Geology, Structure, and Associated Precious Metal Mineralization of Archean Rocks in the Vicinity of Clark Creek, Marquette County, Michigan

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ABSTRACT

The bedrock geology of an 8 mi^2 (20.7 km^2) area northwest of Marquette, Michigan was mapped at a scale of 1:6000. The area of map coverage includes all of sections 19, 20, 28, 29, 30, 32, 33, and 34, and the extreme southwest part of section 27, T49N, R27W. The region lies within the Marquette Greenstone Belt in the northern portion of Marquette County.

The oldest rocks observed in the area are part of a succession of steeply dipping Archean metavolcanics known as the Metavolcanics of Silver Mine Lakes. This group was originally named by Owens and Bornhorst in 1985 (Michigan Geological Survey Division Report OFR-85-2) in an area immediately east of the Clark Creek region and was subdivided into Pillowed Basalt, Pyroclastic, Iron Formation, and Laminated Schist members. In 1986, Johnson and others (Michigan Geological Survey Division Report OFR-86-2) reported on an area immediately to the west which contained foliated, non-foliated, and highly altered basalts of unknown stratigraphic relationship to the Metavolcanics of Silver Mine Lakes. This study allows correlation between these two areas and revision of the members within the Metavolcanics of Silver Mine Lakes to, from oldest to youngest: Lower Pillowed Basalt Member, Mudflow Member, Middle Pillowed Basalt Member, Iron Formation Member, and Upper Pillowed Basalt Member. The Upper Pillowed Basalt Member is subdivided into normal, foliated, and highly altered varieties. Numerous pillow structures in the basalts consistently show the top of beds to be towards the south-southwest. Where visible, bedding and lithologic contacts generally strike between N50°W and N70°W and have dips from 70° to near vertical towards the southwest. The metavolcanics are intruded by the Archean Metagabbro of Clark Creek which roughly parallels bedding. All the pre-existing rocks were then intruded by the Archean Rhyolite Intrusive of Fire Center Mine and the Archean Granodiorite of Rocking Chair Lakes which may be contemporaneous with the rhyolite. An altered variety was mapped for the metagabbro as well as the rhyolite intrusive. During the Late Archean, these rocks were subjected to a period of intense metamorphism and deformation. Occurrence of this event is indicated by lithologic discontinuities along faults, highly sheared intrusive contacts, and zones of highly foliated to schistose basalts which have been interpreted as shear zones. Most foliations have strikes of between N60°W and N75°W with dips between 60° and vertical towards the south-southwest. The Archean rocks are unconformably overlain by quartzites, metagrayw-ackes, and slates of the Lower Proterozoic Michigamme Formation. The rocks in the region were also intruded by very thin diabase dikes immediately following deposition of the Lower Proterozoic sediments. Michigamme Formation rocks, including the diabase dikes, were metamorphosed and faulted near the end of the Lower Proterozoic by the Penokean Orogeny. This orogeny may also have been responsible for minor reactivation of Archean faults and shear zones. Middle Proterozoic (Keweenawan) diabase dikes, typically east-west trending, cut all of the older rock units and structures.

Mineralization in the region exists in two forms: 1) disseminated sulfides within altered country rocks, and 2) quartz-carbonate-sulfide veins. Disseminated mineralization is most prominent in the highly altered variety of the Upper Pillowed Basalt Member and the

Iron Formation Member, but also occurs to a much lesser degree in other Archean rock types. It consists of disseminated pyrite, which is occasionally accompanied by minor amounts of pyrrhotite and chalcopyrite. The gangue minerals in the altered country rocks are primarily carbonate, sericite, quartz, and chlorite. The veins are often associated with shear zones and faults. The chief sulfide mineral is pyrite with much lesser amounts of chalcopyrite, arsenopyrite, and pyrrhotite. Locally, galena and sphalerite are the dominant sulfide vein minerals. The most common gangue minerals in these veins are quartz and carbonate, with lesser amounts of chlorite.

A limited number of gold assays were completed, some of which yielded anomalous values. The highest values were from the highly altered variety of the Upper Pillowed Basalt Member. Additional anomalous values for gold were obtained from the Iron Formation Member. Owens and Bornhorst (1985) also found anomalous gold in this member which we interpret to represent a chemically favorable host for gold mineralization. An anomalous silver assay was obtained from a fault zone with associated galena mineralization.

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INTRODUCTION

The Clark Creek region was mapped as part of a cooperative project between the Geological Survey Division of the Michigan Department of Natural Resources and the Department of Geology and Geological Engineering at Michigan Technological University. The purpose of this project is to extend previously reported geology and mineralization information into a relatively unknown area which contains similar rocks and mineralization.

LOCATION AND ACCESSIBILITY

The Clark Creek region is located along the northern shore of the Dead River Storage Basin in Marquette County, Michigan (latitude 46° 35' 33" to 46° 38' 9" and longitude 87° 39' 21" to 87° 44' 23") (Figure 1). The area laps over the southern boundary of the Negaunee NW 7 1/2 minute quadrangle and the northern boundary of the Negaunee SW 7 1/2 minute quadrangle. The map coverage includes all of sections 19, 20, 28, 29, 30, 32, 33, 34, and the extreme southwest part of section 27, T49N, R27W, Ishpeming Township. Excellent motor vehicle access to the area is available by following one of two routes. Either 12 mi (19 km) north of County Road 502 and US-41 along County Road 510 (paved and gravel) and then 2 mi (3.5 km) southwest on Red Road (gravel), or, 21 mi (34 km) north of US-41 on County Road 573 (Deer Lake Road) (paved) and the North Dead River Road (gravel) (Figure 1).

FIELD METHODS

The Clark Creek region was mapped at a scale of 1:6000 (1 in = 500 ft or 1 cm = 60 m). The boundaries between sections 27-34, 28-33, 20-29, and 19-30 were surveyed east to west using compass and surveyors tape with traverse lines flagged every 250 feet (76 meters). Mapping of outcrops was done by compass and pace, generally along the north-south traverse lines. Contacts were inferred between outcrops except where the density of outcrop was sufficient to allow accurate location on the map. Geology was plotted on an enlarged topographic base from the Negaunee NW 7 1/2 minute quadrangle (5 meter contours) and the Negaunee SW 7 1/2 minute quadrangle (20 foot contours). Some very small outcrops shown in Plate 1 are exaggerated where necessary to show geologic relationships. Clusters of small outcrops are often shown as larger, continuous outcrops for clarity. All contacts and geologic units are shown to scale. Rocks were identified in hand specimen and mineralogy estimated with a hand lens. A Gisco G-816 Proton Precession Magnetometer was used to follow an iron formation in the area.

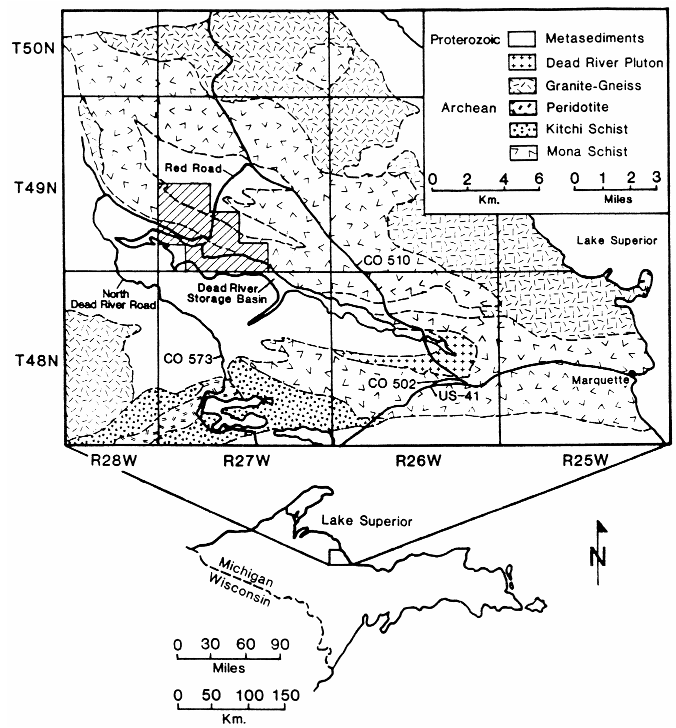

FIGURE 1. Regional geology and location map of the Clark Creek Region (modified from Morgan and DeCristoforo, 1980).

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PREVIOUS WORK

The regional geology surrounding Clark Creek has been described by several workers. The earliest published study comes from Van Hise and Bayley (1895) who named the major units of the Marquette Greenstone Belt; the Mona and Kitchi Schists. Van Hise and Leith (1911) updated the regional picture with work performed by themselves and A. E. Seaman. Some unpublished maps and reports on the regional geology and mineralization of the Marquette Greenstone Belt were produced in the 1930's for the Norgan Gold Mining Company (Kelley, 1936) although study of the Clark Creek region never progressed beyond the regional scale. More recent regional geologic data has been provided by Bodwell (1972) on his map of the Northern Complex and by Gair and Thaden (1968), Puffet (1974), and Clark et.al. (1975) who each produced 7 1/2 minute quadrangle bedrock geological maps which covered areas to the south and east of the Clark Creek region. The bedrock geologic map of the Negaunee SW quadrangle (Clark et.al., 1975) includes sections 28, 29, 30, 32, 33, & 34, and the southern-most portions of sections 19 and 20 of T49N, R27W (Plate 1). These 7 1/2 minute quadrangle geologic maps further delineated several members of the Mona Schist beyond that of Van Hise, et.al. (1897) and described additional formations of both Archean and Proterozoic age in the Marquette area. Morgan and DeCristoforo (1980) published a regional interpretation of the Marquette Greenstone Belt, although the Clark Creek region was not studied in any detail.

BEDROCK GEOLOGIC SETTING

The Clark Creek region is located on the steeply dipping, northwest trending, northern part of the Archean Marquette Greenstone Belt (Figure 1). The southern part of this belt contains mafic lava flows and graywackes grouped together in the Mona Schist; Archean aged basaltic, andesitic, and dacitic volcanic flows and volcaniclastic rocks grouped together to form the Kitchi Schist; and a serpentinized peridotite known as the Deer Lake Peridotite. The northern part contains Archean rocks consisting of dominantly mafic volcanic flows with minor, interbedded volcaniclastic and pyroclastic deposits of intermediate composition, and rare iron formation. These rocks have been intruded by Archean gabbro and subsequently by Archean rhyolite and granodiorite. To the east of the Clark Creek region, this package of Archean rocks is unconformably overlain by breccias and slates with interbedded arkose and conglomerate which was originally mapped as part of the Reany Creek Formation (Owens and Bornhorst, 1985). The northern part of the greenstone belt is bounded by Archean granitoid intrusions to the north and west and by Lower Proterozoic metasediments to the south (Figure 1). The Lower Proterozoic Michi-gamme Formation unconformably overlies the Archean units, but is often found in fault contact with them. Archean and Lower Proterozoic rocks were intruded by two ages of diabase dikes. The early dikes were emplaced during the Lower Proterozoic, roughly contemporaneous with the Michigamme Formation. These intrusives are now metamorphosed to lower greenschist facies. The later dike swarm occurred in the Middle Proterozoic, during Keweenawan time. These dikes are relatively unaltered and essentially undeformed.

UNIT DESCRIPTIONS

ARCHEAN ROCKS

METAVOLCANICS OF SILVER MINE LAKES

The Metavolcanics of Silver Mine Lakes were named by Owens and Bornhorst (1985) for a succession of Archean metavolcanic units in the vicinity of Silver Mine Lakes (sections 34 & 35 of T49N, R27W) (Plate 1). The metavolcanics are subdivided into five members, from oldest to youngest: Lower Pillowed Basalt Member, Mudflow Member, Middle Pillowed Basalt Member, Iron Formation Member, and Upper Pillowed Basalt Member. These members have been modified from those described by Owens and Bornhorst, 1985. The entire volcanic succession lies within the boundaries of the Mona Schist as defined by Clark et.al. (1975).

The Metavolcanics of Silver Mine Lakes have a minimum thickness of at least 7,000 feet (2,135 meters) assuming there is no structural repetition (Plate 1). Rocks within this informal formation can be found in sections 19, 20, 27, 28, 29, 30, 32, 33, and 34, T49N, R27W, to the east into the Fire Center Mine area (Owens and Bornhorst, 1985) and to the west into the Island Lake to Rocking Chair Lakes area (Johnson, et.al., 1987). The northern contact of the formation is a non-conformity. The steeply dipping metavolcanics are unconformably overlain by shallow dipping metasediments correlative with the basal units of the Michigamme Formation (Trow, 1979). An outcrop of relatively undisturbed, Michigamme Formation, basal conglomerate, in the NW 1/4 of section 19 dips approximately 20°N within 200 feet (60 meters) of an outcrop of the steeply south dipping Upper Pillowed Basalt Member. The pillow basalts, at least in this location, were likely to have been the depositional surface for the Michigamme Formation. Along the southern contact of the Metavolcanics of Silver Mine Lakes is a fault. The steeply dipping Metavolcanics of Silver Mine Lakes lie in probable fault contact with steeply dipping slates and metagraywackes of the Michigamme Formation. The fault lies parallel to the Archean Dead River Shear Zone, but is believed to be a very thin (< 20 feet, 6 meters), brittle-deformation zone as compared to the more ductile, 400-600 foot (122-183 meter) Dead River Shear Zone. This brittle-fault zone may have had up to 3000 feet (915 meters) of movement in the vertical direction and possibly some movement in the horizontal direction as well (Weeks, 1987).

Relative ages of the members are based on the presence of abundant pillows in the Upper Pillowed Basalt Member which consistently indicate stratigraphic top to the south. A hypothetical stratigraphic column of the Metavolcanics of Silver Mine Lakes and younger rock units is shown in Figure 2.

Lower Pillowed Basalt Member

The Lower Pillowed Basalt Member (Abl) is the oldest rock unit exposed in the area. It has a minimum thickness of 2,500 feet (762 meters), assuming no structural repetition, and strikes roughly N55°W. The rocks which comprise this member are found in the northeast 1/3 of section 34 and are projected into the NE 1/4 of the SE 1/4 of section 28 although there is no outcrop exposed.

The northern boundary of this unit is along the non-conformity created by the deposition of the Lower Proterozoic Michigamme Formation. The contact appears to dip very shallowly north into the Clark Creek Basin. The southern boundary is a steeply dipping contact with the overlying Mudflow Member. The basalts near the contact, especially at the Silver Mine Lakes Prospect, have a foliated texture.

The outcrops of the Lower Pillowed Basalt Member are usually small scattered knobs or elongate ridges trending to the northwest. Some areas are completely devoid of outcrop due to the thickness of alluvium. A few pillow structures were observed within this unit with vesicles and calcite amygdules along the chilled pillow rinds. Pillows are typically elongate in cross-section, 6-20 inches (15-50 cm) long, and 1 1/2-4 inches (4-10 cm) high. Vesicles are usually elongate in shape and 1/5-4/5 inch (5-20 mm) across.

The basalt is dark green-gray to green-black in color, predominantly fine-grained to aphanitic, and is massive to weakly foliated. Visible mineralogy consists of very fine-grained chlorite, plagioclase, and minor sericite. The samples also contain varying amounts of finely disseminated pyrite which reaches a maximum of 2 volume percent of the whole rock. Closer to the Mudflow Member the basalts appear to be slightly more altered as evidenced by an increased amount of sericite and disseminated pyrite.

Mudflow Member

The Mudflow Member (Amf) is a relatively narrow unit occurring in northeast 1/2 of section 34 and the extreme southwest corner of section 27. Since only three outcrops of this unit were found, an estimate of thickness is difficult. The largest exposure is the section 27 outcrop which has an approximate thickness of 90 feet (27 meters). Strike of the unit is between N50°W and N60°W with dip near vertical towards the southwest.

The northern contact of the Mudflow Member is conformable, stratigraphically above the Lower Pillowed Basalt Member. The southern boundary occurs along a conformable contact with the Iron Formation Member in the east 1/2 of section 34 and a presumed conformable contact with the Middle Pillowed Basalt Member in the west 1/2 of section 34 and in section 27. Notable exceptions to the contacts described above occur in a few locations where the Mudflow Member is surrounded to the north and south by gabbro and/or rhyolite intrusions.

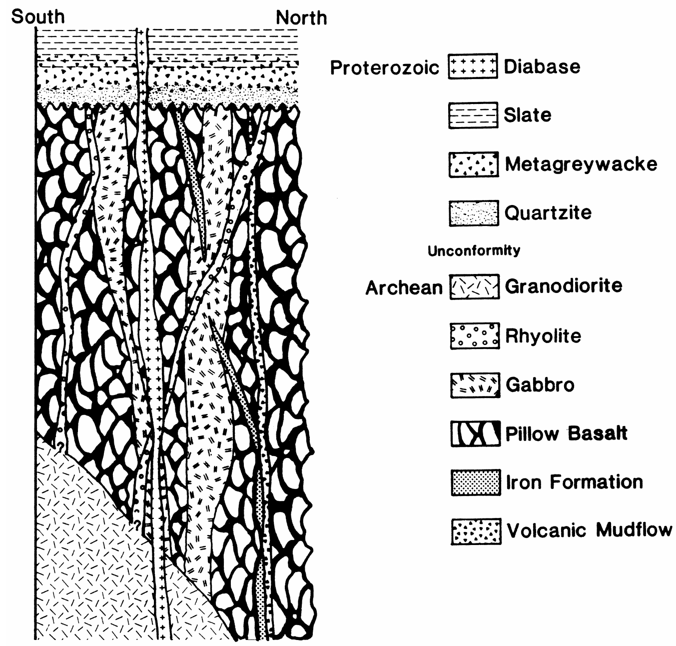

FIGURE 2. Hypothetical stratigraphic column of the Archean and Proterozoic rock units in the Clark Creek Region.

Outcrops are rare and are always low, moss covered knobs. Differential weathering gives the unit a distinctive appearance once the moss is removed. The quartz rich fragments are in raised relief against the finer grained, less quartzose, matrix. The matrix weathers to a light green-tan color and is a green-black color on fresh surfaces. The clasts are white, gray, or brown on both weathered and fresh surfaces. A gradational change in fragment content takes place across the unit where it is exposed in section 27. The bottom of the unit (to the north) shows few of the larger fragments and pods visible in other outcrops. As one moves towards the top, the fragment content increases to a maximum of about 35%. This may represent the “lithic tuff horizon” grading upwards into the “quartz-stringer horizon” described by Owens and Bornhorst (1985) in the Fire Center Area to the east.

The fragment-poor horizon has equant to oblong, sub-angular to sub-rounded grains of relict lithic material. These grains rarely exceed 1/3 inch (1 cm) in size. The matrix is medium to fine-grained, intermediate to mafic in composition, with occasional 1-3 mm phenocrysts of feldspar. The fragment-poor horizon is interpreted as either a well-sorted mudflow or a reworked tuff deposit.

The fragment-rich horizon contains fragments of all shapes from very elongate to sub-equant and varying degrees of rounding from very angular to rounded. The more equant fragments are generally 1/3-4 inches (1-10 cm) across while the elongated fragments can reach lengths of up to 10 inches (25 cm). About 50% of the fragments are white, gray, and black cherts which have been recrystallized to a small degree. The remaining fragments are fine-grained, porphyritic volcanic rocks which appear to have an intermediate composition. The matrix is very similar to the fragment-poor horizon suggesting that the two horizons had a similar genesis. Based on the range of fragment compositions and shapes, we interpret the fragment-rich horizon as a mudflow deposit.

Both horizons are moderately to highly foliated in all outcrop locations. Foliations can often be seen wrapping around larger fragments resulting in an augen appearance. This unit has experienced a large amount of strain relative to the nearby basalts and iron formation. This is most probably due to differential strength properties between this unit and surrounding rocks.

Middle Pillowed Basalt Member

The Middle Pillowed Basalt Member (Abm) is a discontinuous unit found stratigraphically above the Mudflow Member and stratigraphically below the Iron Formation Member of the Metavolcanics of Silver Mine Lakes. The maximum thickness is approximately 1000 feet (305 meters) and occurs in the central part of section 28; the unit pinches out to the east in section 34. The southern contact has been delineated by a ground-based magnetic survey which followed the positive anomaly produced by the iron formation. Most of the region underlain by the Middle Pillowed Basalt Member has a thick cover of unconsolidated sediments. Outcrops of this unit are very poor and consist of only low knobs and small ridges. The eastern-most extent of the basalt is in the northwest corner of section 34 where the contact between the mudflow and iron formation diverges around the Middle Pillowed Basalt Member. The unit has a few outcrops in section 28, and has been projected along strike into sections 29 and 20.

The basalt is light green-black in color with a very fine-grained texture and a massive to weakly foliated appearance. No pillow structures are visible, although it was probably deposited in a subaqueous environment similar to that of the other pillowed basalt members in the Metavolcanics of Silver Mine Lakes.

Iron Formation Member

The Iron Formation Member (Aif) of the Metavolcanics Silver Mine Lakes is least voluminous of all the members. However, it is one of the most important for following stratigraphy since it can be located with reasonable accuracy by using magnetic surveying techniques. The member is extremely variable in thickness, lateral extent, and mineralogic composition. The maximum exposed thickness is only 30 feet (10 meters), which is too thin to adequately show on the map in Plate 1. Thus, the unit thicknesses shown in Plate 1 have been exaggerated. The only outcrops of this unit are at the Silver Mine Lakes Prospect along the eastern boundary of section 34 (Figure 6) and in the stream bed of Clark Creek near the eastern boundary of section 29. Projections have been made from these outcrops and locations indicated by positive anomalies on aeromagnetic maps and ground-based magnetic surveys. With these projections the unit has a strike of roughly N70°W through the middle of section 34, the extreme northeast corner of section 33, the middle of section 29, the northeast portion of section 28, and finally into section 20 where it is overlain by Lower Proterozoic metasediments. The aeromagnetic signature indicates that the iron formation persists beneath these metasediments up into the far northern portion of section 19.

The Iron Formation Member is underlain by either the Mudflow Member or the Middle Pillowed Basalt Member. It is overlain, to the south, by the Upper Pillowed Basalt Member. In some locations the iron formation is surrounded by gabbro and/or rhyolite intrusions.

The unit has a lensoidal shape in cross-section (Owens and Bornhorst, 1985). This is consistent with the observations made in this study. When ground-based magnetic data were examined, vertical field anomaly values on adjacent survey lines spaced 400 feet (122 meters) apart differed by as much as 5000 Gammas. This is probably due to the highly variable thickness and possibly the amount of magnetite present in the rock.

The Iron Formation Member is a gray, dark gray, to black banded rock with alternating bands of micro-crystalline quartz (chert) and magnetite or magnetite-rich chert. In the samples from the Silver Mine Lakes Prospect, the rock is a black, cherty iron formation with 2-5% disseminated sulfides (mainly pyrite). These cherty layers are cross-cut by carbonate veinlets which contain up to 20% sulfides. Some of the veinlets appear to have formed in tension fractures based on their sinusoidal shape. The carbonate in these veinlets may be ankerite because the veins weather to an orange limonite color.

The outcrop exposed in the Clark Creek is different than the one described above. In this location the rock is gray to dark gray in color and shows very distinctive bedding of micro-crystalline quartz and layers of massive magnetite. The magnetic signature here is pronounced enough to produce a large ellipsoidal anomaly on the U.S.G.S. aeromagnetic sheet for Marquette and Baraga Counties. The only similarity of this outcrop to the Silver Mine Lakes outcrop is the presence of carbonate-sulfide veins occupying tension gashes. This outcrop also contains clots of sulfides scattered through the rock which are often associated with the carbonate veins. The sulfides comprise a maximum of 5% of the whole rock.

Upper Pillowed Basalt Member

The Upper Pillowed Basalt Member of the Metavolcanics of Silver Mine Lakes lies directly above the Iron Formation to the south. This is by far the thickest and most voluminous unit in the exposed metavolcanic package. The maximum thickness attained in the Clark

Creek region is 4500 feet (1372 meters) assuming no stratigraphic repetition. The southern contact lies parallel to the Dead River Shear Zone where the basalts are in presumed fault contact with steeply dipping Lower Proterozoic slates of the Michigamme Formation. The member has been subdivided into three varieties based on various criteria. The varieties are as follows: normal, foliated, and highly altered. Placement of contacts between the varieties (Plate 1) is based on a hypothetical cutoff point for the particular feature (foliation or alteration) determined while mapping was in progress. The different varieties are found in sections 19, 20, 27, 28, 29, 30, 32, 33, and 34.

The normal variety (Abu) is found in all of the sections listed above and makes up the majority of the Upper Pillowed Basalt Member. The thickness ranges from 1500 feet (457 meters) in section 34 to 3000 feet (914 meters) in section 19. Contacts with all other varieties of the Upper Pillowed Basalt Member are gradational. Contacts with intrusive rocks can be either sharp or sheared/faulted. This unit is commonly dark green to green-black in color, fine-grained to aphanitic, and massive to moderately foliated. The visible mineralogy includes very fine-grained chlorite, fine-grained plagioclase and sericite, and rarely fine-grained amphibole. Very fine-grained plagioclase crystals show relict igneous microlite textures. Elongate, variably flattened pillows are visible throughout the outcrop area and range in size from 1-8 feet (30-250 cm) in length and 3-30 inches (8-76 cm) in thickness. Many pillows show small bands of vesicles 1/16-1 inch (2-25 mm) in size along the chilled margins. Most pillowed outcrops have a matrix of tan to gray carbonate in the interpillow void space. Stratigraphic tops have been determined in eight locations within this variety of the Upper Pillowed Basalt Member where the shapes of the pillows are cuspate on the bottom and convex on the top. In all localities the top direction is towards the south-southwest. Strikes and dips obtained in two locations average N56°W with dips between 85° and vertical towards the south-southwest.

The normal variety can be slightly altered and moderately foliated. In section 19, along the gradational contact with the highly altered variety, the basalts are progressively more altered as the contact is approached from north to south. Some small altered and foliated zones were also included in the normal variety because they were deemed too small to adequately show on the map in Plate 1. All of these small zones occur along faults or areas interpreted as shear zones but are less than 50 feet (15 meters) across.

Quartz and quartz-carbonate veins can be found throughout this variety. Their sizes range from less than 1/16 inch (2 mm) to 9 inches (23 cm) in width. The veins can carry up to 5% sulfides and may there may be up to 2% disseminated sulfides in the immediately adjacent basalts. Disseminated sulfides occur throughout much of this unit and are usually > 95% pyrite with minor amounts of chalcopyrite and pyrrhotite.

Foliated Variety

The foliated variety (Abf) of the Upper Pillowed Basalt Member, occurs in the southeast part of section 19, and all along the Dead River Shear Zone in sections 29, 32, 33, and 34. Rocks which would previously have been classified as the Laminated Schist of Owens and Bornhorst (1985) have been re-interpreted to be highly foliated pillow basalts. Because of this, they are now included in the foliated variety of the Upper Pillowed Basalt Member of the Metavolcanics of Silver Mine Lakes. This variety has a thickness of approximately 500 feet (152 meters) within the Clark Creek region. The location of the contact was estimated using a hypothetical cutoff point for intensity of foliation. This cutoff was made visually based on color, which is directly related to chlorite content, and on the degree of foliation developed in the rock. The best outcrops are generally found along the shore of the Dead River Storage Basin in the eastern 1/4 of section 33 and all of section 34. In addition to the shoreline outcrops, the foliated variety can also be found cropping out as prominent ridges which often represent slope breaks. The foliated variety ranges in color from medium gray-black to medium green-black. It has an aphanitic texture, a phyllonitic to schistose fabric, and is composed of predominantly chlorite with lesser amounts of albite and/or sericite, quartz, and carbonate. Many of the outcrops in the eastern 1/2 of section 34 contain up to 40% secondary carbonate (dolomite? to ankerite?) as the matrix of brecciated basalt. Other rocks in this locality contain alternating light and dark layers which we interpret as transposed layering which originated as light colored pillow rinds surrounded by darker pillow interiors and darker, interpillow matrix material. Pyrite, as disseminations, is found throughout this variety and can occur locally in concentrations up to 30%. One outcrop, which was sampled for precious metal analysis (#86-49), contains a large amount of graphite along with the foliated basalts. The graphitic portion is a dull gray color and exhibits anastomosing foliation surfaces which are defined by the graphitic cleavage. The schistose basalt which surrounds the graphitic zone is a green-gray color with shear pods of sulfides which reach a maximum of 30% of the rock. The anomalous gold and silver values shown for sample 86-49 are determined from a mix of the graphitic zones and sulfide-rich, schistose basalts. The precious metal values are most likely carried by the sulfide-rich, schistose basalts. We interpret the graphitic pods to be unmineralized, graphitic slates of the Lower Proterozoic Michigamme Formation which were faulted into the basalts. Clark, et.al. (1975) and Puffet (1974) both describe the metasediments occurring to the south of the Dead River Storage Basin as “carbonaceous slates and graywackes.”

A few outcrops within the foliated basalt of section 19 exhibit abundant fragments of vesiculated pillow rinds which are interpreted to be fault-fragmented pillow basalts. It is also possible that these fragmental pillows may represent a hyaloclastite flow rather than a deformational zone. Since, however, no other hyaloclastite-like units were encountered along the assumed strike of these outcrops it has been included with the foliated basalts.

Highly Altered Variety

The highly altered variety (Aba) of the Upper Pillowed Basalt Member of the Metavolcanics of Silver Mine Lakes is found in the central part of section 34, the southern part of section 19, section 30, and west-central section 29. The maximum observed width of this variety occurs in sections 19 and 30 (Plate 1), 2500 feet (762 meters). Outcrops occur as moderate to large cliff faces, low ridges trending along strike of the unit, and as low isolated knobs. In the same manner as was described for the foliated variety, the contacts of the highly altered variety with other varieties of the Upper Pillowed Basalt Member were interpreted from field examination of hand samples and are gradational. The important factors for this determination were color on a fresh surface and mineralogy. The basalt of the highly altered variety becomes more gray-black in color than those of the normal variety due to increased carbonate and sericite alteration, and less chlorite. A few small regions of alteration within the Upper Pillowed Basalt Member were included with the normal variety because of their very limited extent.

The highly altered variety of the Upper Pillowed Basalt Member is dark to light gray in color and takes on a green hue near the gradational contact with the normal variety, where the intensity of alteration is lower. The basalts are aphanitic to very fine-grained and are composed of carbonate, sericite, plagioclase, chlorite, and quartz. The fabric varies from massive in most areas to very strongly foliated along the Dead River Shear Zone in sections 30 and 29 (Figure 4). If the alteration were not present, the basalts along this zone would have been included in the foliated variety described above. In rare cases, pillow structures can still be observed on weathered faces of this basalt variety.

Some of the most highly altered rocks found are in the NW 1/4 of section 30. In this area, the alteration type varies from outcrop to outcrop (i.e. - one a predominantly carbonatized basalt and the next a sericitized basalt). Localized talc alteration is present in one outcrop. Structural complexity is also very high in this 1/4-section. The three roughly east-west trending faults shown on Plate 1 are a simplified representation of the numerous faults present. This area is interpreted as a portion of the Archean Dead River Shear Zone.

Age and Origin of the Metavolcanics of Silver Mine Lakes

The Metavolcanics of Silver Mine Lakes are the oldest rocks in the area. They are Archean in age based upon correlation with the Mona Schist of Clark et.al. (1975), Puffet (1974), and Gair and Thaden (1968). The absolute age is probably around 2.75 Ga based on a Rb/Sr date of silicic tuffs from section 9, T50N, R27W (Morgan and DeCristoforo, 1980). The minimum age is constrained by a U-Pb date of 2.70 +/- .015 Ga for a rhyol-ite intrusive which cuts similar basalts in a drillhole in the NW 1/4 of the SE 1/4 of section 16, T49N, R27W (Trow, 1979). The metavolcanic succession consists of subaqueous volcanic flows with relatively thin, interbedded mudflow and iron formation units. The water depth can be estimated at less than 500 meters (1640 feet) since the vesicles are almost always larger than 1 mm (Compton, 1985).

METAGABBRO OF CLARK CREEK

The Metagabbro of Clark Creek is named for coarse-grained, metamorphosed gabbroic intrusives cropping out to the northeast of Clark Creek in the west-central portion of section 28 (Plate 1). The gabbros are considered to be dikes and concordant sill-like bodies. Thicknesses range from 1500 feet (457 meters) in section 29 to less than 75 feet (23 meters) in the western part of section 30. Outcrops are generally well exposed and form large cliffs and ridges which are sub-parallel to the strike of the Metavolcanics of Silver Mine Lakes. Based on textural and mineralogic changes noted in the field, the unit was sub-divided into two varieties: normal and altered.

The normal variety of the Metagabbro of Clark Creek (Ag) is found in sections 19, 20, 28, 29, 30, 33, and 34 (Plate 1). Contacts are generally sharp, where exposed, with a general decrease in grain size when approaching contacts with the Metavolcanics of Silver Mine Lakes. In some localities, well developed foliation in the gabbro and adjacent basalts indicates that the contact may be a shear zone.

The gabbros are medium to dark green-black on a fresh surface, holocrystalline, medium to very coarse-grained, and massive to strongly foliated. The mineralogy of the normal variety is composed of blue-green amphibole, gray plagioclase, chlorite, and minor opaques (pyrite, magnetite, and minor pyrrhotite). The more foliated zones within the gabbro have a much higher percentage of chlorite which causes a deeper green color in outcrop. Lower Proterozoic metadiabases and metagabbros are also known to exist along with the Archean metagabbros in this area (Johnson, et.al., 1987). Due to similar grain size and metamorphic grade, however, these units were indistinguishable in the field with one exception. A Proterozoic dike was recognized in section 30 where it cuts the highly altered variety of the Upper Pillowed Basalt Member. It has been included with the Lower Proterozoic rocks because it lacks the prevalent alteration present in the southern part of section 30.

Altered Variety

The altered variety (Aga) often occurs in very small zones along with the foliated portions of the normal variety. The only place in which the alteration zone is large enough to map separately is in the center of section 34. In this area a 600 foot (183 meters) thick metagabbro is surrounded on all sides (Plate 1) by faults. The color is usually a medium to dark gray with plagioclase crystals forming augens which are surrounded by chlorite, carbonate, quartz, and minor sericite. The rock has a unique undulating, schistose texture along the foliation surface. The intensity of alteration is higher towards the southern edge of the unit where it is in presumed fault contact with the highly altered variety of the Upper Pillowed Basalt Member of the Metavolcanics of Silver Mine Lakes. The foliation within the gabbro and basalt along this contact is likely due to movement along the nearby Dead River Shear Zone.

Age and Origin of the Metagabbro of Clark Creek

The age of the Metagabbro of Clark Creek is Archean since it is cut by rhyolite dikes which have been dated at 2.70 +/- .015 Ga (Trow, 1979). Most of the gabbroic units seen in this region are sill-like bodies which were probably intruded into the basaltic pile at depth while volcanic activity was still underway at the surface. The gabbro and basalts are chemically similar which suggests a common genetic history (Bornhorst and Baxter, 1987).

RHYOLITE INTRUSIVE OF FIRE CENTER MINE

The Rhyolite Intrusive of Fire Center Mine is named for two prominent rhyolite dikes located at the Fire Center Mine, near the center of section 35, T49N, R27W (Owens and Bornhorst, 1985). These rhyolites occur as both dike-like and sill-like bodies in the Clark Creek region. The width of the rhyolite intrusives are extremely variable from a fraction of an inch to over 400 feet (4 mm to > 121 meters). Because of the difficulty of showing a dike less than 40 feet (12 meters) in width on the map in Plate 1, they have been omitted. It should be noted that in the area of the section 30 prospect in the northern part of section 30, many rhyolite dikes, of both normal and altered varieties, were encountered which were below this minimum size criteria. It also appears that this area has at least two ages of rhyolite intrusive activity as some dikes are cut by the east-west faults while others appear unaffected. Outcrops can be either topographic positives or negatives depending on the amount of alteration and/or foliation present. Some larger (>300 feet, 90 meters) bodies can be seen in ground-based magnetic data as small, broad, negative anomalies. Contacts are rarely visible and are usually faulted if seen.

The Rhyolite Intrusive of Fire Center Mine has three common textural varieties. The first two, porphyritic and granular, are grouped together as the normal variety. The third is an aphanitic texture which is typically altered and is thus termed the altered variety.

The normal variety (Ar) can be found in sections 19, 20, 28, 29, 30, 33, and 34. The most common textural type of rhyolite is the quartz porphyry. This type has anhedral relict phenocrysts of quartz from 2-8 mm across. The next most common type is a quartz-feldspar porphyry. These rocks have relict phenocrysts of subhedral potassium feldspar and/or plagioclase as well as anhedral quartz of similar size. The matrix of both types are fine-grained to aphanitic and consists of quartz, carbonate, feldspar, and minor sericite. Color ranges from dark gray to light gray to pink. The granular variety is generally light pink with a roughly equidimensional texture of quartz and feldspar grains 2-5 mm across. Disseminated sulfides are usually less than 1% if present. The rhyolites are commonly massive to well foliated. The more foliated rocks have a higher sericite content and minor amounts of chlorite. A few rhyolites are brecciated with very angular fragments set in a matrix of very fine-grained, gray to white carbonate.

Altered Variety

The altered variety (Ara) of the Rhyolite Intrusive of Fire Center Mine occurs in section 30. It is a light green to green-gray, aphanitic, schistose rock. It is identified in the field primarily by color and lack of visible grains. The rock is composed of partially recrystallized quartz, feldspar, and interstitial sericite. The sericite grains often define a crude foliation direction. Disseminated sulfides are up to 5% in the altered variety. The alteration and disseminated mineralization is probably the result of hydrothermal activity.

Age and Origin of the Rhyolite Intrusive of Fire Center Mine

The Rhyolite Intrusive Of Fire Center Mine is 2.70 +/- .015 Ga old based on a U-Pb date on a zircon for a rhyolite from a drillhole approximately 2 miles (3.2 km) north of the Clark Creek region (Van Schmus, 1978). The rhyolites may be related to regional-scale, post-volcanic, granitoid plutonism (Bornhorst and Baxter, 1987).

GRANODIORITE OF ROCKING CHAIR LAKES

The Granodiorite of Rocking Chair Lakes (Agr) is named for the dominantly granodioritic intrusions which occur around the Rocking Chair Lakes in section 10, T49N, R28W (Johnson, et.al., 1987). In the Clark Creek region, the Granodiorite of Rocking Chair Lakes is only found in the extreme northwest corner of section 19 (Plate 1). This is the easterly extension of an east-west trending stock which intrudes the hinge area of a large fold in sections 13, 14, and 15 of the Silver Creek to Island Lake Area (Johnson, et.al., 1987). Outcrops are rare and usually heavily weathered when observed. Contacts of the granodiorite in the Clark Creek region are not exposed but are considered to be intrusive in nature against the metagabbro. The granodiorite is medium pink-gray, medium-grained, and is composed of plagioclase, K-feldspar, quartz, amphibole, and minor sericite, epidote, carbonate, and chlorite. In section 19 the granodiorite contains more amphibole than reported by Johnson, et.al. (1987) perhaps due to assimilation of the gabbroic country rocks.

Age and Origin of the Granodiorite of Rocking Chair Lakes

The Granodiorite of Rocking Chair Lakes is considered to be Archean in age. It intrudes the Metavolcanics of Silver Mine Lakes and the Metagabbro of Clark Creek but has not been observed cutting any of the dikes which are part of the Rhyolite Intrusive of Fire Center Mine (Johnson, et.al., 1987). The granodiorite may be syn-tectonic and synchronous with the rhyolite intrusives (Bornhorst and Baxter, 1987; Johnson, et.al., 1987).

LOWER PROTEROZOIC ROCKS

MICHIGAMME FORMATION

The Michigamme Formation (Xm) is a Lower Proterozoic metasedimentary unit composed of slate, metagraywacke, and iron formation, with a minor quartzite at the base. In the Clark Creek region, the basal layer contains beds of conglomerate within quartzites. The basal layer presumably grades upward into the nearby slates and graywackes. Thicknesses of the different units can not be estimated due to very poor exposure. Outcrops of the Michigamme Formation are rare, but it is believed to underlie areas within sections 19, 20, 27, 28, 29, 30, 32, 33, and 34 (Plate 1). The basal conglomerate-quartzite horizon, which is exposed in the western portion of section 19, is a relatively thin unit lying unconformably upon the Archean metavolcanics. This horizon may correlate with the Goodrich Quartzite as described by Klasner (1978). The slates and graywackes lie stratigraphically above the quartzite and are probably interbedded.

The conglomerate unit is medium gray to black on the fresh surface and weathers to a rusty iron-oxide color and is generally clast supported. The clasts make up 40-60% of the rock, and are sub-angular to rounded, ovoid to very elongate, and 1/8-10 inches (1/2-25 cm) in long dimension. The clasts are white quartzose sandstone/quartzite, dark gray chert, gray rhyolite, white vein quartz, and minor black phosphatic fragments. The matrix is a gray, massive, medium-grained, ferruginous quartzite. The graywacke is medium gray, very fine to medium-grained, massive and consists of quartz, feldspar, and minor mafic minerals (amphibole?). The slates are gray to black, fine to very fine-grained, bedded, with occasional 1/3-1 inch (1-3 cm) thick sandy layers. The bedding is shown by color variation between laminations which range from 1/5-4/5 inch (2-20 mm) thick.

Metadiabase

The Lower Proterozoic metadiabase (not shown on plate 1) from section 30 is included in the Michigamme Formation due to the probable age correlation (Johnson, et.al., 1987). The outcrop was found in an open exploration trench which has since been covered. The dike, which cuts the highly altered variety of the Upper Pillowed Basalt Member of the Metavolcanics of Silver Mine Lakes, is 5 inches (12 cm) thick, green-gray in color, very fine-grained, massive, and has a well developed chill margin. The diabase has not been effected by the deformation or extensive hydrothermal activity prevalent in the adjacent Archean rocks. It has, however, been metamorphosed to lower greenschist facies by Penokean thermal metamorphism centered in Republic, Michigan. This indicates that it cannot be Archean or Keweenawan and must be Lower Proterozoic in age.

Age and Origin of the Michigamme Formation

The age of the Michigamme Formation is generally considered to be Lower Proterozoic, in the range of 1.9-2.1 Ga (Clark, et.al., 1975). The age relations in the local area may be somewhat confused since it has been suggested that the Clark Creek Basin may represent a restricted depositional environment. Whether this is true or not, the overall environment present at the time of formation was that of a shallow sea which eventually deepened to form a continental shelf.

MIDDLE PROTEROZOIC ROCKS

KEWEENAWAN DIABASE

The Keweenawan Diabase (Yd) is an intrusive rock which cross-cuts all previous structures and units. The strike of the dikes are generally east-west but may deviate locally to follow pre-existing structure. Dike thickness is typically around 80 feet (25 meters) but a few dikes are as thin as 3 feet (1 meter) or as thick as 150 feet (46 meters). The diabase is a dark gray to black on fresh surfaces and weathers to a dull rust-brown color. It is medium-grained with 2-7 mm laths of plagioclase set in a finer grained matrix of pyroxene, magnetite, and olivine. The diabase can be highly magnetic and may produces large negative anomalies on ground-based magnetic and aeromagnetic surveys.

Age and Origin of Keweenawan Diabase

The Keweenawan Diabase has been correlated across the western Upper Peninsula of Michigan and dated at approximately 1.1 Ga. The intrusives are associated with magmatic activity of the Mid-Continent Rift System.

CORRELATION OF ROCK UNITS

The stratigraphic correlation of rock units within the Clark Creek region to those of Clark, et.al. (1975), Owens and Bornhorst (1985), and Johnson, et.al. (1987) is shown in Figure 3. The Metavolcanics of Silver Mine Lakes are equivalent to that of Johnson, et.al. (1987) and Owens and Bornhorst (1985). The members which comprise the Metavolcanics of Silver Mine Lakes have been updated from the Pillowed Basalt, Pyroclastic, Iron Formation, and Laminated Schist members reported by Owens and Bornhorst (1985). The new members are as follows, from oldest to youngest: Lower Pillowed Basalt Member, Mudflow Member, Middle Pillowed Basalt

Member, Iron Formation Member, and Upper Pillowed Basalt Member. The Metavolcanics of Silver Mine Lakes are also correlative with the Mona Schist of Puffet (1974) and Clark, et.al. (1975) based on lithologies and limits of the former unit.

The Metagabbro of Clark Creek is equivalent to that of Johnson, et.al. (1987) and Owens and Bornhorst (1985). It is correlative to the metagabbro mapped by Clark, et.al. (1975) which was considered Archean in age. It may also correlate with some of the outcrops mapped by Puffet (1974) as a metadiabase intrusive of uncertain age. This is possible because Lower Proterozoic metadiabase and Archean Metagabbro within areas of greenschist facies metamorphism are often difficult to distinguish in the field.

The Rhyolite Intrusive of Fire Center Mine is equivalent to that of Johnson, et.al. (1987) and is correlative to the Rhyolite Porphyry of Fire Center Mine of Owens and Bornhorst (1985) and the felsic intrusive unit mapped by Clark, et.al. (1975). It is also possible that the intrusion of the Rhyolite Intrusive of Fire Center Mine into the Metavolcanics of Silver Mine Lakes may have been contemporaneous with the emplacement of the Granodiorite of Rocking Chair Lakes (Johnson, et.al., 1987).

The Granodiorite of Rocking Chair Lakes most likely correlates with the nonfoliated, granitoid intrusives of the Compeau Creek Gneiss described by Gair and Thaden (1968). This correlation is based on spatial association and mineralogical similarities (Johnson, et.al., 1987).

The Michigamme Formation was originally mapped in this area by Clark, et.al. (1975) as an undifferentiated Lower Proterozoic metasediment. A thin diabase dike (included in the Michigamme Formation) was found intruding the highly altered variety of the Upper Pillowed Basalt Member of the Metavolcanics of Silver Mine Lakes. This dike correlates with the Lower Proterozoic Metadiabase of Johnson, et.al. (1987) and with the Lower Proterozoic Metadiabase mapped by Clark, et.al. (1975).

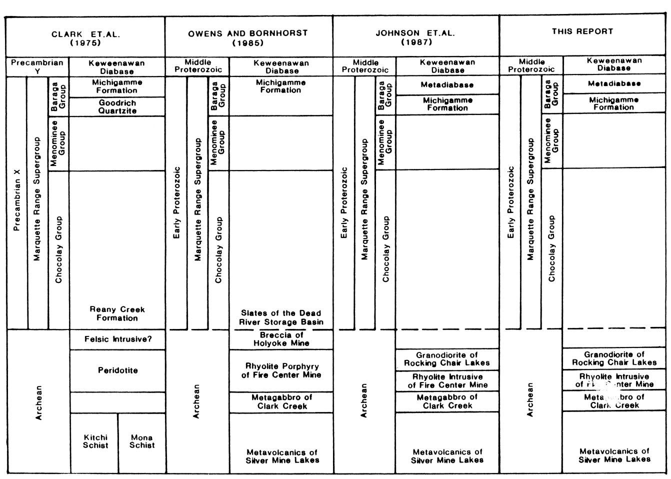

FIGURE 3. Correlation chart for rock units in the Clark Creek Region.

Middle Proterozoic, Keweenawan (1.1 Ga) diabase dikes are equivalent to those mapped by Johnson, et.al., (1987), Owens and Bornhorst (1985), Clark, et.al. (1975), and Puffet (1974).

METAMORPHISM

The Archean units were first deformed and metamorphosed by a Late Archean tectonic event. This event was responsible for a relatively high degree of deformation and metamorphism. The metamorphism is most evident in amphibolitized basalts and gabbros in the northwest portion of the Silver Creek to Island Lake Area (Johnson, et.al., 1987). Archean metamorphism in the Clark Creek region is in the low to middle greenschist facies. Relict igneous features are still visible in the basalts as felty textures and in the gabbros as ophitic to sub-ophitic textures.

Archean metamorphism of basalts and gabbros is evidenced by the alteration of primary pyroxene to secondary hornblende which has then suffered some retrograde alteration to chlorite. In gabbros, plagioclase is partially replaced by very fine grained sericite. In more schistose rocks, particularly in the foliated variety of the Upper Pillowed Basalt Member of the Metavolcanics of Silver Mine Lakes, chlorite may be the dominant mineral present.

The rhyolite and granodiorite intrusives exhibit the metamorphism to a much lesser degree. These rocks commonly have recrystallized grain boundaries, sericite alteration of feldspars, and minor, possibly hydrothermal, development of chlorite.

The next metamorphic event which effected the area was the Penokean Orogeny (1.8-1.9 Ga). The Lower Proterozoic sediments and diabase of the Michigamme Formation were deformed and metamorphosed during this event. James (1955) delineated three Penokean metamorphic nodes in the western Upper Peninsula. These nodes range from sillimanite grade at the center to chlorite grade around the perimeter. The Clark Creek region lies within the chlorite isograd of the Republic node as defined by James (1955). The Penokean metamorphic event had little or no obvious thermal effect on the Archean rocks since they were previously metamorphosed to greenschist facies or higher.

The rocks of the Michigamme Formation are metamorphosed to lower greenschist facies. The quartzites and metagraywackes have recrystallization textures whereas the slates contain chlorite which is aligned into a slaty cleavage, typically at an angle to bedding. The Lower Proterozoic diabase has been metamorphosed to a fine grained amphibole-plagioclase-chlorite rock.

STRUCTURE

The rocks in the Clark Creek region were affected by two deformational episodes: Archean and Lower Proterozoic (Penokean). The first event folded, sheared, faulted, and metamorphosed the Archean rocks of the Marquette Greenstone Belt in Late Archean time. The second event folded, faulted, and metamorphosed the Lower Proterozoic sediments and diabase of the Marquette Range Supergroup. This event also resulted in block faulting of Archean rocks along reactivated Archean structures.

Foliations

The foliations in the Clark Creek region are defined by slaty, phyllonitic, and schistose cleavages. These cleavages are most prominently displayed in the lepidoblastic textured, mafic rocks. Most foliations in the Archean rocks are interpreted to have been formed during the Late Archean tectonic event. The strike of Archean foliations ranges from N50°W to N75°W which is sub-parallel to the Dead River Shear Zone. Dips of these foliations range from 50° to vertical towards the southwest. Some additional Archean foliations which strike N20°W to N35°E and dip from 30° to near vertical towards the west are probably related to movement along younger N-S Archean faults.

Lower Proterozoic metasediments display a moderate to well developed cleavage which is related to Penokean deformation (1.8-1.9 Ga). The Lower Proterozoic foliation visible in the metasediments to the south of the Dead River Shear Zone has a strike of N53°W and a dip of 83° to the southwest. Cleavage measurements of metasediments to the north were not obtained but are probably similar to those observed by Johnson, et.al. (1987); approximately N70°W, with moderate dips towards the south. Penokean foliation was not recognized in the Archean rocks.

Folds

The Archean rocks in the Clark Creek region lie on the southern limb of a steeply plunging, synformal anticline. Bedding dips near vertical and is younging towards the south. The nose of the regional fold is exposed to the west of the study area in the Silver Creek to Island Lake Area (Johnson, et.al., 1987). The hinge region of this structure has been intruded by the Granodiorite of Rocking Chair Lakes which extends into the northwest corner of the study area in section 19 (Plate 1). It is not clear whether a fold may or may not relate rocks of the Clark Creek region to Archean mafic rocks to the south, since movement along the Dead River Shear Zone probably caused lateral and vertical juxtaposition of units during the Archean deformational event.

Some very small scale folds are visible in the altered variety of the Rhyolite Intrusive of Fire Center Mine. The folds are generally less than an inch in amplitude and represent approximately 50-70% shortening.

Faults and Shear Zones

There are several generations of faults in the Clark Creek region (Figure 4). All of these faults probably had their initial movement during various pulses of the Late Archean deformational event. Faults are recognized in the field in a variety of ways: 1) offset or truncation of lithologic units, 2) breccias and associated secondary mineralization, 3) localized, intense foliation of rocks, and 4) topographic lineaments which generally correlate with other features.

The oldest faults in the study area are generally southeast-northwest to east-west trending. The faults are generally ductile in nature and probably represent a deformational regime where the ratio of the rate of recovery to the rate of strain was > 1 (Wise, et.al., 1984). Relative movement directions are difficult to determine since these faults generally have a strike parallel or sub-parallel to the strike of lithologic units. Also trending southeast-northwest is a large shear zone which was initiated during the Late Archean, probably at the same time as the faults described above. This shear zone, known as the Dead River Shear Zone, is typified by steeply dipping, phyllonitic to highly schistose metavolcanic rocks. These rocks constitute the foliated variety of the Upper Pillowed Basalt Member of the Metavolcanics of Silver Mine Lakes (Plate 1). The highly deformed Archean rocks within the Dead River Shear Zone are in presumed fault contact with steeply dipping slates of the Lower Proterozoic Michigamme Formation. The slates moved along a Lower Proterozoic normal fault which is parallel to the Dead River Shear Zone but only reactivated a small part of the Archean structure. The high degree of foliation and hydrothermal alteration visible in Archean rocks is absent in the adjacent Lower Proterozoic rocks, including a Lower Proterozoic diabase dike which cuts the Archean foliation. Therefore, the Dead River Shear Zone began as an Archean ductile shear zone which subsequently had a minor portion reactivated as a brittle fault during the Penokean Orogeny.

The early Archean faults are truncated, and occasionally offset by, slightly younger, north-south to northeast-southwest trending Archean faults. The deformational regime for these faults was in the brittle range where the ratio of the rate of recovery to the rate of strain was < 1 (Wise, et.al., 1984). It is likely that movement along these faults took place in the waning stages of the Late Archean deformational event since the zone of highly altered basalts is offset by them.

The youngest known fault is the Lower Proterozoic fault which places Archean metavolcanic rocks in presumed fault contact with the metagraywackes and slates of the Michigamme Formation. This fault, which is parallel to the Dead River Shear Zone, truncated the earlier north-south trending faults which may have offset the Dead River Shear Zone. The foliated variety of the Upper Pillowed Basalt Member along the shore of the Dead River Storage Basin in the southeast corner of section 34 contains pods of graphitic slates within schistose, pyrite-rich basalts. These graphitic slate pods are a part of the Michigamme Formation which was faulted into the foliated basalts during the Lower Proterozoic. Outcrops of graphitic slates have been indentified on the southern shore of the Dead River Storage Basin (Puffet, 1974).

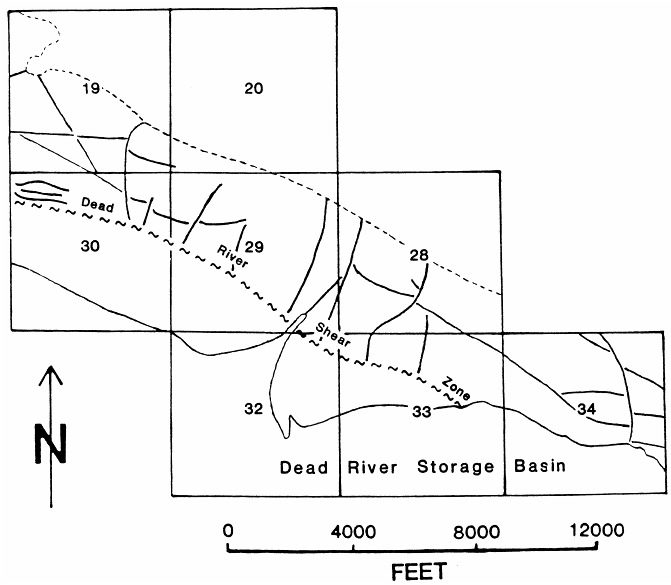

FIGURE 4. Location map of the major faults in the Clark Creek Region (T49N, R27W).

Some diabase dikes, intruded during Keweenawan time (1.1 Ga), diverge from their dominantly east-west trend to follow the trace of fault zones such as the dike in southern section 34 (Plate 1). The extent of fault movement, if any, during this period is unknown.

MINERALIZATION

Historical Activity

The Clark Creek region has been explored for base and precious metals since the late 1800's. The location of the more significant prospects and two of the drill holes for which logs were available are shown in Figure 5.

One of the largest exploration programs to date was undertaken by the Norgan Gold Mining Company during the mid 1930's (Kelly, 1936). The Norgan study included geologic mapping along the northern limb of the Marquette Greenstone Belt, sampling, trenching, and a 12 hole drilling program. Exploration was sporadic until 1970 when Humble Oil Company drilled four holes in the area. Two of these holes were drilled in section 19 within the Clark Creek region. The drill logs for these holes were obtained during this study and are included in Appendix A. During 1984 Nicor Minerals of Denver also carried out a drilling program along the north part of the belt. The locations and drill logs for these holes, however, were not available.

During the time field work for this study was being conducted, exploration was being actively undertaken by two companies: Calahan Mining Company and Kerr-McGee Corporation. The exploration activity included geologic mapping, sampling, trenching, and drilling. As of this writing, the majority of the recent work in the Clark Creek region has been concentrated in the northern portion of section 30. This area will subsequently be referred to as the Section 30 Prospect.

Silver Mine Lakes Prospect

The Silver Mine Lakes Prospect is located along the border of sections 34 and 35, T49N, R27W (Figure 5). The prospect consists of trenches, test pits, and two shafts which were sunk in the Mudflow Member of the Metavolcanics of Silver Mine Lakes (Figure 6). The prospect was investigated by the Norgan Co. in the 1930's for it's silver potential. At that time the prospect was known as "The Lead Pits" for the abundant galena present.

The mineralization at this prospect consists of quartz and quartz-carbonate veins of varying sizes (1 mm - 10 cm) which cut the metavolcanic rocks. The quartz-carbonate veins host base metal mineralization consisting of galena, sphalerite, and very minor chalcopyrite and pyrite. The galena and sphalerite in the veins is generally found in euhedral intergrowths surrounded by carbonate material.

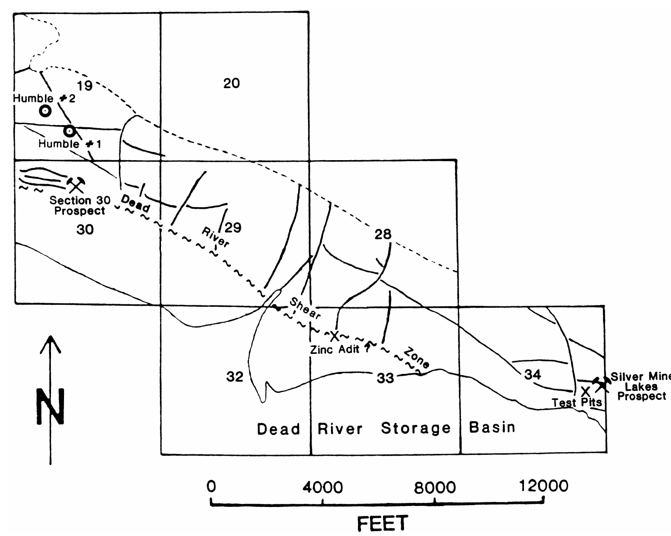

FIGURE 5. Location map of prospects in the Clark Creek Region (T49N, R27W).

Section 30 Prospect

The Section 30 Prospect is the most recent prospect within the Clark Creek region. It is located within the highly altered variety of the Upper Pillowed Basalt Member of the Metavolcanics of Silver Mine Lakes. There are some small gabbroic dikes of the altered variety of the Metagabbro of Clark Creek which are too small to be shown in Plate 1. There are also several discrete periods of rhyolite intrusive activity in the area of the prospect. Some of the dikes are highly altered to green quartz-sericite schists, whereas others are less altered in appearance and exhibit a typical porphyritic texture. Many of these dikes are not shown in Plate 1 due to their small size. There are many trenches at the prospect as well as several new drill holes. A figure with their locations is not included in this report, however, since exploration is ongoing at this time.

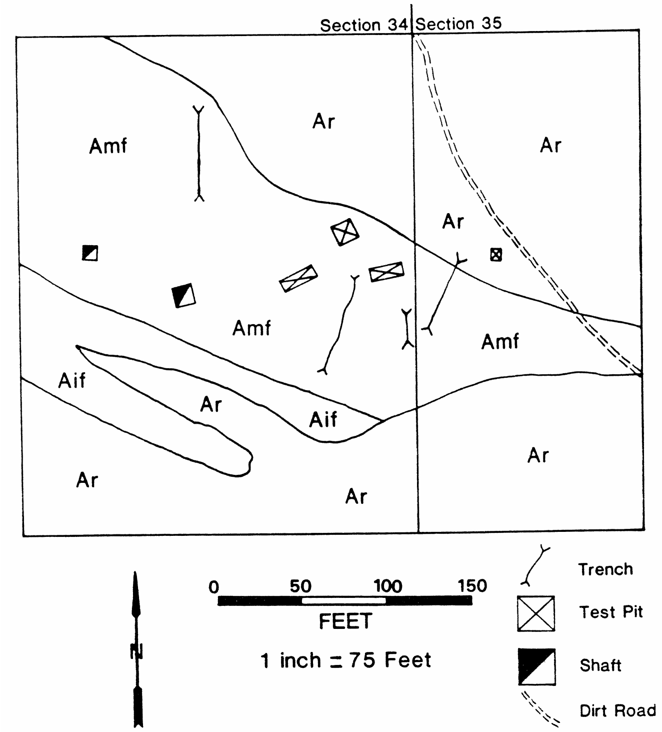

FIGURE 6. Sketch map of the Silver Mine Lakes Prospect. Ar = Rhyolite Intrusive, Amf = Mud-flow Member, Aif = Iron Formation Member

Mineralization in the Section 30 Prospect consists of both vein and disseminated mineralization. The veins are subordinate to the disseminated mineralization in volume. They consist of localized quartz veins 1/2-10 cm across with occasional chalcopyrite and pyrite clots and carbonate-quartz veins 2 mm to 4 cm across which contain galena and sphalerite very similar to that found in the Silver Mine Lakes Prospect. The disseminated mineralization is contained mainly in the altered basalts which are carbonatized, sericitized, silicified, and chloritized. The mineralization consists almost entirely of disseminated pyrite, although chalcopyrite, arsenopyrite, and pyrrhotite occur in very minor, localized amounts. Relatively abundant disseminated mineralization occurs along the margins of the rhyolite intrusives. It is not clear, however, what role these dikes played in the mineralizing history.

Additional Prospects

There are two additional prospects in the area which deserve minor mention. The first is a series of five test pits located along the contact of a rhyolite porphyry and Archean gabbro in southeast section 34. These pits are 6-8 ft^2 (2-2.5 m^2) about 4-7 feet (1.5-2 meters) deep and are now partially filled with forest debris. They were probably dug at the same time as the shafts of the Fire Center Mine (Owens and Bornhorst, 1985) in section 35, just to the east.

The other prospect is along the Dead River Shear Zone in the northwest portion of section 33. The prospect is shown on the 7 1/2 minute quadrangle map by Clark, et.al. (1975) and is described by Segerstrom and Raymond (1966) based on geochemical work in 1963. These workers state that the prospect is "exceptionally rich in sphalerite." Unfortunately, we were unable to locate the prospect during this study.

Segerstrom (1968) outlined areas of anomalous copper, lead, and zinc for stream-sediment and/or soil samples in the vicinity of the Section 30 Prospect. The anomalous values are probably related to the late-stage base-metal mineralizing event described elsewhere in this report.

Character of Mineralization

The mineralization in the Clark Creek region appears to have been formed in two separate stages. The first stage consisted of quartz veining and localized formation of disseminated sulfide mineralization adjacent to these veins. Anomalous amounts of gold were emplaced at this time along with these sulfide minerals. During the time disseminated mineralization was being emplaced, the country rocks were undergoing various degrees of alteration. The more highly altered localities tend to have a higher percentage of disseminated sulfide mineralization. This allows the use of alteration zones as targets for further exploration. The second stage consisted of carbonate-quartz veining and associated base metal mineralization. There does not appear to be as widespread alteration associated with this later mineralizing event.

Disseminations

The disseminated sulfide mineralization occurs within zones of altered country rocks. The volume of sulfide minerals occurring as disseminations greatly exceeds that occurring within veins. The most pervasive area of dissemination is found in the highly altered variety of the Upper Pillowed Basalt Member in sections 19 and 30. The sulfide disseminations reach a maximum of 20% of the whole rock in very highly altered zones and 40% in localized shear zones. The dominant sulfide mineral is always pyrite which may or may not be accompanied by minor amounts of chalcopyrite, arsenopyrite, and pyrrhotite. The occurrence of abundant disseminations can usually be related to nearby faults or shear zones.

Veins

Quartz veins can be found in any and all of the Archean rock units. Sizes of these veins can range from a few millimeters to more than 16 feet (5 meters) in width. The quartz is milky-white in appearance and can exhibit sharp or fragmental contacts with the country rock. The veins are most often found to be devoid of any sulfide minerals but on rare occasion will host chalcopyrite and/or pyrite clots. These clots are usually less than 1/4 inch (6 mm) in size.

Late carbonate-quartz veins are also present in all of the Archean rock types. Widths range from 1/8 inch (3 mm) to 18 inches (45 cm), the later occurring as breccia veins. The smaller veins exhibit 1/2-1 inch (12-25 mm) alteration haloes when found in previously unaltered rocks. The larger breccia veins consist of very angular clasts of porphyritic rhyolite surrounded by micro-crystalline, gray carbonate. Nearly all of this carbonate has a rust colored weathered surface suggesting that it is ankeritic in composition. Sulfides found in the carbonate veins are predominantly galena and sphalerite with minor amounts of pyrite and chalcopyrite. The galena and sphalerite are found intergrown with one another in subhedral to euhedral masses 1/4-1 inch (6-25 mm) across.

Age and Paragenesis of Mineralization

The age of mineralization is considered to be Late Archean since the Lower Proterozoic fault which parallels the Dead River Shear Zone truncates the area of highly altered basalts. The disseminated sulfide and quartz vein mineralization and associated alteration is interpreted as synchronous with the northwest-southeast trending faults and the Dead River Shear Zone. The faults and Dead River Shear Zone in particular acted as relatively permeable conduits for mineralizing fluids which deposited sulfides and associated gold. The late carbonate-quartz veins and associated base and precious metal mineralization may be related to the north-south trending faults which offset the earlier alteration zones. Sample 86-163, which comes from one of these fault zones, contains pyrite and minor pyrrhotite within a very highly altered basalt. Examination of the sample in a polished mount reveals brecciated textures in the pyrite with base-metal sulfides draping over these brecciated pyrite fragments. We interpret these textures as a second, base-metal, mineralizing event which followed a period of deformation, which faulted the early-formed alteration zones and associated mineralization.

Gold and Silver Assay Data

Thirty samples were analyzed for gold content and four for both gold and silver content. The samples at background levels are listed in Table 1 and shown in Figure 7. Those samples with an anomalous content of gold and/or silver are listed in Table 2 and are shown in Figure 8.

Anomalous gold was considered to be any value above 10 PPB (Parts Per Billion) (Kwong and Crocket, 1978). Anomalous silver was considered to be any value above the detection limit of 0.5 PPM (Parts Per Million). Nearly all of the samples which yielded anomalous gold values contain relatively abundant secondary sulfide minerals. Samples which showed an anomalous silver content contained relatively abundant galena.

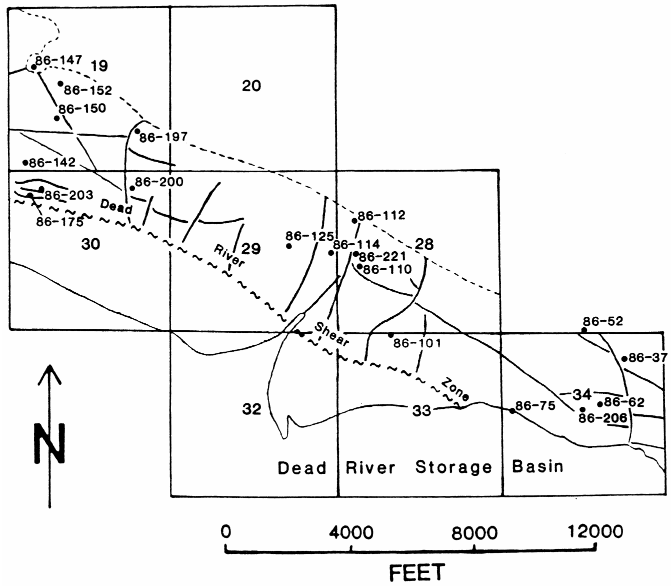

FIGURE 7. Location map of samples which yielded background values of gold and/or silver content. Township-49North, Range-27West

TABLE 1

Background Gold and Silver Analyses from the Clark Creek Region

Sample Number	Rock Type	Au (PPB)	Ag (PPM)
86-37	Ar	2	
86-52	Abl	<1	
86-62	Ar	<1	
86-75	Abf	1	
86-101	Ag	4	
86-110	Ag	<1	<0.5
86-112	Ar	<1	
86-114	Aif	4	
86-125	Abu	7	
86-142	Aba	2	
86-147	Xm	<1	
86-150	Abu	<1	
86-152	Abu	7	<0.5
86-175	Ara	7	
86-197	Ar	<1	
86-200	Ar	<1	
86-203	Aba	3	
86-206	Aga	1	
86-221	Ag	4	

Sample Descriptions

86-37 Outcrop sample of green-gray, weakly altered rhyolite porphyry. Quartz-feldspar phenocrysts are generally ½-2 mm. Specimen has 3-7 cm quartz veins with 1-2% disseminated sulfides in the surrounding rock.

86-522 Outcrop sample of green-black, fine-grained, massive pillow basalt. Surrounding outcrop has < 1% disseminated sulfides with 3-6 mm vesicles partially filled with carbonate.

86-62 Outcrop sample of gray, medium-grained, rhyolite porphyry. Quartz-feldspar phenocrysts are 1-5 mm.

86-75 Outcrop sample of green-gray, fine-grained, highly foliated, pillow basalt. Inter-pillow material is mainly carbonate with rare clots of pyrite and minor chalcopyrite.

86-101 Grab sample of dark green-black, coarse-grained, massive gabbro. Specimen has extensive quartz-carbonate veining and 2-3% disseminated sulfide mineralization.

86-110 Outcrop sample of green-black, coarse-grained, well jointed, weakly foliated gabbro.

86-112 Outcrop sample of light pink-gray, coarse-grained, massive, granular rhyolite.

86-114 Outcrop sample of gray-black, fine-grained to aphanitic, chert-magnetite, banded iron formation. Disseminated sulfides (1-3%) in rock are cross-cut by carbonate-sulfide veins emplaced within tension gashes.

86-125 Outcrop sample of green-gray, fine-grained, highly foliated basalt. Sample contains several quartz and quartz-carbonate veins ranging in size from 2 to 10 mm.

86-142 Outcrop sample of dark gray, fine-grained to aphanitic, highly foliated, highly altered basalt. Abundant quartz and quartz-carbonate veining with 2-6% concentrations of sulfides occurring sporadically in vein material and as disseminations.

86-147 Outcrop sample of dark gray, sub-angular to sub-rounded, chert-, rhyolite-, and quartz-pebble conglomerate. Sample is from the unconformable basal contact of the Michigamme Formation upon the MSML. Clast sizes range from 2 to 150 mm and may include rare phosphatic grains.

86-150 Outcrop sample of green-gray, fine-grained, well foliated, pillow basalt. Quartz veins (2-100 mm) containing minor amounts of chlorite cut the basalt at an oblique angle to the obvious foliation.

86-152 Outcrop sample of green-black, fine-grained, weakly foliated, pillow basalt.

86-175 Outcrop sample from the Section 30 Prospect. Pink-gray, fine-grained to aphanitic, highly foliated, altered rhyolite. Quartz and quartz-carbonate veins (1-12 mm) comprise up to 20% of the sample. Disseminated sulfides are rare.

86-197 Outcrop sample of light gray-black, fine-grained, highly foliated, rhyolite porphyry. Quartz and quartz-carbonate veins (1-5 mm) occur up to 10-15%.

86-200 Outcrop sample of gray-white to pink, fine-grained, weakly foliated, rhyolite porphyry. Quartz and quartz-carbonate veins (1-3 mm) up to 6-8%.

86-203 Outcrop sample of medium green-gray, fine-grained, highly foliated, altered basalt. Small (1-5 mm) quartz and quartz-carbonate veins host minor amounts of pyrite, chalcopyrite, and possibly pyrrhotite. Veins make up 3-5% of the sample.

86-206 Outcrop sample of gray-black, medium-grained, very highly foliated, altered gabbro. Highly contorted quartz-carbonate veins (1-10 mm) occur throughout the sample (8-10%).

86-221 Outcrop sample of green-gray, very coarse-grained, massive gabbro. Clots of quartz and pyrite (2-8 mm) are present throughout the sample (2-3%).

Neutron activation and fire assay analysis by Nuclear Activation Services Limited of Hamilton, Ontario, Canada. Detection limits; Gold - 1 PPB; Silver - 0.5 PPM.

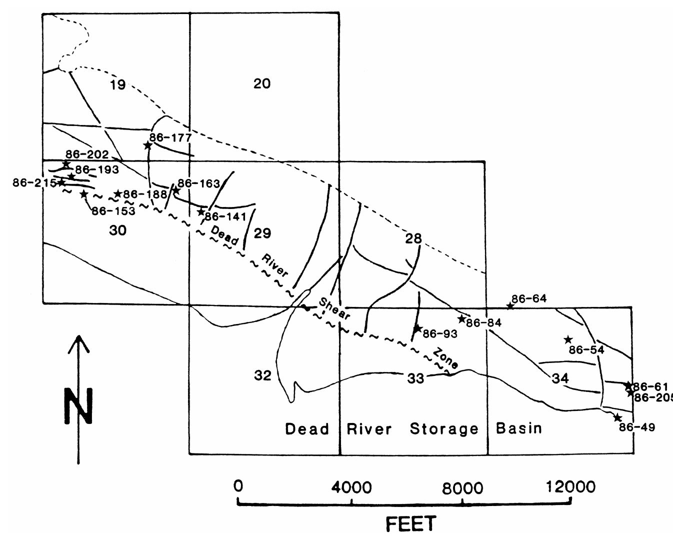

FIGURE 8. Location map of samples which yielded anomalous values of gold and/or silver content. Township-49North, Range-27West

TABLE 2

Anomalous Gold and Silver Analyses from the Clark Creek Region

Sample Number	Rock Type	Au (PPB)	Ag (PPM)
86-49	Abf-Xm	51	1.5
86-54	Ag	110	
86-61	Amf	19	3.0
86-64	Ar	44	
86-84	Ag	12	
86-93	Abu	18	
86-141	Aba	1000	
86-153	Aba	17	
86-163	Aba	1200	
86-177	Aba	1700	
86-188	Aba	330	
86-193	Qtz vein	86	
86-202	Aba	13	
86-205	Aif	120	
86-215	Ara	290	

Sample Descriptions

86-49 Outcrop sample of variously colored, graphitic slates and schistose basalt. Very highly foliated shaley sediment with up to 20% graphite within schistose basalts which contain 10-15% sulfides in sheared pods. Zones contain color variation from black to gray to orange (limonite and carbonate). The graphitic slates are interpreted as fragments of Michigamme Formation which were faulted into the foliated Archean basalts.

86-54 Outcrop sample of gray-black, medium-grained, well foliated gabbro with a quartz vein (1-2 cm) hosting 2-3% sulfides.

86-61 Grab sample from dump material at the Silver Mine Lakes Prospect. Dark gray, fine-grained, highly foliated, mudflow deposit. Specimen contains quartz-carbonate veins (5-25 mm) with abundant (up to 15%) galena and sphalerite mineralization.

86-64 Outcrop sample of gray, very fine-grained, highly foliated, weakly altered rhyolite. Sample has cross-cutting veins and veinlets of quartz and quartz-carbonate (5-20 mm) (3-5%). No sulfides are visible in hand sample although the weathered surface has a bright limonitic color.

86-84 Outcrop sample of green-black, medium-grained, weakly foliated, gabbro. Disseminated sulfides occur up to 3%.

86-93 Outcrop sample of medium gray, fine-grained, well foliated, altered basalt. Sample has sulfide-rich quartz veins (5-10 mm). Sulfides up to 4% in vein material.

86-141 Outcrop sample from a 12-15 cm shear zone within fine-grained, altered, pillow basalts. The zone is very highly foliated and contains 30-40% disseminated sulfides.

86-153 Grab sample from the Section 30 Prospect of fine-grained, altered basalt. Specimen contains quartz-carbonate veins (7-10 mm) with galena, sphalerite, and minor pyrite. Sulfides up to 3% in vein material.

86-163 Outcrop sample of gray-white, fine-grained, very highly foliated and altered basalt. Specimen is up to 75% secondary quartz with sub-angular, 10-15 mm, altered basalt clasts in places. Disseminated sulfides occur throughout (5-20%). Microscopic examination of sulfides reveals brecciated pyrite and minor pyrrhotite with coatings of sphalerite which contain exsolved chalcopyrite blebs. Sulfides are always surrounded by the secondary quartz.

86-177 Outcrop sample of green-gray, fine-grained, weakly foliated, altered basalt. Specimen has quartz and quartz-carbonate veins (1-30 mm) with 3-5% euhedral pyrite grains, and minor chalcopyrite. Country rock has ≈ 1% disseminated sulfides.

86-188 Sample from a 3-5 meter shear zone in fine-grained, altered basalt. Appearance is very similar to 86-141 in texture and sulfide content but is from a thicker zone.

86-193 Grab sample of quartz vein material from Section 30 Prospect Area with 5-10% altered basalt clasts. Sample has 2-4% pyrite and 1-2% chalcopyrite present as sulfide clots within the quartz.

86-202 Outcrop sample from near the Section 30 Prospect. Medium green-gray, well foliated, altered basalt near a contact with green, highly foliated and altered rhyolite. Sample contains disseminated sulfides (1-2%) and small (5-20 mm) quartz pods.

86-205 Outcrop sample of black to dark tan, aphanitic, cherty iron formation. Specimen contains 3-5% disseminated sulfides and an additional 2-3% in cross-cutting sulfide veinlets (1-5 mm). Some small (1-5 mm) carbonate veinlets are also present. Microscopic examination of the sulfides revealed very minor amounts of native gold occurring as discrete 2-5 micron grains within the iron-rich chert bands.

86-215 Outcrop sample of gray-green, fine to very finegrained, highly foliated, altered rhyolite. Specimen has deformed quartz veinlets with pyrite, arsenopyrite, and minor pyrrhotite.

Neutron activation and fire assay analysis by Nuclear Activation Services Limited of Hamilton, Ontario, Canada. Detection limits; Gold - 1 PPB; Silver - 0.5 PPM.

GEOLOGIC HISTORY

The earliest recorded event in the Clark Creek region was the extrusion of subaqueous, tholeiitic, pillow basalts which formed the Lower Pillowed Basalt Member of the Metavolcanics of Silver Mine Lakes. These basalts were likely deposited in a water depth of less than 1640 feet (500 meters) based on observed vesicle sizes (Compton, 1985). The age of the basalts is slightly greater than 2.7 Ga based on the radiometric age dating of a rhyolite which intrudes basalts in the Clark Creek Basin (Trow, 1979), and analogous rocks in Canada. Following eruptions of the early basalt, a relatively thin mafic to intermediate volcanic mudflow was deposited. After renewed basaltic flow activity which produced the Middle Pillowed Basalt Member of the Metavolcanics of Silver Mine Lakes, an exhalative(?), oxide-facies, banded iron formation was deposited. Renewed extrusion of subaqueous pillow basalts produced the Upper Pillowed Basalt Member of the Metavolcanics of Silver Mine Lakes. The volcanic pile was then intruded by dikes and sills of gabbro (Metagabbro of Clark Creek). The mafic rocks were synchronously deformed and intruded by syn- to post-tectonic rhyolite and granodiorite (2.7 Ga). The rhyolites may represent differentiated portions of the granodiorite plutons. An episode of syn- to post-tectonic hydrothermal alteration with associated precious metal mineralization occurred the end of the Archean. The Late Archean deformation and hydrothermal activity produced the foliated variety of the Upper Pillowed Basalt Member of the Metavolcanics of Silver Mine Lakes and the altered varieties of the Upper Pillowed Basalt Member, the Metagabbro of Clark Creek, and the Rhyolite Intrusive of Fire Center Mine.

The region next experienced an extended period of uplift and erosion. This weathering and erosion was followed by the deposition of Lower Proterozoic quartz-sandstones, graywackes, and shales of the Michigamme Formation (1.9-2.1 Ga) and the intrusion of Lower Proterozoic diabase dikes. The Michigamme-age rocks were deformed and metamorphosed during the Penokean Orogeny (1.83-1.89 Ga). Archean rocks were faulted during the Penokean Orogeny, but show no significant Penokean metamorphism since they were already metamorphosed to greenschist facies.

During Keweenawan time (1.1 Ga) the region was intruded by diabase dikes associated with the Mid-Continent Rift System.

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Humble #1 Drillhole Log

MINE OR EXPL. North Dead River — SECTION 19 T.49N, R.27W.

HOLE NO. 1 West Grid — COLLAR ELEV. 1560' (475.5 m)

INCLINATION -45° — COURSE S. 20° W.

LOCATION SE 1/4 of the SW 1/4

Beginning date 11-17-70

Type of Material	Footage	Remarks
Glacial Till	109	
Metadiabase	109'4"	
Andesitic - Basaltic G.S.	407'7"	
Felsite	408'2"	
Andesitic - Basaltic G.S.	411'7"	
Felsite	421'3"	
Andesitic - Basaltic G.S.	500'	

TABLE A1. Drillers log for drill hole Humble # 1.

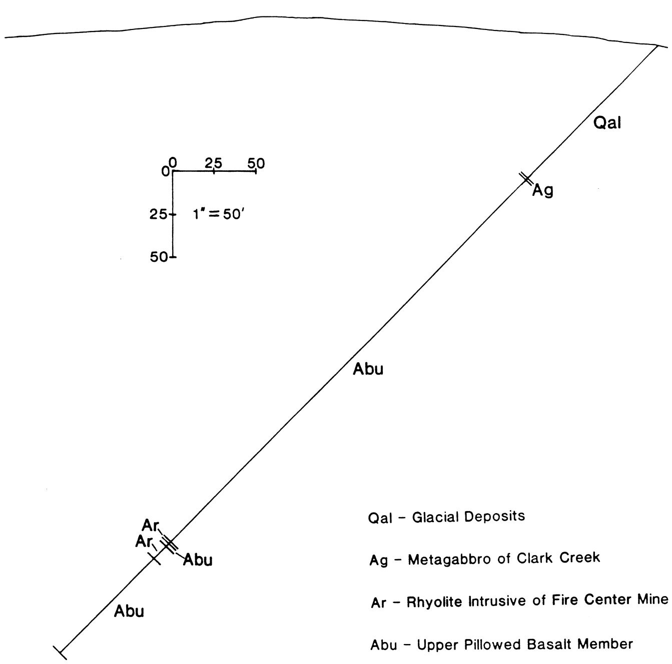

FIGURE A1. Graphical log for drill hole Humble # 1.

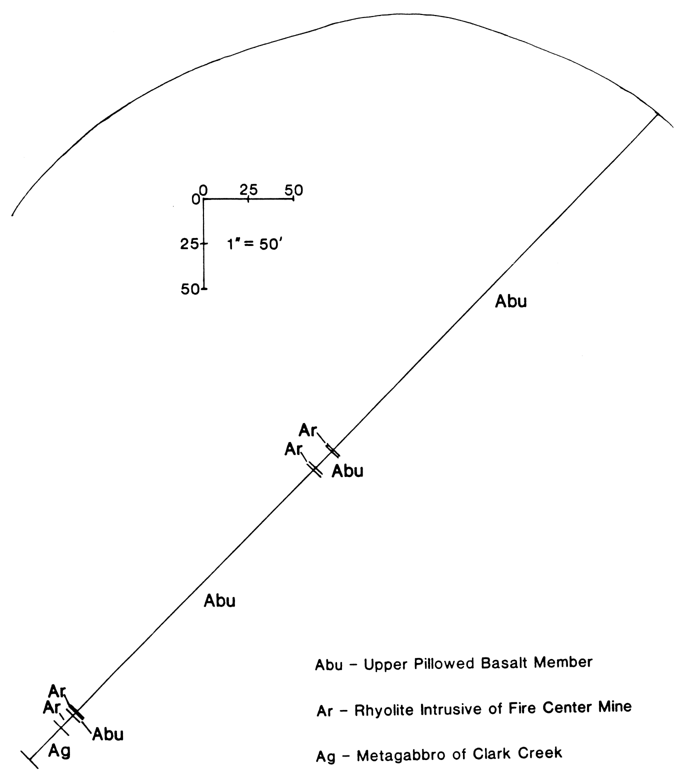

FIGURE A2. Graphical log for drill hole Humble # 2.

Humble #2 Drillhole Log

MINE OR EXPL. North Dead River SECTION 19 T.49N, R.27W.

HOLE NO. 2 WEST GRID COLLAR ELEV. 1660' (506 m)

INCLINATION -45° COURSE S.20°W.

LOCATION NW1/4 of the SW1/4

Beginning date 11-4-70

Type of Material	Footage	Remarks
Andesitic-Basaltic G.S.	262'2"	
Felsite	262'10"	
Andesitic-Basaltic G.S.	274'9"	
Felsite	276'	
Andesitic-Basaltic G.S.	463'8"	
Felsite	464'3"	
Andesitic-Basaltic G.S.	466'4"	
Quartz-Eye Porphyry	476'10"	
Metadiabase	500'	

TABLE A2. Drillers log for drill hole Humble # 2.