, although units were missing from the original cross sections. Interpretations of the geology are also from the original reports and cross sections. Locations of the drill holes can be found on Figure 12. Abbreviations have been used on the cross sections in order to save space and time; explanation of the abbreviations used can be found on the following page.

LIST OF ABBREVIATIONS USED IN THE FOLLOWING FIGURES AND TABLES

cb -- carbonate
ch -- chert
db -- diabase
gs -- greenschist
min -- mineralized
nd -- no data
py -- pyrite
QV -- quartz vein
qz -- quartz
rh -- rhyolite (porphyry)
sch -- schist
sh -- sheared
sz -- shear zone
tr -- trace

TABLE A1.

Log for drill hole #1. Collar inclination is about 34 from the horizontal in a northeast direction. Total Depth: 427f.

DEPTH(Feet)	DESCRIPTION	ASSAY (in oz. Au/ton preceded by interval assayed in feet)	
0-42	Fine grained - silky luster, dull to dark gray green schist.		
42-133	Medium grained gray green schist (sheared medium grained diabase).	120-130	tr. to .005
133-135	Brecciated pink chert, carbonate and dark gray schist.	130-138	.01
135-138	Brecciated gray to black schist.		
138-142.5	Mixed quartz, carbonate and pink chert.	138-170	tr. to .005
142.5-188.5	Medium graine gray green schist (sheared diabase).	170-175 175-190	.01 tr.
188.5-194	Banded gray green, black schist.	190-194	.01
194-198	Dull gray rhyolite.		
198-199.5			
199.5-206	Dull gray rhyolite.	194-210	tr.
206-210	Diabase dike.		
210-245		210-240	tr.
245-246.5	Mineralized shear zone.	245-250	.03
246.5-293	Fine grained, dull gray rhyolite.	274-276	.04
293-340	Greenschist.	335-336	.02
340-347	Contact shear zone.	340-345.5	.03
347-395	Fine grained, dull gray rhyolite.	345.5-427	nil to .01
395-407	Fine grained diabase		
407-427	Greenschist (sheared amygdaloidal flows).		

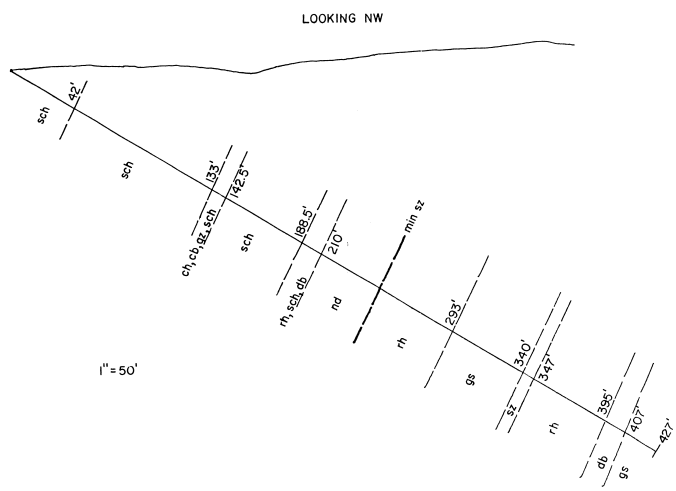


FIGURE A1. Drill hole #1.

TABLE A2.

Log for drill hole #2. Collar inclination is 43° about S45°W. Total Depth: 151'.

DEPTH(Feet)	DESCRIPTION	ASSAY (in oz. Au/ton preceded by interval assayed in feet)	
0-14	Black muck, sand and gravel.		
14-151	Fine grained basaltic flows, with carbonate veins; mineralization is as follows:		
	Galena and chalcopyrite	14-15	.13
	Chalcopyrite and pyrite	15-24	.01-.03
	Pyrite	24-119	nil
	Arsenopyrite	119-120	.03
	Quartz	120-120.75	.20
	Arsenopyrite	120.75-122	.02
	Pyrite	122-124.5	.01
	Arsenopyrite	124.5-125.5	.08
	Quartz vein	125.5-126	.25
	Arsenopyrite	126-126.5	.08
	Pyrite	126.5-151	nil

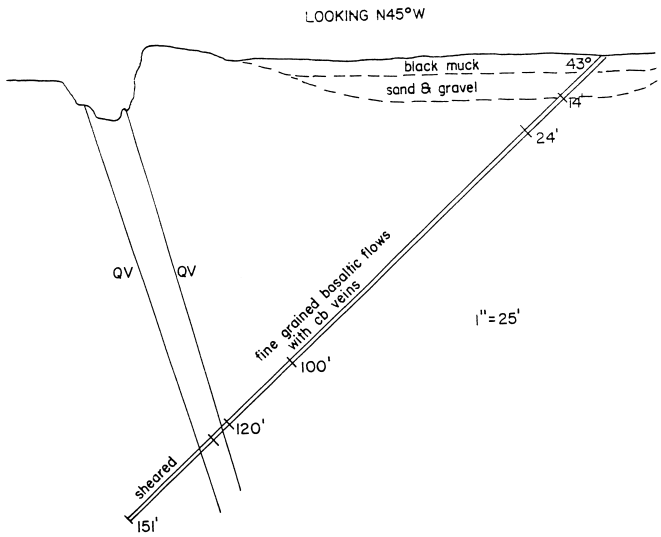


FIGURE A2. Drill hole #2.

TABLE A3.

Log for drill hole #3. Collar inclination is about 50°, approximately S45°W.

DEPTH(Feet)	DESCRIPTION	ASSAY (in oz. Au/ton preceded by interval assayed in feet	
0-22	Fine grained diabase		
22-69	Fine grained basaltic flows (amygdaloidal).		
69-137	Same with pillow structures-- badly brecciated and considerable carbonates.	72-75	.005
137-186	Fine grained basaltic flows (amygdaloidal).	185-186	.01

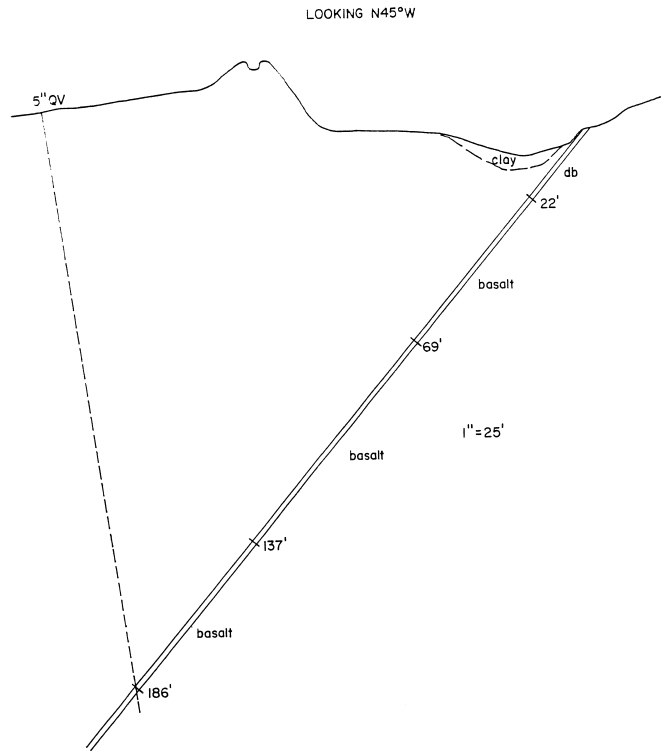


FIGURE A3. Drill hole #3.

TABLE A4.

Log for drill hole #4. Collar inclination is 21.5°, approximately N45°E. Total Depth: 252'.

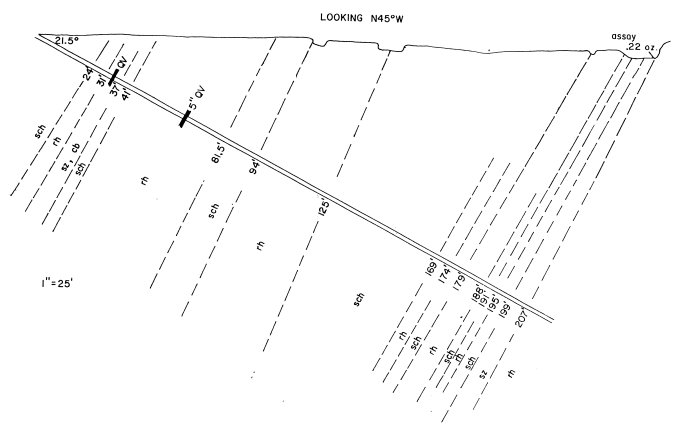


FIGURE A4. Drill hole #4.

TABLE A5.

Log for drill hole #7. Collar inclination is 55°, approximately N45°E. Total Depth: 75'.

DEPTH(Feet)	DESCRIPTION	ASSAY (in oz. Au/ton preceded by interval assayed in feet)	
0-2	Clay.		
2-22	Fine grained light green schist (some carbonates).	9.4-10.6	.035
22-32	Fine grained dull gray quartz rhyolite; sheared.	22-32	tr.
32-56	Coarse grained grading to pink rhyolite porphyry at base; quartz and carbonate at 50-51'.		
56-70	Light green, fine grained sheared basalt (considerable carbonate).	68.5-70	.045
70-70.6	Quartz vein.	70-70.8	.20
70.6-75	Light green, fine grained sheared basalt (considerable carbonate).		

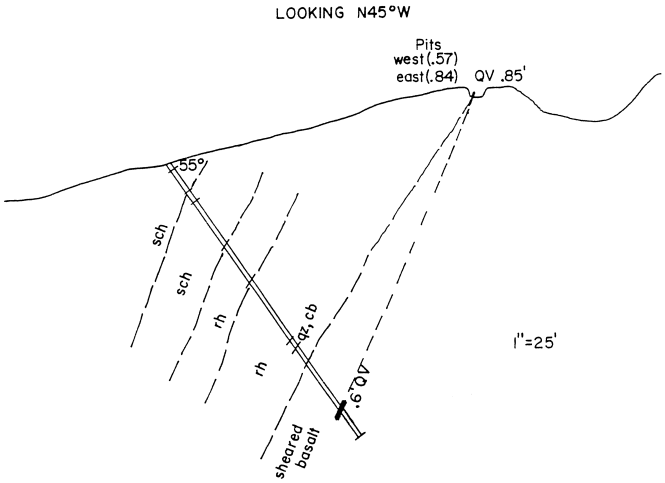


FIGURE A5. Drill hole #7.

TABLE A6.

Log for drill hole #8. Collar inclination is 50°, approximately N45°E. Total Depth: 144'.

DEPTH(Feet)	DESCRIPTION	ASSAY (in oz. Au/ton preceded by interval assayed in feet)	
0-20.8	Fine grained light gray-green schist.		
20.8-21.7	Contact shear zone with quartz.		
21.7-48	Fine grained dull gray rhyolite.	20.8-42	nil to .01
48-65.5	Coarser grained light pink rhyolite porphyry; quartz and carbonate at 55.5-57.5'.		
65.5-79	Fine grained sheared basalt (considerable carbonate).	67.6-82.2	.005
79-83	Tuff and carbonate.		
83-132	Fine grained sheared basalt (considerable carbonate)		
132-144	Fine grained dark green diabase.		

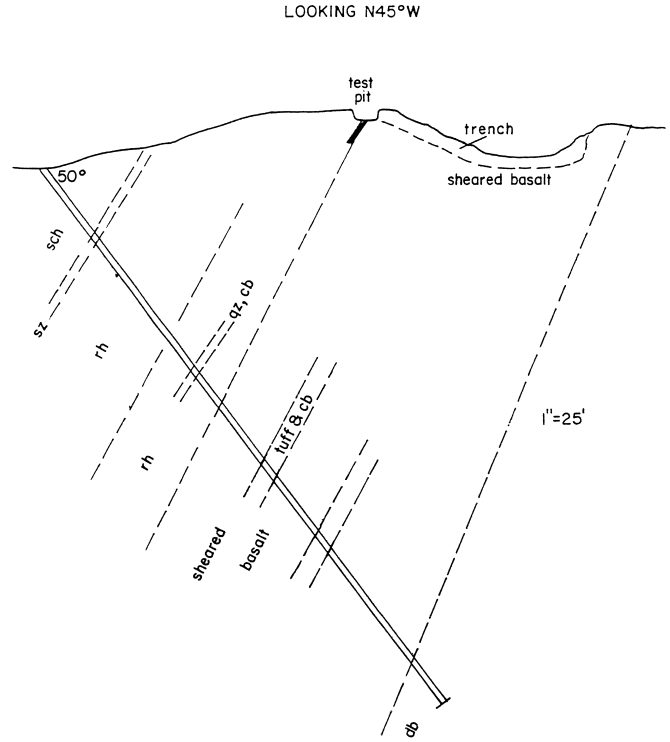


FIGURE A6. Drill hole #8.

TABLE A7.

Log for drill hole #9. Collar inclination is 50°, approximately N45°E. Total Depth: 130'.

DEPTH(Feet)	DESCRIPTION	ASSAY (in oz. Au/ton preceded by interval assayed in feet)	
0-23	Fine grained, light green schist (some carbonates).	22-23	.015
23-35	Fine grained, dull gray, quartz-rhyolite.		
35-37.6	Quartz vein and pyrite.	35-37.5	.05
37.6-39.5	Pyrite.	37.5-39.5	.13
39.5-52	Fine grained, dull gray, quartz-rhyolite.		
52-64.5	Brecciated rhyolite, coarser grained; pink at base.		
64.5-75	Green schist.		
75-82	Coarse grained, pink rhyolite porphyry.		
82-85	Contact shear zone.	82-85	.02
85-130	Light green to olive green sheared basalt (considerable carbonate, slightly oxidized).	92-95	.04

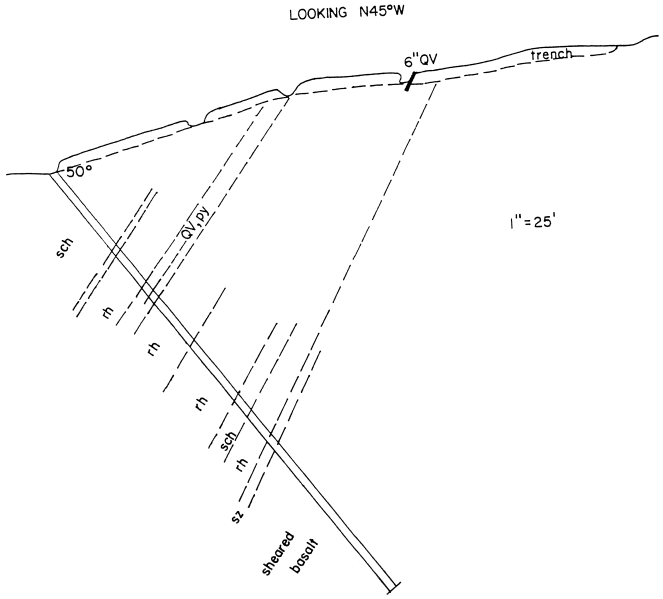


FIGURE A7. Drill hole #9.

TABLE A8.

Log for drill hole #10. Collar inclination is 50°, approximately N45°E. Total Depth: 75

DEPTH(Feet)	DESCRIPTION	ASSAY (in oz. Au/ton preceded by interval assayed in feet)	
0-29.1	Fine grained, dull gray rhyolite.		
29.1-31.5	Mineral shear zone.	29.1-30.1 30.1-31.5	.04 .10
31.5-54	Coarser grained, grading to pink, rhyolite porphyry.		
54	Shear zone.		
54-75	Fine grained light green sheared basalt (considerable carbonate).		

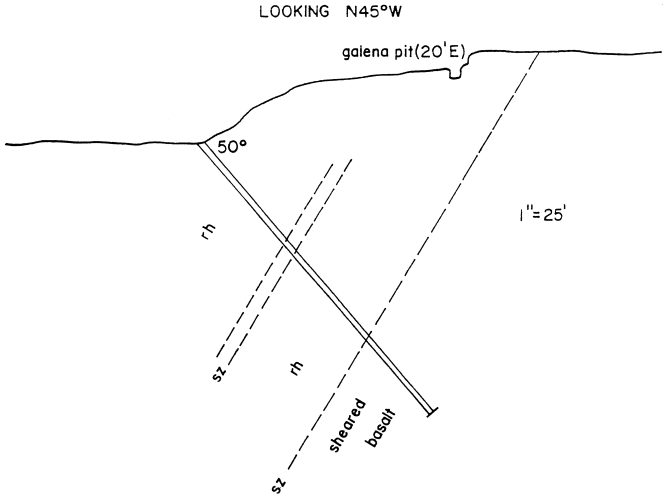


FIGURE A8. Drill hole #10.

TABLE A9.

Log for drill hole #11. Collar inclination is 30°, approximately south. Total Depth: 132'.

DEPTH(Feet)	DESCRIPTION	ASSAY (in oz. Au/ton preceded by interval assayed in feet)	
0-15	Fine grained, dull gray rhyolite.		
15-19	Fine grained, dull gray rhyolite, with quartz stringers.	15-26.5	nil to .005
19-23	Fine grained, dull gray rhyolite.		
23-51	Fine grained, dull gray rhyolite, with carbonate.	31-33	.03
51-58	Coarse grained, pink rhyolite porphyry.		
58-67	Fine grained, dull gray rhyolite.		
67-82	Coarser grained rhyolite; pink towards bottom.		
82-85.5	Quartz vein and carbonates.		
85.5-99	Coarser grained rhyolite, to pink at base.		
99-132	Fine grained, dull gray rhyolite, only slightly sheared--some carbonates.		

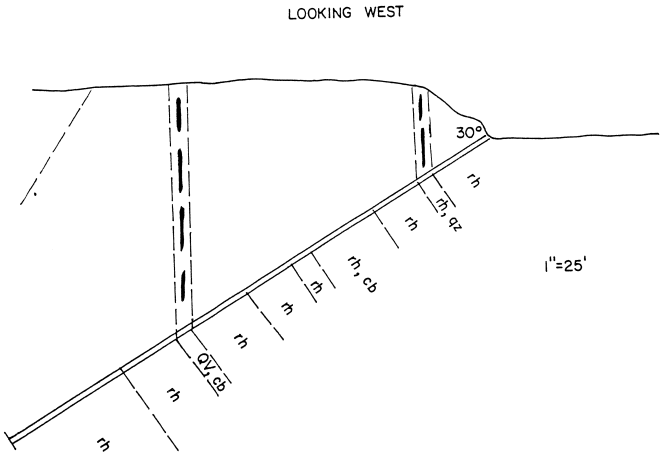


FIGURE A9. Drill hole #11.

TABLE A10.

Log for drill hole 12. Collar inclination is 50°, approximately N45°E.

DEPTH(Feet)	DESCRIPTION	ASSAY (in oz. Au/ton preceded by interval assayed in feet)	
0-20	Black muck, gravel, and boulders.		
20-32	Fine grained, dull gray rhyolite.		
32-36	Mineralized shear.	32-35.5	.015
36-39	Fine grained, dull gray rhyolite.		
39-44.45	Fine grained schist, with quartz and pyrite.	40.75-43.2 43.2-44.45	.02 .06
44.45-54.1	Coarse grained, pink rhyolite porphyry.		
54.1-55.9	Contact shear zone.	55.2-55.9	.005
55.9-83	Fine grained, light green schist--considerable carbonate.		

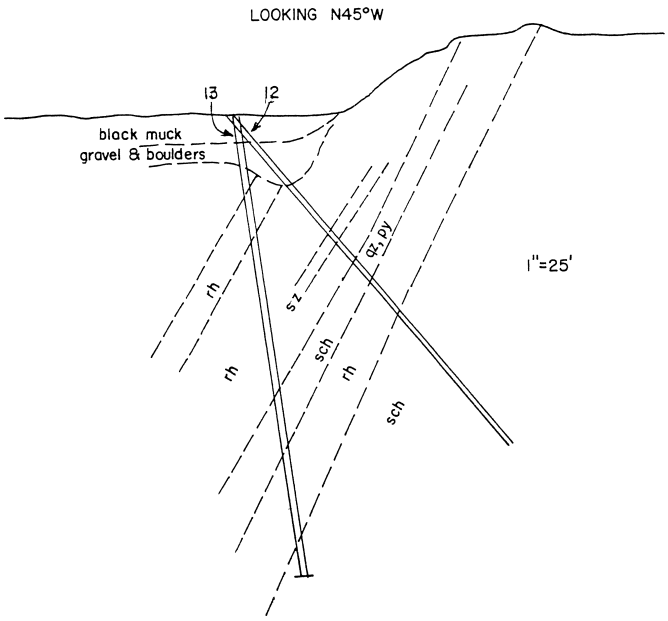


FIGURE A10. Drill holes #12 and #13.

TABLE A11.

Log for drill hole #13. Collar inclination is 80°, approximately N45°E. Total depth: 97'.

DEPTH(Feet)	DESCRIPTION
0-11	Black muck, gravel, and boulders.
11-17	
17-31	Rhyolite breccia.
31-59	Fine grained, dull gray rhyolite.
59-79.5	Fine grained schist.
79.5-92	Coarse grained pink rhyolite porphyry.
92-97	Fine grained, light green schist.

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