THE GEOLOGY OF THE WILLROY PROPERTY
MANITOUWADGE LAKE, ONTARIO

by

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ABSTRACT

Manitouwadge, a copper-zinc-silver mining camp, lies 150 miles east of Port Arthur, Ontario, and 25 miles north of Lake Superior. A series of volcanics and sediments, now metamorphosed and migmatized to hornblende schists, quartz feldspar gneisses, and granite gneiss, underlies the Manitouwadge area. These have been folded into an overturned syncline which strikes east-west and plunges gently to the northeast. Three sets of faults are known with at least four periods of movement. The latest of these has offset the mineral deposits and some of the north striking diabase dykes. The two important deposits lie on the south limb of the syncline near the contact between granite and quartz feldspar gneiss. The Willroy property is adjacent to, and immediately west of, the Geco mine.

The gneisses on the Willroy property exhibit a complete gradation from quartzite to iron rich hornblende gneiss, and are thought to be sediments that have been metamorphosed to a grade indicated by the amphibolite facies. Detailed mapping and drill hole correlation indicates the presence of several small folds in the east striking formations. All the sulphide deposits occur within individual formations where they are folded. The folds appear to be related to the major deformation, as are numerous pegmatite dykes which cut across the gneisses.

The ore occurs in three tabular sulphide replacement bodies, with a strike parallel to that of the enclosing formations. These orebodies plunge to the east at 45 degrees, parallel to the plunge of the folds. The ore consists of pyrite, pyrrhotite, chalcopyrite, sphalerite, galena and tetrahedrite. Silver is present, and is apparently contained in the sulphide minerals.

Although precise structural controls are not known, the sulphide deposits of the area all occur adjacent to small folds. Further work in the area might well be concentrated on outlining and prospecting similar structures.

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INTRODUCTION

General

Fieldwork for the problem consisted of detailed mapping of the property by pace and compass survey at a scale of two hundred feet to the inch, and of logging the core of diamond drill holes. This work was carried out in the summer of 1955 while the writer was engaged in regional mapping of the Manitouwadge area for the Ontario Department of Mines. The property was revisited briefly in the fall of 1956 and some additional work was done.

Location and Access

The Manitouwadge Lake area lies about 150 miles east of Port Arthur, (see Figure I, Location and Access Map) and about 40 miles north of Lake Superior, midway between the transcontinental lines of the Canadian National Railways and the Canadian Pacific Railways. The town of Manitouwadge is connected to the Trans Canada Highway, at Marathon, by a 70 mile all weather road. Spur lines into the area have been built by both railways. Manitouwadge Lake is large enough

to be used as a landing strip for most float-equipped aircraft, and these were used extensively in the early stages of development of the area.

Topography and Drainage

The Manitouwadge area (see Preliminary Map of Manitouwadge Lake area, in pocket) covers part of the height of land between the Pic River and the Black River drainage systems. Both these rivers flow south into Lake Superior. A few miles north of the map area, the land drains northwest into Hudson Bay.

The dominant topographic feature in the area is the 300 to 400 foot high ridge which runs west from Mose Lake along the north shore of Manitouwadge Lake to and beyond Pusamakwa Lake. To the south the land is relatively flat, while north of the ridge the country consists of low rounded hills, the highest being about 200 feet.

History

Manitouwadge Lake was the centre of one of the best hunting grounds in the district, and the gossan zones there were well known to the Pic River Indians. In 1930, Moses Fisher, one of the Indians, guided Dr. J.E. Thomson up the Black River to the area. Thomson returned the following year, made a rough map of the area in a limited time, and noted:

> ....the heaviest mineralization observed by the writer in the whole area is found near the northern contact of this belt. (Manitouwadge greenstone belt) At intervals for a distance of two miles along the contact, either sulphides or a surface gossan have been noted. On the west side of the creek that flows into the northeast arm of Manitouwadge Lake, sulphides occur over a width of eight feet in a lens of quartz and chlorite schist contained in granite gneiss and pegmatite. Pyrite, pyrrhotite and traces of chalcopyrite are the sulphide minerals. A grab sample of this material contained no gold values. (Thomson 1932, p. 44).

Thomson concluded:

> It seems logical to assume that this (Manitouwadge greenstone belt) is only a shallow roof pendant which has been eroded so close to the granite batholith that any gold veins would have largely disappeared. (op. cit. same page)

The low price of copper in the depression, and the mining fraternity's low opinion of greenstone belts of small areal extent caused interest to lapse, and the area was virtually forgotten.

With the increase in the price of base metals following World War II, however, showings such as this were reinvestigated. Moses Fisher staked the best showings in 1947, but could not sell them. An old nickel showing east of the Pic River was staked in 1952, and a minor rush followed. This property came to nothing, but it did serve to stimulate interest in the area. In 1953, two weekend prospectors, Roy Barker and Bill Dawidowich of Geraldton became interested in Thomson's map of Manitouwadge Lake, and were flown in,

by Jack Forster, to look at the showings. They were impressed with the area, but had to fly home for more supplies. When they returned they found that the ground they wanted had been staked by two other prospectors. These two men, however, failed to record their claims when samples gave negative nickel assays. Barker and Dawidowich then staked the ground and some additional claims.

In August the property was examined by W.S.Hargraft, and later Geco Mines Co.Ltd., was incorporated to work the claims comprising the original showing. A major orebody was outlined, and, in November 1953, the company announced ore reserves totalling 14,889,000 tons grading 1.72% copper, 3.55% zinc, and 1.73 ounces of silver. The biggest staking rush in Ontario's mining history followed.

Barker and Dawidowich's claims to the west of Geco were combined with some claims belonging to Consolidated Howey Mines Ltd., and a new company, Willroy Mines Ltd., was formed, the name Willroy coming from the first names of the two prospectors. Other properties in the area have been drilled, but are not being developed at the present time. Of these, the properties held by Nama Creek Mines and Lun Echo Gold Mines are the most promising.

Geco Mines Ltd. now has blocked out ore reserves of 15,277,000 tons. Two shafts have been sunk, number one, a five compartment shaft is 1250 feet deep, and number two,

a three compartment shaft, 500 feet. A mill is under construction, and production is expected in the spring of 1957, with an initial milling capacity of 3,300 tons a day.

Willroy Mines Ltd., has ore reserves of over 2,000,000 tons, and has sunk a four compartment shaft to a depth of 850 feet, and is sinking a smaller ventilation shaft. A mill is under construction with a capacity of 1,000 tons a day.

REGIONAL GEOLOGY

Table of Formations

Era	Period	Epoch	Group	Lithology
Cenozoic	Quaternary	Recent		clay, sand, peat
		Pleistocene		glacial till, gravel, silt, varved clays
		Unconformity		
Proterozoic	Keweenawan			diabase dykes
		Intrusive contact		
Archaean				granite, pegmatite, granite gneiss
			Intrusive	contact
				Metamorphosed basic intrusives
			Intrusive	contact
			Nama	quartz feldspar gneisses, hornblende gneisses
			Pusamakwa	hornblende schists

All the consolidated rocks in the area are Precambrian in age, and may be divided into three main groups:

(1) A succession of volcanics and sediments, with minor basic intrusions, that has been folded and metamorphosed.

(2) Granite, pegmatite, and migmatite, intruding the metamorphic sequence.

(3) Later intrusions of diabase, in north striking dykes.

Metamorphic Rocks

Pusamakwa Group:

The hornblende schists of the Pusamakwa Group crop out in a one to two mile wide belt stretching from east of Mose Lake, across the area to Pusamakwa Lake. They continue for some distance west of the map area (Preliminary Map of the Manitouwadge Lake Area, in pocket). The schists strike west and dip steeply.

The two main rock types of the group are, a finely banded schist, and one that shows little or no banding. Of these, the latter type is more common, forming many layers ranging in thickness from 20 feet to more than 100 feet. Each stratum has a medium-grained, gneissic central portion, but grades into a finer grained and schistose rock at the borders. The schists are composed, almost entirely, of

hornblende and plagioclase. Pye (1956) has found supposed vestiges of pillow structures in some of the thicker layers. In view of their composition, (hornblende, andesine, with minor quartz, magnetite and sphene) and their appearance, it seems likely that these schists are metamorphosed basic flows.

These thick strata of schist are separated by thin layers of laminated schist. This rock has a striking banded appearance, caused by the alternation of dark, hornblende rich layers and light plagioclase and quartz layers. The layers range in thickness from a fraction of an inch to several inches. Differential weathering of the dark and light laminae gives an outcrop a distinct, ribbed appearance. Occasional lenticular fragments of the unbanded schists are found in the laminated schist. The presence of these fragments, and the stratification indicated by the compositional layering suggest that the rock is probably a metamorphosed tuffaceous sediment deposited in the periods between flows. As no name has been given to this group of rocks, the author suggests that they be called the Pusamakwa Group. A type section can be obtained along the straight valley running south from Pusamakwa Lake.

To the south, the schists grade into a quartz feldspar hornblende biotite gneiss, which in turn grades into biotite granite gneiss. The mineralogical changes involved in this gradation are an increase in the biotite content at

the expense of hornblende; an increase in the microcline content; and a change in the plagioclase from sodic andesine to albite-oligoclase. The quartz feldspar hornblende biotite gneiss has been included with the volcanics by Pye (1956), but was recorded as a sediment on the preliminary map which is included with this report.

Nama Group:

The Nama Group, a thick sequence of feldspathic gneisses, lies to the north of the Pusamakwa group. This sequence stretches from east of Mose Lake, westward to Cadawaja Lake, where it swings north to Nama Creek and northwest to Rabbitskin Creek. The foliation of these gneisses and the trace of certain marker horizons in the series show that the whole has been intensely folded. The rocks of this group strike almost east-west over most of the area, but swing around to the north in the western part of the area. The dip is steep along the east-west portion, gradually becomes more shallow to the west, as the group swings north.

This group of gneisses is unnamed at present, and for it the writer suggests the name "Nama Group". A type section can be seen along either of the north trending valleys of Fox Creek or Slim Lake. The contact between the Nama Group and the Pusamakwa Group is gradational. Over a distance of about 1000 feet, strata of hornblende schist alternate with strata of feldspathic gneiss. The Nama Group can be

broken into three main divisions. The first unit north of the contact consists of 4000 feet of quartz feldspar gneisses, with some hornblende gneiss strata occurring to the west. The next division is 1500 feet thick and is composed of quartz feldspar gneisses with many hornblende gneiss layers. This section is the most important economically, as all the significant mineral deposits discovered so far are found within it. The third unit in the sequence is approximately 2500 feet of quartz feldspar gneiss containing only a few lenses of hornblende gneiss. This division is of unknown thickness, as it is bordered on the north by granite. The granite contact is quite sharp here, in contrast to the southern contact of the Pusamakwa Group with granite.

Most of the rock types of the Nama Group are found on the Willroy Property, and a detailed description of them will be given later in this report. In brief, they are quartzite, quartz microcline gneiss, quartz oligoclase biotite gneiss, and hornblende gneiss. Many intermediate rock types are present also and field mapping is extremely difficult. In addition, several special varieties of gneiss arise from the presence of varietal minerals such as garnet and pyroxene.

One of these varieties of gneiss is a most unusual rock, consisting of alternating layers of quartz and magnetite pyroxene garnet gneiss. Strata of this rock are quite continuous, and have served to outline the structure, since the

rock is easily recognized, and can be traced between outcrops by its magnetic properties.

As will be shown later these rocks exhibit many characteristics of sediments, and are considered to be the metamorphic equivalents of quartz sandstone, shale, calcareous grits, and iron formation.

Metamorphosed Intrusives:

Small lenticular bodies of metagabbro, are found in the Manitouwadge area, usually in the Pusamakwa group. None occur on Willroy ground. These bodies intrude the enclosing hornblende schists, and are themselves cut by granite and pegmatite. The rock is quite massive and consists of hornblende and plagioclase with smaller amounts of quartz, biotite, and magnetite.

Several kinds of minor intrusive rocks are apparently associated with these metagabbro intrusions. A massive amphibolite and a pale pink feldspathic rock have both been described (Pye 1956) as grading into the metagabbro. Also, narrow dykes and sills of fine-grained foliated rock have been found in the Geco ore zone. They are unmineralized and may cause a serious ore dilution. These have the same composition as the metagabbro.

Intrusive Rocks

Granitic Rocks:

Granitic rocks are found in three main areas, in the southeast and southwest corners, and in the north central to northeast parts of the map area. Numerous small dykes and sills are found throughout the rocks of the Pusamakwa and Nama Groups. The granite areas in the southeast and northwest are believed to be connected beyond the map area, and to extend to the south (Thomson 1932). The smaller body in the northeast is localized along a synclinal axis, and is probably a satellite mass. Granitic rocks consist of biotite granite gneiss, massive granite, migmatite, and pegmatite in order of abundance.

The occurrence of biotite granite gneiss as a transition between migmatite and massive granite has already been described under the Pusamakwa Group. The rock is a pale pink, medium-grained rock, composed of quartz, oligoclase, microcline and biotite. It may also occur as thin layers alternating with quartz feldspar hornblende biotite gneiss to form the migmatite. This granite gneiss is by far the most predominant granitic rock in the Manitouwadge area.

Massive, fine-grained, pink granite occurs in the area to the northeast. Also many small dykes and sills of granite intrude the migmatite and the gneisses. Pegmatite is also abundant as dykes, as thick as a hundred feet. At least

three ages of pegmatite intrusion are known:

(1) Post metamorphism, and pre-granite

(2) Penecontemporaneous with granite

(3) Post granite

The pegmatite is typically grey, but in places has a pink and even green colour. The dykes have simple mineralogy, being composed of quartz, plagioclase, and microcline, with minor amounts of mica.

Diabase:

As in many areas of the Precambrian Shield, the youngest rock in the area is diabase. This occurs as north trending dykes ranging in width from a few feet to a few hundred feet. They are quite persistant, at least one can be traced for four or five miles. Their grain size increases with the width of the dyke, the ophitic texture in some of the larger dykes being clearly visible to the unaided eye.

Possibly these dykes are related to similar rocks of Keweenawan age one hundred miles to the west (in the vicinity of Lake Nipigon). In most areas of the Canadian Shield, similar dykes are dated tentatively as Keweenawan.

Cenozoic

Much of the area is covered with glacial debris and associated fluvio-glacial and lacustrine deposits. Many gravel

hills are present, including at least one esker. In addition, many parts of the district are covered with cross-bedded and ripple marked silts or varved clays. Glacial striae observed on many outcrops indicate a movement toward the southwest. Recent lake, stream, and swamp deposits consist of clay, sand, and peat.

Structure

Folding:

As can be seen on the Preliminary Map of the Manitouwadge Lake Area, the volcanic and sedimentary succession forms a large fold, striking and plunging to the northeast. This fold is clearly outlined by the bands of hornblende gneiss in the sedimentary sequence. Near Mose Lake the formations strike southwest and dip steeply north, farther east they swing west with a vertical dip (in the vicinity of Geco) and at Willroy they strike northwest and dip to the north, the dip decreasing as the strike approaches north. On the western boundary of the map sheet, the rocks strike north and finally double back and strike northeast, dipping steeply south.

Thus, a large asymmetrical trough is outlined, plunging northeast at 15 to 20 degrees. The trough is considered to be a syncline, although top determinations are not reliable as the rocks have been completely metamorphosed.

It is possible that the syncline itself has been subjected to a later cross folding along a north striking axis. West of the map area, beds on the nose of the fold dip 5 to 10 degrees to the east, but farther to the east they dip 15 to 25 degrees. Still farther east, along the limbs of the syncline, drag folds, lineations and other structures, thought to be related to the major fold, plunge to the east at 35 to 55 degrees. The syncline thus appears to have a plunge steepening to the east, which suggests that the fold has been arched at right angles to its axis. This secondary deformation may have formed the favourable loci for the mineral deposits of the area. This would account for the seemingly anomalous fact that the larger bodies occur on the limbs of the fold, while the deposits on the nose, normally a favourable position, pinch out. The beds in the nose of the fold lie at right angles to the line of action of the force required to produce a secondary fold. This force would press the beds in the nose of the fold together, and spread those on the limbs apart.

Faulting:

Following the folding, the area was subjected to disturbances that led to the development of several series of faults. Most of these faults are indicated by straight, deep, valleys. The three main types of fault present are:

(1) Strike faults, along the south limb of the fold.

(2) Transverse faults, striking north.

(3) Diagonal, northwest striking faults.

The best example of the first type of fault has been called the Agam Lake fault. This fault is a wide zone of graphitic schist, striking east from Cadawaja Lake to Manitouwadge Lake. It is mineralized in several places with pyrite and pyrrhotite, and is therefore pre-ore in age. The exact displacement on the fault has not been determined.

North striking faults are more abundant, some, such as the Slim Lake fault, apparently terminate against the Agam Lake fault, while others, such as the Nama Creek and Fox Creek faults cut off the strike fault. This indicates at least three periods of movement, the first two preceding mineralization, and the last following it. The Fox Creek fault offsets the Geco Orebody.

The long diagonal fault traversing the area from southeast to northwest appears to displace the Fox Creek fault. Shallow, southeast dipping beds on the northwest limb of the fold are displaced by this fault, while vertically dipping beds on the south limb are not. From this evidence it is supposed that the movement was mainly vertical, the west side having moved up relative to the east. Near Mose Lake, a diabase dyke occurs in this fault, and has been brecciated. North of the Geco mine, two diabase dykes are

offset by this fault. Movement along the diagonal fault was probably the last activity in the area.

Although faults are numerous in the area, and movement seems to have taken place repeatedly, the total horizontal displacements are nowhere greater than a few hundred feet. Many of the faults have considerable vertical displacement also, but the magnitude of these displacements is not known as few of the faults have been studied in any detail.

Mineral Deposits

All of the important mineral deposits of the area are sulphide replacement bodies containing, in order of abundance, pyrrhotite, pyrite, chalcopyrite, sphalerite, and galena. The sulphide bodies are found in a variety of host rocks, but all of the important discoveries to date occur within the rocks of the Nama Group.

The age of the galena in the Manitouwadge area is estimated at 2,600 ± 120 million years by lead isotope ratio determined by J. Tuzo Wilson of the University of Toronto (Wilson, personal communication to E.G. Pye, 1956). This is an age similar to that obtained for galena associated with the gold ores of Timmins Ontario and the Golden Manitou and Barvue of Quebec, and would be considered Archaean in age.

The sulphide minerals, as has been mentioned already, are later than strike faults and earlier than some transverse

faults in age. The diabase dykes at Geco (Langford 1955) appear to be post-ore. The sulphides cause minor alteration in pegmatite dykes, and are therefore later than the dykes.

The most important deposit in the area, that of the Geco mine, occurs in quartz muscovite schist as a large tabular body of sulphides standing vertically and plunging 45 degrees to the east. Adjacent to this, with similar attitude, and contained in the same layer of schist, lies the Willroy No. 1 zone.

Several sulphide bodies occur in strata of hornblende gneiss, particularly in the iron rich, magnetic type, known as iron formation. Examples of this occurrence are the Willroy No. 2 and No. 3 zones, and the Lun Echo deposits. All these bodies lie wholly within layers of the gneiss, and those on the limbs of the fold plunge to the east in a manner similar to the Geco body. None, however, is as large as Geco.

A replacement body in biotite schist has been outlined on the property of Nama Creek Mines Ltd., but this is not being developed at the present time. Other small sulphide deposits occur in the graphitic schist of the Agam Lake fault, but contain little copper and neither zinc nor lead.

GEOLOGY OF THE WILLROY PROPERTY

Location and Access

The Willroy property lies immediately west of the Geco mine and about one and a half miles north of Manitouwadge Lake. Part of this property is considered in this report. This part is almost two miles long and about one half mile wide, and embraces the upper part of the Nama Group cropping out along a portion of the south limb of the major fold.

An all weather road to the south connects the property to Manitouwadge townsite at the west end of Manitouwadge Lake. A railway spur will be completed shortly to connect the property with the Canadian National Railway and the Canadian Pacific Railway lines north of Geco.

Topography

A dominant topographic feature of the property is the straight deep valley containing Slim Lake (see Geological Map of the Willroy Property in pocket). From this valley, the land rises 150 feet to a point near the secondary baseline 2,000 feet west of the lake, and slopes away gradually to the north and west. East of the lake, a broad east-west ridge, stretching from the vicinity of the two shafts east beyond

the Willroy fault in the main feature. The trace of the Willroy fault is expressed as a sharp gully cutting across this ridge. East of the ridge, the ground slopes down to Willroy Lake, and rises slowly beyond. Two large outcrop areas occur north of Willroy Lake and are small hills. Strike Lake occupies part of an east-west depression that extends across the northern edge of the property to Slim Lake.

Stratigraphy

The rocks of the Willroy property lie in the upper part of the Nama Group, and they represent a stratigraphic section of about 1800 feet. The strata dip vertically or steeply north, and the geological map, in effect, shows the section. Figure VIII, Variations in the Succession Across the Willroy Property (in pocket) has been prepared to show the stratigraphic section. For this purpose the intrusive rocks were omitted and some corrections were made for the dip of the beds.

The stratigraphic section is divisible into four lithologic units:

(1) Quartz oligoclase biotite gneiss, quartz microcline gneiss and quartzite with interlayered iron rich hornblende gneiss

(2) Quartz oligoclase biotite gneiss (garnetiferous) with interbedded iron rich hornblende gneiss

(3) Quartz muscovite schist

(4) Hornblende gneiss with minor layers of quartz oligoclase biotite gneiss.

Unit one is a wedge extending across the bottom of the section, thinning gradually to the west. The southern boundary of this wedge is not known as it lies beyond the area of detailed mapping.

Quartz oligoclase biotite gneiss is the most common rock type of this unit. It is medium-grained and ranges in colour from an even, light grey, with and without dark layers, to quite a dark grey, the colour being a function of the biotite content such that in the extreme case, the rock becomes a biotite schist. The layered varieties of gneiss have a corrugated appearance on a weathered surface because the darker layers are more susceptible to decomposition.

Quartzite and quartz microcline gneiss occur as small lenses within this unit. Quartzite is a medium-grained, even-bedded, rock consisting of layers of quartz, one to six inches thick (Plate I). Quartz microcline gneiss is also a medium-grained rock, ranging from a massive rock, pink in colour, to a light grey banded rock. This latter variety cannot be distinguished from quartz oligoclase biotite gneiss in the field. In outcrop, both these rocks appear fairly fresh, with biotite layers, where present, slightly decomposed.

Interlayered with the other rocks of the first and

second unit are numerous strata of dark, well-banded, iron rich hornblende gneiss. In outcrop the rock is commonly very rusty, but its banded appearance is visible in spite of the alteration. The gneiss consists of alternate layers of dark gneiss containing hornblende, pyroxene, garnet, magnetite and quartz; and coarse-grained, clear, quartz with minor inclusions of feldspar, magnetite and pyroxene. The layers range from a fraction of an inch to a foot or more in width, the lighter layers are, in general, slightly wider than the others, but are always of the same magnitude. Two types of layering are observed, one a wavy type with many bifurcations (Plate II), the other an evenly banded type (Plate III). The dark laminae in the rock are similar in composition to the hornblende gneiss (low silica) that occurs in unit four of the succession, but was distinguished in the field by the presence of magnetite in amounts large enough to deflect a compass.

The second unit is the largest in the succession, and forms a wedge that is 1600 or more feet thick at the western edge of the property, thinning to 400 feet east of the Willroy fault, and thickening again to 600 feet at the boundary. It is known to pinch out completely on Geco's ground to the east.

The predominant rock type in this unit is quartz

oligoclase biotite gneiss (garnetiferous) (Plate IV), similar to the layered quartz oligoclase biotite gneiss in almost every respect, but containing garnets in the darker layers. These garnets range in size from 1/16 of an inch to 3/4 of an inch, the larger garnets being found in the wider biotite rich layers. As in the previous unit, layers of iron rich hornblende gneiss are present. Some are lenslike in character, but others are remarkably continuous. Other minor layers of hornblende gneiss, quartz oligoclase biotite gneiss, and quartz microcline gneiss are present, but have no great lateral extent, and are useless for correlation purposes.

Unit three, the smallest, does not exceed 400 feet in thickness, and is more commonly about 200 feet thick. It extends from the eastern boundary to a point east of the Willroy fault where it splits. The south limb wedges out a few hundred feet beyond this fault, and the north continues to a point halfway between the Willroy and Slim Lake faults. A small lens of similar rock occurs within unit two in a somewhat lower stratigraphic position. This extends a few hundred feet on either side of Slim Lake.

This unit consists of quartz muscovite schist with a few minor lenses of quartz oligoclase biotite gneiss. Quartz muscovite schist (Plate V), is a coarse crenulated schist, quite rusty in outcrop. It is easily decomposed, and with the exception of the large outcrops in the eastern part of the area, it crops out in few places.

The quartz muscovite schist contains a thin layer of micaceous quartzite, a white rock which lacks the rusty appearance typical of the rest of the unit (Plate VI). This rock is composed entirely of quartz, which occurs as large eyes, up to six inches long, and muscovite, which, mixed with quartz, forms the matrix of the rock. This layer ranges in thickness from twenty five feet to a few inches, in places pinching out completely. It has been traced through the main outcrop area for a distance of about one thousand feet.

The uppermost unit lies along the north boundary of the property, and therefore its total thickness is unknown. It tapers out to the west near Slim Lake. The major rock type of this unit is hornblende gneiss, which is an extremely variable rock. The most common type has been called garnet amphibole gneiss in the field, and is a dark green, schistose, rock with prophyroblasts of red garnet up to one inch in diameter (Plate VII). The schistose part of the rock weathers readily, leaving garnets protruding to give the rock its characteristic knobby appearance. In some layers of the gneiss the garnets are absent, and the rock consists of hornblende, plagioclase, and some biotite. Other bands of schist are similar to the finely laminated hornblende schists of the Pusamakwa Group. Finally, there is an unusual coarse-grained rock composed of pink and grey feldspar and large prismatic crystals of hornblende, up to an inch long. Also included in this series are several lenses of the quartz

feldspar gneisses that have been described above. The more important of these are shown on the map.

Origin of the Gneisses

All the gneisses appear to be metamorphosed sediments. Previous authors (Pye, 1955, 1956, Langford 1955) are agreed on a sedimentary origin for all the rocks except the quartz muscovite schist. The hornblende gneisses, particularly the iron rich variety, although considered to be a sediment by both the aforementioned authors, remains somewhat of an enigma.

Feldspathic Gneisses:

The feldspathic gneisses form the bulk of the section, and they exhibit a complete gradation, from quartzite to hornblende gneiss. The first step in this gradation is an increase in the microcline content at the expense of quartz as the rock grades from a quartzite to a quartz microcline gneiss. More pronounced layering and an increase in plagioclase content follow the gradation into quartz oligoclase biotite gneiss. Further, garnets and a few grains of hornblende appear in the darker, biotite rich layers of the gneiss. This, then is the quartz oligoclase biotite gneiss (garnetiferous), the predominant rock of the section. Quartz oligoclase biotite gneiss (garnetiferous) grades, in turn, into the hornblende gneiss, which is also garnetiferous, by an increase in the number and the width of the dark laminae. Biotite

layers are numerous in the hornblende gneiss, although hornblende is the dominant mafic mineral. The plagioclase in this gneiss is more calcic than in the feldspathic gneisses.

This gradation is not caused by an increase in metamorphic grade, but is thought to be a change in the original sediments. The gradation proceeds, in general, from quartzite at the south of the section to hornblende gneiss on the north, but strata of hornblende gneiss occur at all points in the stratigraphic section. The quartzite and quartz microcline gneiss are rather minor, and were probably a quartz sandstone and an arkose respectively. The two varieties of quartz oligoclase biotite gneiss were pelitic rocks. Hornblende gneiss is a limier phase of the pelitic rocks, and it may be formed from a marl of a reworked tuff.

It can be seen, on the stratigraphic variation diagram (Figure VIII) that the arenitic rocks of unit one grade upwards and westwards along strike into the more pelitic rocks. These in turn grade into hornblende gneiss, this gradation being best shown in the northwest corner of the mapped area. Here, the pelite has many small lenses of hornblende gneiss, and grades eastward along strike into the large lens that comprises the fourth stratigraphic unit.

The hornblende gneiss is similar to amphibolites and hornblende gneisses described by Read (1931) from Central Sutherland. Read thinks these rocks are metamorphosed

sediments. Adams and Barlow (1910) have described an amphibolite produced by metamorphism of an impure limestone. The rock they mention is similar to the Manitouwadge gneiss, although it contains much more lime. In contrast, the hornblende gneiss is unlike hornblendic rocks produced by metamorphism of known igneous bodies (epidiorites) described by Wiseman (1934). Also, they are wholly unlike the massive metamorphosed basic intrusives that are found elsewhere in the Manitouwadge area (see above). The presence of considerable amounts of zircon, generally considered to be more abundant in the acidic rocks (Mason 1952) and the definite gradation into pelitic rocks in the field, argue in favour of a sedimentary origin. It is likely that the sediment was derived, in part, from volcanic material. In fact, some thin strata of hornblende schist similar to the finely laminated schists of the Pusamkwa Group were observed. It is also possible that the gneiss was derived from a marly sediment. The hornblende gneiss is associated with, and grades into the iron rich variety of hornblende gneiss, which, as will be shown below, is probably a metamorphosed iron formation. This gradation involves an increase in the content of magnetite, the addition of pyroxene in some rocks, and a great increase in the quartz content. Most of the quartz occurs as discrete layers alternating with layers of the gneiss.

Iron rich hornblende gneiss

The iron rich hornblende has provoked much specu-

lation by geologists working in the area. This rock is remarkably banded, and consists of alternating layers of clear, coarse-grained quartz and dark hornblende gneiss. The dark laminae consist of garnet, hornblende, diopside, quartz, and feldspar.

Some geologists consider the hornblende gneiss strata to be silicified shear zones, or gneisses into which quartz has been introduced along favourable horizons, while others favour a sedimentary origin for the rock. A third possibility, that of lateral secretion of quartz into low pressure areas from the surrounding rocks, as a part of the processes of metamorphism, may be considered. The lack of a carbonate and chlorite alteration zone around these formations such as has been described by Boyle (1955), and the bedded nature of the strata argue against this possibility.

The hypothesis of silicification may be summarized as follows. Shearing took place along certain horizons, followed by introduction of quartz and some sulphides into these shears. The rock is in effect a series of quartz veins. As evidence, the proponents of this theory point out that some quartz layers have been observed that cut through the other layers of gneiss, as would be expected of a vein. Sulphides, thought to be of hydrothermal origin, are associated with these formations at many localities. Quartz may be related to the pegmatite dykes, since gradational contact between the two

rocks have been observed. This quartz is thought to have been introduced into the gneiss where it caused retrograde metamorphism, and alteration of the ferromagnesian minerals to chlorite. The magnetite is partly introduced with the quartz, and partly the result of a breakdown of the mafic minerals.

In all fairness to the proponents of this theory it should be mentioned that this was a theory based on field evidence only. Examination of thin sections of the hornblende gneiss shows that the mineral identified as chlorite in the field is actually green hornblende and diopside. These minerals have suffered little or no retrogression, nor has the garnet that is present. Unlike the pyrite and the other sulphides that can be seen surrounded by small areas of alteration, magnetite occurs as small crystals, and has had no retrogressive effect on the surrounding minerals. The gradation of quartz into the pegmatite was not observed by the author, but since pegmatitic material has penetrated the other gneisses of the area in several localities, it is entirely possible that this may be the explanation for the relations that have been cited. The few crosscutting quartz layers may be, in part, original sedimentary features, and in part features of the mobilization of the quartz during metamorphism and deformation of the series.

The author concludes that iron rich hornblende gneiss

is sedimentary in origin, and that the following observations support this conclusion. The rock is distinctly bedded, with the beds in all cases roughly parallel to the contact of the formation, and to the enclosing feldspathic rocks. Some layers are quite continuous, and others, while lensing out, recurr in the same stratigraphic position. On the regional map it can be seen that these formations are, with few exceptions, confined to the upper part of the Nama Group. Finally, these gneisses are by no means as uncommon as has been thought. Somewhat similar gneisses are reported from the Mesabi Range as a contact metamorphic phenomenon (Van Hize and Leith 1911), from Western Australia (Miles 1946, 1952), from northern Michigan's Gogebic Range (Van Hize and Leith 1911), from elsewhere in Northern Michigan (James 1954) and from Sierra Leone (Marmo 1956), as regional metamorphic rocks. The few chemical analyses available are compared with chemical analyses of other types of iron formation, and they seem to conform best to those of the Marquette Range of Michigan.

Some speculation is warranted as to the type of sediment that this gneiss represents. James (1955) concludes that magnetite is not produced from hematite by metamorphism, but is rather contained in the original sediment. It is thought therefore that the Manitouwadge rocks were originally deposited as magnetite and minor iron silicates alternating with layers of chert. The deposit was in part evenly banded as most iron formations are, and in part wavy banded similar to that described from the Mesabi Range.

> This taconite differs from the banded taconite in which the banding is parallel, by the irregular arrangement of the bands which are often not continuous but pinch out or split and curve in the most irregular manner or end apruptly...
> (Gruner 1946, p. 34-35).

and

> light-colored cherty beds alternate with brown or black bands composed mostly of magnetite with interstitial chert, iron silicates, and carbonate. The wavy bands which generally make up 5 to 20 per cent of the volume of the rock, are roughly parallel although they do swell and pinch out, split and reunite, or connect with adjacent bands. They range from minute stringers to bands one and a half inches thick and commonly have sharp boundaries each lined with a thin layer of siderite or dolomite.
> (White, 1954, p. 12).
>
> (Compare with plates II and III)

James has also described such bedding from the Gogebic Range of Northern Michigan. In each of these localities, the magnetite iron formation had this characteristic irregular bedding which can be seen on many of the outcrops of iron rich hornblende gneiss. Some carbonate was observed adjacent to the dark bands in the Willroy gneiss.

On metamorphism, the chert bands were recrystallized and quite possibly became mobile, thereby accounting for the crosscutting relationships already discussed. Recrystallization has proceeded farther than in other localities and the quartz is slightly coarser than in the iron formations of Northern Michigan (James 1955). Inclusions of ferromagnesian minerals were found near the quartz grain boundaries. These

TABLE I

CHEMICAL ANALYSES OF IRON FORMATION

Sample	G40A	D28b	D22a	GAN	IF_1	IF_2	IF_3	IF_4
SiO_2	66.22	74.68	40.91	64.22	47.34	39.53	50.02	77.94
Al_2O_3	0.74	1.87	4.96	10.55	1.11	0.57	0.97	0.24
Fe_2O_3	16.04	2.52	1.93	3.56	19.77	38.21	10.05	9.47
FeO	9.88	11.94	34.08	9.31	23.26	15.18	28.29	7.72
MgO	1.94	0.78	4.19	1.67	3.12	2.29	4.13	1.97
CaO	2.21	3.19	4.64	4.01	2.53	1.40	2.63	1.17
Na_2O	0.30	0.30	0.75	1.20	nd	-	0.08	0.04
K_2O	0.03	0.10	0.25	1.40	nd	-	nd	0.10
H_2O+	0.36	0.28	0.94	0.93	tr	1.16	0.42	0.41
H_2O-	0.02	0.06	0.07	0.05	-	-	-	0.20
CO_2	1.03	3.19	5.93	1.03	0.41	-6	1.55	0.79
TiO_2	0.03	0.11	0.28	0.40	nd	-	nd	-
P_2O_5	0.12	0.12	0.16	0.09	nd	-	0.09	0.09
Cr_2O_3	0.01	0.01	0.01	0.01	nd	-	-	-
MnO	1.65	0.74	1.53	0.84	nd	1.40	0.74	0.39
V_2O_3	0.01	0.01	0.01	0.01	nd	-	-	-
Carbon (org)	-	-	-	-	0.34	-	-	-
Sulphur	-	-	-	-	-	0.15	-	0.90 (FeS_2)
Total	100.59	99.90	100.64	99.28	98.02	99.89	98.92	100.51

G40a Iron rich hornblende gneiss, Geco
D28b Iron rich hornblende gneiss, Delmico property
D22a Hornblende gneiss, Delmico property
GAN Iron rich hornblende gneiss, Lun Echo property
IF_1 Average of 22 analyses of magnetitic Biwabik iron formation, Mesabi, Gruner (1946)
IF_2 Average of 4 analyses, Gogebic Iron formation, Irving & Van Hize (1892)
IF_3 Average of 4 analyses of grunerite magnetite schist, Marquette Van Hise & Leith (1911)
IF_4 Siliceous Jaspilite, Western Australia, Miles (1946)

were probably small impurities in the chert layers.

From the preceding evidence the author concludes that this is a former ferruginous sediment. This hypothesis is in agreement with former writers (Pye 1955, 1956; Langford 1955), who have, in fact, called the rock iron formation. In this report iron formation is called iron rich hornblende gneiss for several reasons. In the first place, the two varieties of hornblende gneiss are quite similar in their general appearance, and were originally mapped as one unit by Willroy geologists. Unfortunately the core from several important drill holes was lost before it could be re-examined. Secondly, the two gneisses occur adjacent to one another, and detailed examination shows that a complete gradation exists between the two types of gneiss. However a field distinction can be made between the two. The iron rich variety is magnetic, and is well banded with layers of coarse-grained quartz. Thin section examination shows that diopside is the predominant green mineral in the iron rich gneiss, compared with hornblende in the other type. Bulk chemical analyses (Table 1) show that iron rich hornblende gneiss contains less iron than the other variety. However it should be remembered that most of the iron is present as magnetite in iron rich hornblende gneiss, whereas in the other type which contains little quartz, most of the iron is combined with silica in hornblende.

Quartz Muscovite Schist

Quartz muscovite schist occurs in many small lenses associated with all the other rocks in the area, and in one large wedge which comprises unit three of the stratigraphic section. This wedge extends to the east, off the property, where it widens and contains the Geco orebody.

Langford (1955) considers this schist to be a zone of alteration around the Geco orebody, but later work there (R.C.E.Bray, personal communication) indicates that the schist is actually a layer, and has been folded. The behaviour of the stratum on the Willroy property supports this view. Here it appears to fit into the sedimentary sequence quite well.

Pye (1956) on the other hand, believes that the schist layer represents a pre-metamorphism bedding plane fault that has a post-metamorphism movement on it. This conclusion is based on the fact that this structure appears to truncate a pegmatite dyke in the Geco west orebody, and is traceable for four miles to the west. In addition, reverse drag folds in the Geco ore zone indicate a movement of the north side down and to the west. Pye considers that the pre-metamorphism movement produced a sericitized greywacke of arkose and that later metamorphism changed it to a muscovite biotite quartz gneiss (Pye, personal communication).

However, comparable features are not found on the Willroy property. A prominent pegmatite dyke striking southwest from the east end of Strike Lake may be traced across the quartz muscovite schist in outcrop, with no apparent offset. Other pegmatite dykes are also traceable in drill holes and outcrop across the schist layer. The quartz muscovite schist stratum does not extend across the property, but bifurcates and pinches out to the west. The reverse drag folds at Geco may be associated with the reverse limb of the major drag fold there.

The quartz muscovite schist is probably a metamorphosed quartz muscovite sand. The micaceous quartzite, is a pure layer occurring in the middle of the main layer of schist. The entire unit shows pronounced thickening and thinning, which may be attributed to stretching. The micaceous quartzite marker horizon pinches and thickens within the main unit, and has large quartz augen surrounded by a quartz muscovite matrix. If deformation was significant in the formation of this rock, then it must have occurred at the same time as the metamorphism since later shearing through the layer would have caused retrograde metamorphism.

Summary

The assemblage of sediments that has been metamorphosed to form the gneisses of the Willroy property includes quartz sandstone, arkose, pelitic rocks and iron

formation. The lenslike nature of the formations and the presence of quartzite and iron formation indicates that all the sediments were of the stable shelf type.

We may therefore envisage a stable shelf, where quartz sands and arkoses were deposited in small lenses in more pelitic sediments. Intermittent ponding (James 1954) lead to the deposition of iron formation. Gradually as the shelf became unstable, the pelites became more calcareous or else had volcanic material added to them. A slight reversal of conditions lead to the deposition of a quartz muscovite sand that later formed the quartz muscovite schist. Finally the sediments became calcareous again and the lens of sediment that later formed the hornblende gneisses of the fourth stratigraphic unit was deposited.

Grade of Metamorphism

The rocks have been metamorphosed to the amphibolite facies. That most of the gneisses fit into the lower range of this facies is indicated by the presence of epidote in many of them. Most of the rocks fit into almandine-diopside-hornblende subfacies (Turner and Verhoogen 1951), but the quartz muscovite schist fits into the highest subfacies (Cordierite-anthophyllite) of the amphibolite facies. Evidence of inequilibrium are present in all the rocks, and it is apparently impossible to classify them further.

Intrusive Rocks

Granitic Rocks

Pegmatite: Pegmatite is the most common intrusive rock, occurring everywhere on the property, as large dykes, such as are shown on the map, and also as small stringers. The dykes range in thickness from a fraction of an inch to many feet. In general they strike 60 degrees east of north and dip 20 to 30 degrees northwest. Local steepening of dip and many ramifications complicate the general trend. The unusual shape of some of the dykes shown on the map are caused by the topography, which, although it is not very rugged, exerts a marked control on the dyke outlines because the dykes dip at such a low angle.

The pegmatite is simple, containing quartz, and grey, pink, or green feldspar, muscovite, and biotite. The grain size is coarse, some feldspar grains are two inches across, and mica books are commonly an inch or better in diameter and ½ inch thick. Potash feldspar gives the dyke its colour; pink and grey dykes are common, but green coloured ones are rare.

Pegmatite in the Willroy is probably closely related to, and younger than granite. Pegmatite dykes cut across granite dykes with fairly sharp contacts, although they both have the same general trend. Pegmatite intrudes the gneisses,

and is thought to be cut in turn by diabase, although this relationship was not actually observed on the Willroy property.

Granite: Associated with the pegmatite is a massive, medium-grained rock that has been called granite in the field. It appears to be a minor phase of the main granite mass to the north. The rock occurs with pegmatite in the larger dykes, and is believed to be slightly earlier than the pegmatite.

Permeated Gneiss: Adjacent to some of the pegmatite dykes, the gneiss contains much introduced granitic material. In some places the gneiss is cut by many granite stringers, and in other places the whole rock has a pinkish tinge. In at least two localities near Willroy Lake the gneiss is completely changed to a massive, grey and black mottled rock, which is similar in composition to the biotite granite gneiss found elsewhere in the district. One of these zones appears on vertical section J (see Figure IX, Vertical Sections, in pocket) where it lies just above an irregularity in a pegmatite dyke. The permeated gneiss zones are thought to have been caused by introduction of material by solutions emanating from the dykes.

Diabase

The latest intrusive is olivine diabase, which occurs as north striking dykes. At least three of these dykes occur

in the Willroy property. One wide dyke apparently runs up the Slim Lake valley, and was observed in drill hole No. 140 (see Figure VII, Geological Map, Willroy Property). Another, observed in both drill holes and outcrop, passes just west of the No. 2 and No. 3 ore bodies, and bifurcates to the north. The third, which has only been seen in outcrop, occurs near the Willroy fault.

Structure

Folding

Folding on the Willroy ground is minor. The strata strike across the property at a fairly constant azimuth of 090 to 100, and begin to swing to the northwest near the west boundary of the property. In the eastern portion of the property the dip is vertical, while in the main part of the area, near the two shafts, the dip is 70 degrees north. West of Slim Lake the dip flattens to 65 to 55 degrees to the north.

Several small folds in the formations are noted, however. These appear to be incipient drag folds of a type conformable with the main fold. They plunge 35 to 50 degrees to the east, and their axial planes strike across the succession at an azimuth of 050. These axial planes dip approximately 65 degrees to the southeast as shown in Figure II (Structural Elements of the Willroy Property). Measurements of lineation show that minor structures (crenulations, augan, prismatic crystals, etc), are parallel to these folds.

The pegmatite dyke swarm, too, seems to be related to these folds. These dykes occupy tensional fractures striking northeast and dipping northwest from 20 to 30 degrees. This is perpendicular to the axial planes of the folds. Therefore it appears likely that the pegmatite dykes are controlled by tensional fractures produced by folding. Thus, the major deformation and the granitic intrusions were probably closely related in time.

Faulting

Two of the area's transcurrent north-south faults cut across the Willroy property. One, the Slim Lake fault appears as a deep, straight, valley, while the other, called the Willroy fault in this report, is not marked by so pronounced a topographic feature.

Willroy Fault: The existence of the Willroy fault was suggested by the small gully east of the shaft hill. Also, drill holes No. 120, 122 (see Figure VII) cut a zone of brecciated rock. Detailed mapping shows that several structures are offset by the fault. The No. 3 ore body and the small fold that contains it, as seen in sections D and E (Figure IX) plunge approximately 45 degrees to the east. In section F the structure and the ore appear at a higher elevation than would be expected. Also, several prominent pegmatite dykes, particularly the wide one in drill holes No. 116, 99, do not appear in the expected position in the

hole (No. 85) (see Figure IX, Section F). It is thought, therefore, that the fault, which strikes slightly east of north, has a vertical component of displacement of 200 feet east side up relative to the west. If the movement were solely vertical, the beds, which strike east and dip 70 degrees to the north, would have a sinistral horizontal displacement of 80 feet. In actual fact, however, the structure has moved dextrally 80 feet. The horizontal component of movement is, therefore, 160 feet east side south relative to the west. Applying this displacement to the shallowly dipping pegmatite dykes gives them an apparent horizontal displacement of 350 feet sinistrally. The relation between the fault and the diabase dyke, which dips vertically, is not definitely known, but the outcrop data suggest that the dyke has been faulted, and therefore is displaced 160 feet dextrally.

Slim Lake Fault: There are few outcrops and few drillholes near Slim Lake, and, as a result, the stratigraphy is not well known. A possible marker bed of quartz muscovite schist, just south of the layer of hornblende gneiss containing No. 2 ore zone, seems to have been moved 100 feet, west side south. In addition, the many pegmatite dykes west of Slim Lake may correlate with some of the dykes observed in deep drill holes east of the lake. The movement is thought to have been mainly vertical, with some slight horizontal displacement. An exact solution of the fault, however, must await further information.

Petrography

Quartzite

Quartzite was not examined by the writer, but is reported by Langford (1955) to be a crystalline mosaic, containing 70 to 90 per cent quartz. The remainder is principally biotite, with minor amounts of feldspar, epidote, garnet, and zircon. Biotite flakes are well aligned, and variations in the biotite content give the rock its laminated appearance.

Quartz Microcline Gneiss

As the name suggests, this gneiss is predominantly a mosaic of clear quartz (50-60%) and microcline (15-20%). Five to ten per cent of plagioclase, ($An_{12?}$), untwinned and highly altered to carbonate and sericite is present. Small amounts of colourless muscovite and weakly pleochroic biotite are also present. The accessory minerals are epidote, sphene, magnetite, and zircon. The foliation of the gneiss is the result of alignment of the mica flakes.

Quartz Oligoclase Biotite Gneiss

The mineral assemblage of quartz oligoclase biotite gneiss is quite constant, but proportions of the minerals show a considerable range. Of the principle minerals, quartz is the most abundant, comprising 20 to 50 per cent of the rock. Plagioclase (An_{20-34}), partly prophyroblastic, makes up 10 to 45 per cent of the gneiss, and is somewhat altered to sericite

and carbonate. The biotite content of the rock may be 5 to 20 per cent, but in the darker laminae this may rise to 65 per cent. Microcline is absent in most specimens, but may be present in amounts up to 10 per cent. Garnet is conspicuous when present, but in few places exceeds 5 per cent of the rock. It occurs as porphyroblasts up to 5 mm in diameter, showing sieve structure. The garnet is slightly pink in plane polarized light, and has an index about 1.81 (Langford 1955) which indicates that it is near almandite in composition. Muscovite is commonly present in small amounts. Hornblende is a constituent of some of the dark layers, where it has rims of colourless cummingtonite. Hornblende is pleochroic, X = yellow-green, Y = dark yellow-green, and Z = blue-green. Accessory minerals include epidote, zircon, magnetite, sphene, and some apatite. The rock is well foliated.

Hornblende Gneiss

Hornblende gneiss is a very variable rock, and a general description of it is difficult. The main constituent of the rock is hornblende, present in amounts ranging from 30 to 65 per cent. It occurs as blades commonly 1 mm long, but in places as long as 5 mm. It is pleochroic X = light green, Y = dark yellow-green, and Z = blue green. Some hornblende grains are rimmed by cummingtonite. In one specimen the amphibole is all anthophyllite, slightly pleochroic in grey and brown. This is probably an intermediate variety, close to gedrite. Plagioclase may be present, and

ranges in composition from An_{34} to An_{44}. It is predominantly An_{44}, but is zoned in most cases. Microcline occurs in some sections, and may comprise 20 per cent of the rock. As a general rule, however, it is absent. Quartz makes up, at the most, 20 per cent of the gneiss. Commonly 10 per cent of the gneiss is biotite, and the dark layers may be composed of 30 to 40 per cent of this mineral. It is pleochroic in yellow and brown, and the maximum absorption colour in some specimens is a rich chestnut, or a dark green. Garnet porphyroblasts, up to 20 mm in diameter, are present in most phases of the gneiss. Magnetite is universally present, comprising as much as 10 per cent of the rock. Other common accessory minerals are sphene, apatite, and zircon. Epidote is rather unusual, but is present in a few sections.

A compositional layering and alignment of the biotite flakes and hornblende grains, give the gneiss a strong foliation. In addition, large garnets give the rocks a porphyroblastic texture.

Another variety of hornblendic rock is associated with the quartz oligoclase biotite gneiss as minor lenses. Plagioclase is the prevalent mineral in this type, comprising 25 to 50 per cent of it. Hornblende and quartz are each present in amounts ranging from 15 to 20 per cent. Microcline and biotite each form about 10 per cent of the rock, and the accessory suite of minerals is similar to that of the

feldspathic gneisses. An unusual feature of the rock is its content of green clots, in places as large as 15 mm in diameter. In thin section these clots appear as masses of randomly oriented hornblende and biotite grains. The gneiss is not markedly foliated, or layered, and hand specimens from these strata are quite massive.

Iron Rich Hornblende Gneiss

Iron rich hornblende gneiss consists of layers of dark, fine-grained gneiss alternating with layers of coarse-grained clear quartz. Thin section examination shows the main mineral of the dark layers to be green pyroxene. This pyroxene lies in the diopside-hedenbergite series. It is faintly pleochroic in yellow and blue shades of green. Its properties, $Z \wedge c = 40$ degrees, birefringence .025, N_Z between 1.69 and 1.72 indicate that the mineral falls close to diopside, and has at the most 20 molecular per cent of hedenbergite. Anhedral quartz grains with undulatory extinction and sutured boundaries form a mosaic which comprises 30 to 65 per cent of the rock. The hornblende content is generally small, although it may be as large as 25 per cent. Biotite occurs in some sections, its maximum absorption colour being a dark brown-green or green. Garnet is present as spongy growths, commonly elongate parallel to the bedding of the rock, but in some places in a more spherical shape. A magnetite content of 10 to 15 per cent gives the gneiss its mag-

netic properties. Magnetite occurs as coarse crystals, concentrated along the bedding planes, or as minute dusty inclusions throughout the other minerals. Plagioclase, microcline, sphene, apatite, and zircon occur in very minor amounts in the rock.

Quartz Muscovite Schist

Quartz muscovite schist consists of 60 per cent quartz and 25 per cent muscovite with 5 or 10 per cent biotite. Muscovite is very faintly pleochroic in a pale brown, and the biotite is more strongly pleochroic in straw yellow and brown. Minor amounts of plagioclase and magnetite are noted. The plagioclase is highly altered to sericite and clay minerals. Alignment of the mica grains gives the rock a strongly schistose appearance. The background is a mosaic of slightly strained quartz.

Micaceous Quartzite Marker Horizon

Micaceous quartzite is a variety of quartz muscovite schist which contains no biotite. It consists of 80 per cent quartz and 15 per cent muscovite with minor magnetite and altered plagioclase. Quartz grains are strained and some are quite large, up to 1 mm in diameter. These large grains contain numerous inclusions of muscovite.

Permeated Gneiss

Forty-five per cent of the permeated gneiss is

plagioclase, occurring as large zoned grains with slightly altered centres and clear unaltered rims. The centres are andesine An_{36} and the rims are oligoclase An_{20}. Quartz and microcline each comprise 20 per cent of the rock. Some quartz is present as small rods in plagioclase grains. Biotite, pleochroic in yellow and brown, is the chief mafic mineral. A little hornblende is present, and the two mafic minerals together make up 15 per cent of the rock. The accessory minerals present are apatite, sphene, epidote, zircon, and magnetite. Chlorite, carbonate, and sericite are minor alteration minerals.

Pegmatite and Granite

The pegmatite specimen that was examined contains quartz, albite An_{10}, and muscovite. Microcline and biotite are also present in some of the other dykes. The finer-grained granite that occurs with the pegmatite in some dykes is perhaps a better indicator of the composition of the granitic rocks. Albite is predominant, forming 45 per cent of the rock, quartz and microcline form 25 per cent each, and biotite and muscovite the remainder. The plagioclase has been slightly altered to sericite and clay minerals. Mica flakes are subhedral in the pegmatite and rather ragged in the granite. Quartz and feldspar grains are anhedral in both rocks.

Diabase

Diabase is composed principally of plagioclase An_{45} laths surrounded by grains of augite. Plagioclase is altered to sericite, carbonate, and clay minerals, and its composition has only been determined tentatively. Augite is partly altered to chlorite, but is much fresher than the feldspar. The pyroxene is colourless, has a high moderate relief and birefringence, and $Z \wedge c = 55$ degrees. Magnetite comprises almost 10 per cent of the rock, and occurs as euhedral grains. One large grain of serpentine was noted and is thought to represent a former olivine grain. The rock is fine-grained and has an ophitic texture. It is tentatively classed as olivine diabase, as no quartz is present, and one possible pseudomorph after olivine is noted.

MINERAL DEPOSITS

Ore Bodies

No. 1 Ore Body

The No. 1 ore body, located near the east boundary of the property, is of tabular shape, and has a vertical dip. The body has been traced by diamond drilling for 1500 feet horizontally to the eastern boundary of Willroy ground. In longitudinal section, the upper limit of commercial mineralization appears as a wavy line that plunges gently to the east at 15 degrees, and the lower limit plunges regularly to the east at 50 degrees. The regular plunge of the lower limit is broken just east of section K (Figure IX, Vertical Sections) where it is offset 200 feet east side up. The upper line shows only a slight curve above this point. In cross section the ore body appears tabular, with a maximum width of 50 feet, and a slight taper downwards. It dies out abruptly above and below by splitting into two tongues separated by a zone of sulphides of submarginal grade.

A much smaller body lies 200 feet west and 50 feet north of the western extremity of the No. 1 zone. This smaller body also plunges east at 50 degrees, and has a cross section similar to the No. 1 zone.

In both ore bodies, sulphide grains are disseminated

throughout the quartz muscovite schist, and are concentrated along foliation planes and crenulations. Lenses of massive sulphides occur within an envelope of disseminated sulphides. The predominant mineral present is pyrrhotite, with chalcopyrite, pyrite, and some sphalerite. The No. 1 ore body is estimated to contain 740,000 tons of ore grading 1.45 per cent copper, 0.36 per cent zinc, and 0.42 ounces per ton silver.

No. 2 Ore Body

The No. 2 ore body lies in a stratum of iron rich hornblende gneiss 200 feet north of the main (No.1) shaft. The ore body plunges to the east at 35 degrees, and consists of massive sulphides, largely pyrite, pyrrhotite, sphalerite, galena and rare chalcopyrite. Only a part of the gneiss is ore, and the boundary of the ore body is quite sharp. The ore zone cuts diagonally across the iron rich hornblende gneiss layer that contains it, lying on the north side to the east, and on the south side to the west. A smaller pod of ore lies in a hornblende gneiss formation 100 feet to the south. This also plunges east at 35 degrees. Little is known about the No. 2 zone, as it has been traced horizontally by drilling for only 800 feet. It will be tested more thoroughly from the underground workings. It is tentatively estimated to contain 420,000 tons grading 0.03 per cent copper, 7.24 per cent zinc, and 3.80 ounces per ton silver over widths of 7 to 15 feet.

East of the No. 2 zone, near the Willroy fault, at least two small pods of massive sphalerite have been indicated by drilling, one lying in quartz muscovite schist, and the other in iron rich hornblende gneiss. Very little is known of their extent as yet.

No. 3 Ore Body

The No. 3 ore body lies 500 feet south of the main shaft and is the largest ore body on the property. The ore zone has been exposed in test pits as is indicated on the geological map (Figure VII). The ore lies within a stratum of iron-rich hornblende gneiss in a manner similar to the No. 2 zone, cutting slightly across the layer of gneiss. The ore body plunges to the east at 40 degrees and has been traced beyond the Willroy fault which displaces it slightly. It contains pyrrhotite, pyrite, chalcopyrite, sphalerite and some galena. On the surface the mineralized zone has been traced for 400 feet with widths up to 25 feet. The ore body is reported to contain 1,000,000 tons grading 1.24 per cent copper, 10.25 per cent zinc, and 1.8 ounces per ton silver. Recent development work has outlined 125,000 tons additional to this estimate. At the neighbouring Geco mine, the grade has proved higher than that obtained from estimates based on drill core samples. The first reports from the underground development at Willroy also indicate a higher grade.

A fourth mineralized zone lies in an iron rich hornblende gneiss layer west of Slim Lake. It is apparently of no great size, although it has not been tested fully as yet. The assemblage of sulphide minerals is similar to that of the No. 2 zone.

Structural Controls

Each of the Willroy ore bodies lies wholly within one bed. Each is tabular in shape, and essentially conformable to the strike of the strata, and of the foliation in the vicinity. In addition, each plunges to the east at angles ranging from 35 to 50 degrees. Ore bodies on neighbouring properties have similar characteristics.

Several small folds in the strata occur on the Willroy property. These have been described above in the discussion of structure, and are shown to be related to the major fold. The sulphide zones found thus far on this and neighbouring properties occur in or near such folds. Number 1 zone lies above and to the east of a small fold, and the small zone to the northwest lies in a similar position relative to another small fold. The No. 2 and No. 3 zones lie in different stratigraphic positions, but are related to the same small folds. One interesting difference between these two ore bodies is that the No. 2 ore body occurs right in the fold, while the No. 3 lies east of the fold, between it and

the next one. The small sphalerite zones east of the No. 2 ore body are associated with the fold that lies east of the No. 3 ore body. The small zone west of Slim Lake lies, like No. 2 ore body in a folded layer of hornblende gneiss.

It is thought that folding has created areas favourable to sulphide deposition. Some strata are apparently unfavourable, because they are devoid of mineralization. Iron rich hornblende gneiss and quartz muscovite schist contain all the important ore bodies so far discovered, but many strata of these rocks are barren. The exact nature of the relation between folding and ore deposition must remain unsolved for the present.

A stratigraphic control is evident, in that all the known ore bodies, and all the promising prospects lie in the upper part of the Nama Group. Pye (1956) considers them to be related to pre-ore bedding fault, represented by the quartz muscovite schist.

There is an increase in grade and width of ore below a flat lying pegmatite dyke in the Geco west ore body, (Pye 1956). Pegmatite dykes may have had a similar effect on the Willroy ore bodies, but this cannot be determined from drill core evidence.

Ore Minerals

Chalcopyrite and sphalerite are the valuable sul-

phide minerals of the deposit. Galena is present in small quantities in the No. 2 ore body. Pyrite and pyrrhotite are present in the ore, and they comprise over one half the sulphide mineral content. These two minerals, pyrite in particular, are disseminated throughout the country rock.

Pyrite

Pyrite is found throughout the ore bodies, and in minor amounts in the enclosing rocks. It occurs as small cubes, up to 10 mm across. Massive pyrite is found rarely in the deposit as strongly brecciated zones, partly replaced by later sulphides, principally pyrrhotite (Figure IV A). Pyrite cubes set in a matrix of later sulphides are observed in all parts of the three ore bodies, but, on close examination they appear to have been partly eaten away by the later minerals (Figure IIIA). One polished section shows a quartz veinlet containing pyrite fragments, pyrrhotite, and sphalerite, bisecting a pyrite crystal (Figure IIIB).

Pyrrhotite

Pyrrhotite, like pyrite is found widely disseminated in the country rock. Lenses of massive pyrrhotite, one or two feet wide, are quite common throughout the area. In the ore zones, pyrrhotite occurs generally as scattered remnants, and locally as massive lenses. Apparently pyrrhotite was easily replaced by later sulphides, and as a result, only a few of these lenses remain. Pyrrhotite is replaced by chalco-

pyrite, sphalerite and galena, and itself replaces pyrite, particularly in breccia zones.

Chalcopyrite

Chalcopyrite is abundant in the No. 1 and No. 3 zones, but rare in the No. 2 zone. Contact relations show it to be younger than pyrite and pyrrhotite. The relation between chalcopyrite and sphalerite is more complex. A few exsolution dendrites of sphalerite were seen in chalcopyrite, from the No. 1 zone (Figure VA). Langford (1955) has shown that these are oriented parallel to crystal directions in the chalcopyrite at Geco, but too few were observed in Willroy specimens to investigate this relation. Chalcopyrite exsolution blebs in sphalerite are more common. These have also been described by Langford (1955), and are of four types. (see Figure V B).

(1) with no apparent orientation, emulsion type
(2) oriented along grain boundaries
(3) oriented along twin planes in sphalerite
(4) oriented along cleavage planes

All these types are present in the Willroy ore.

When pyrite cubes are surrounded by sphalerite and chalcopyrite, the chalcopyrite occurs as ragged rims around the pyrite. These rims are thought to be the result of deposition of chalcopyrite around the pyrite and later re-

placement of part of the chalcopyrite by sphalerite. Chalcopyrite rims might also be attributed to exsolution along the sphalerite grain boundaries, or to later invasion of chalcopyrite along the sphalerite pyrite contact. Exsolution rims are smoother, however, and contact invasions less continuous than the rims that are present here. The chalcopyrite is thought to have commenced deposition slightly before sphalerite, but considerable overlap in the time of deposition is certain. Spectographic analysis of chalcopyrite (by H.T. Carswell, University of British Columbia) shows it to contain silver and tin in small amounts.

Sphalerite

Sphalerite is abundant in the No. 2 and No. 3 zones and is also present in the No. 1 zone. Its relations to chalcopyrite have been discussed above. Staining with hydriodic acid shows that the sphalerite has many lamellar twins. The intensity of twinning varies in the ore, and it is thought to have been caused by mutual interference between the grains of sphalerite during growth, rather than by an external deformation (Edwards 1954). The sphalerite is dark in color, similar to the sphalerite at Geco which was found to contain 7 per cent iron and 0.1 per cent manganese (Langford 1955). Chalcopyrite exsolution intergrowths in sphalerite are common only in parts of the ore that contain discrete chalcopyrite grains. Massive sphalerite zones are

quite common in the ore, and are continuous, retaining the same relative position in the ore body from one drill section to the next.

Galena

Galena is rare in the No. 1 zone, but common in the No. 3 and especially in the No. 2 zones. It occurs in fractures and in small replacement veins cutting across all the other sulphide minerals (Figure IV B). Small blebs of galena are also seen along the contact between sphalerite and gangue, and along fractures and cleavage planes in the gangue minerals, particularly biotite and hornblende.

Tetrahedrite

Tetrahedrite occurs in very small amounts in specimens of No. 3 zone ore. The mineral is in blebs too small for a positive identification or a determination of its paragenetic relations. Tetrahedrite is placed tentatively with galena in the paragenetic sequence because it occurs with galena in the ore.

Silver

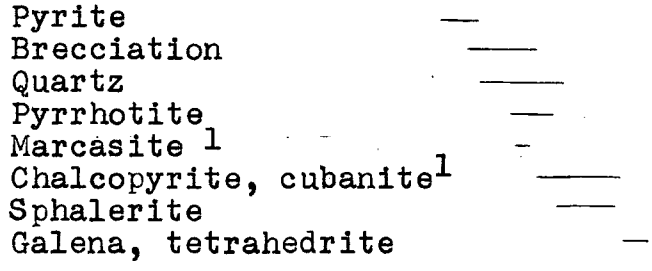
Silver assays as high as 25 ounces per ton have been recorded in the No. 2 zone, but examination of specimens from these places for silver or a silver mineral has proved fruitless. Langford (1955) has shown that silver assays at Geco follow the high copper values. Spectrographic analyses

of Geco and Willroy chalcopyrite show silver is present in significant amounts. Much silver is indicated by assays in the Willroy No. 2 zone, however, and this zone contains little chalcopyrite. Spectrographic analyses of galena and sphalerite from Willroy (C. Cross, University of British Columbia) indicate that silver is present in both these minerals. It is concluded that silver is present in Willroy ore in galena, chalcopyrite, tetrahedrite and sphalerite.

Paragenesis

The paragenesis is quite straightforward, and is summed up in the following diagram. Pyrite is the earliest sulphide mineral, its deposition being followed by a period of brecciation, and deposition of quartz. Pyrrhotite deposition overlaps the quartz, and precedes chalcopyrite and sphalerite, which also overlap quartz. Chalcopyrite and sphalerite deposited with considerable overlap, but with chalcopyrite, in part, preceding the other mineral. Galena, with some tetrahedrite, were the last minerals to form.

Paragenetic Diagram



1. Noted at Geco, included here for completeness

Gangue Minerals

The gangue minerals of the Willroy ore bodies are unreplaced memnants of the enclosing strata. Quartz is the predominant gangue mineral because it is least susceptible to replacement. The other minerals of the enclosing rocks have been altered considerably. Diopside has been altered to hornblende, which in turn has altered to cummingtonite. Some of the cummingtonite has changed to chlorite. Muscovite and biotite are changed to chlorite, and the feldspars become cloudy with minute particles of sericite and carbonate. In short, hydrothermal activity had a retrogressive metamorphic effect on the gneiss. Possibly some iron was introduced to the gneiss to form cummingtonite from hornblende.

Classification

Several temperature indicators are present in the ore. Pyrrhotite is indicative of temperatures in excess of 500 degrees Centigrade (Edwards 1954). Sphalerite exsolution in chalcopyrite also indicates a temperature of this magnitude. Chalcopyrite exsolution from sphalerite occurs at 400 to 350 degrees Centigrade and galena and tetrahedrite are indicative of temperatures below 500 degrees.

The original layering in the gneiss is preserved im the ore. Sulphides replace the minerals of the dark layers,

and heal fractures in the quartz of the light-coloured layers. The general character and the estimated temperature of formation of these deposits indicate they are hypothermal replacement bodies.

SUMMARY

(1) The Manitouwadge area is underlain by a series of hornblende schists and quartz feldspar gneisses which have been folded into an overturned syncline which strikes east-west and dips gently northeast. The Willroy property covers part of the south limb of this fold.

(2) The gneisses of the Willroy property exhibit all gradations from quartzite to iron rich hornblende gneiss.

(3) This group of gneisses is thought to represent a former stable shelf assemblage consisting of quartz sandstone, arkose, pelite, limey pelite and ferruginous sediment.

(4) East-plunging folds in the formations, apparently related to the main fold, are present on the property.

(5) Pegmatite dykes, which strike north of east and dip flatly to the northwest, occupy tension fractures related to the major deformation.

(6) Three tabular, hypothermal, sulphide replacement ore bodies are present. Each is wholly enclosed in one stratum and plunges to the east at approximately 45 degrees.

(7) Each of these bodies is related to a small fold in the strata, as are other, smaller sulphide replacement zones.

(8) Post-ore faulting has occurred, and has offset at least one of the three ore bodies a few hundred feet.

(9) The sulphide minerals present are pyrite, pyrrhotite, chalcopyrite, sphalerite, galena, and tetrahedrite. Silver is present in economic quantities, and is apparently contained in the sulphide minerals.

(10) The deposition of the sulphides has caused only minor alteration of the surrounding gneisses.

CONCLUSION

The exact structural control of the ore bodies is not known. The obvious relation of ore to small folds should not be overlooked. It is probable that other deposits may be found, both on the Willroy ground and in other parts in similar environments of the area. Detailed geological mapping is necessary to disclose any other folds similar to the ones described, which should then be prospected carefully.

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A P P E N D I X

PLATE I

Quartzite

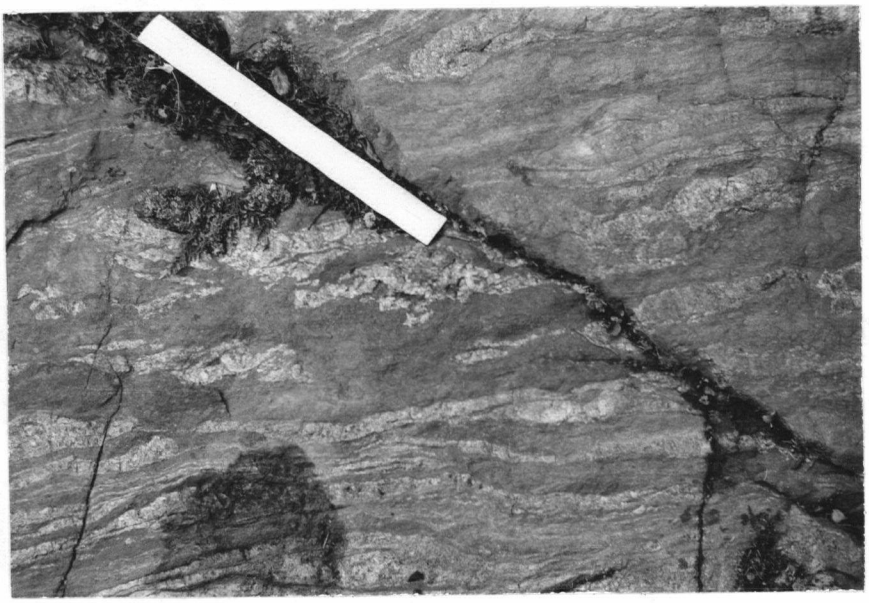


PLATE II

Iron rich hornblende gneiss, wavy banded

PLATE III

Iron rich hornblende gneiss, evenly banded

PLATE IV

Quartz oligoclase biotite gneiss (garnetiferous)

PLATE V

Quartz muscovite schist

PLATE VI

Micaceous quartzite marker horizon

PLATE VII

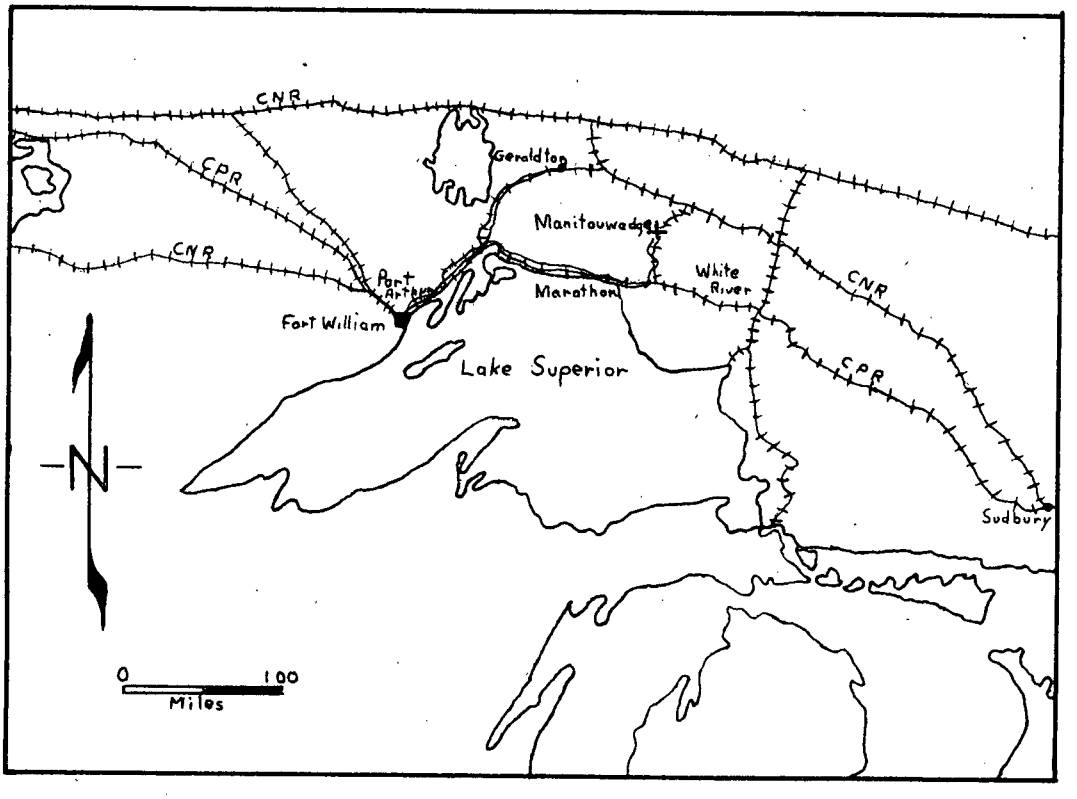
Hornblende gneiss

List of Abbreviations used in

Figures III, IV, and V

Pyrite	Py
Pyrrhotite	Po
Chalcopyrite . . .	Cpy
Sphalerite	Sp
Galena	Gn

FIGURE I



LOCATION & ACCESS
MAP
MANITOUWADGE AREA

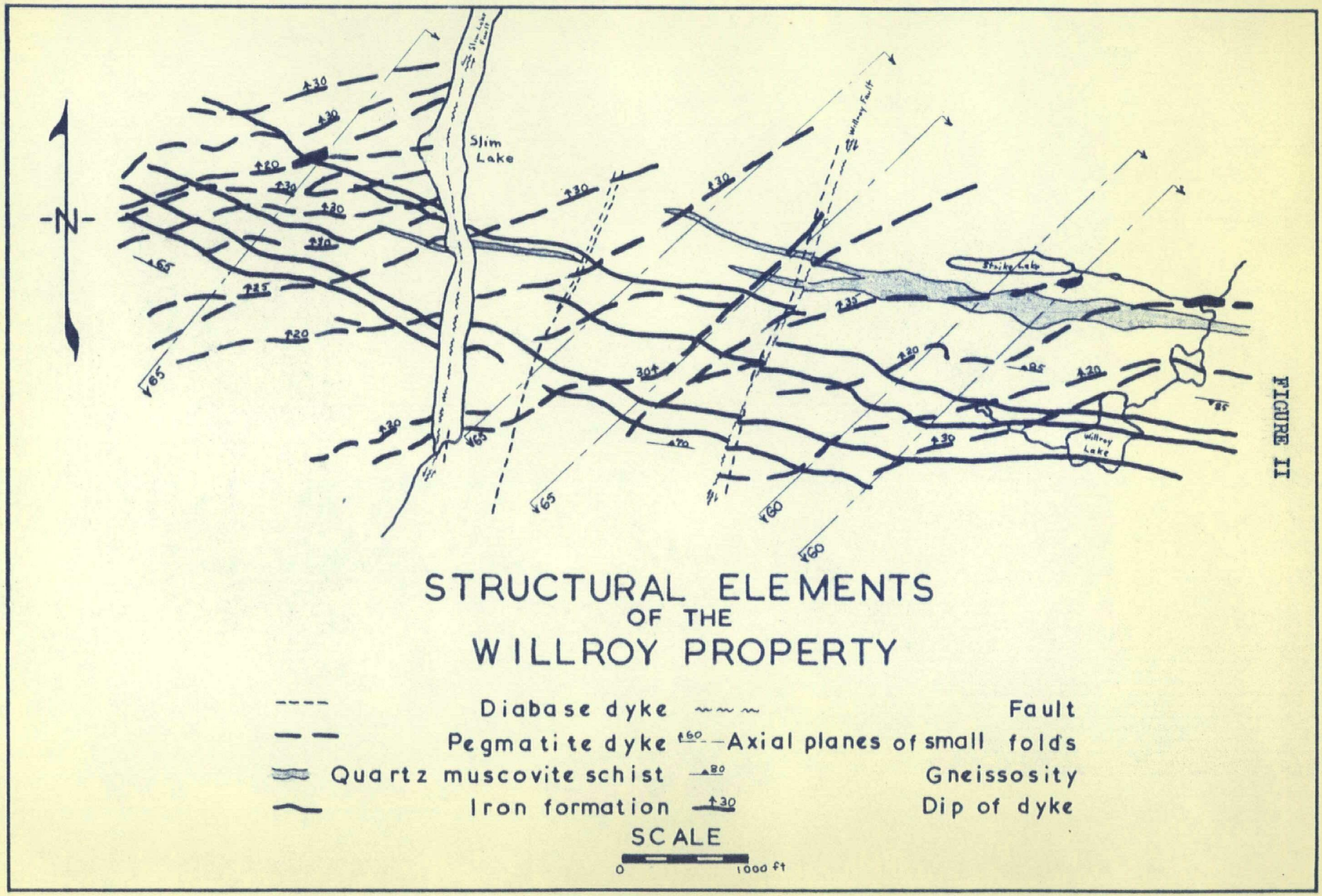
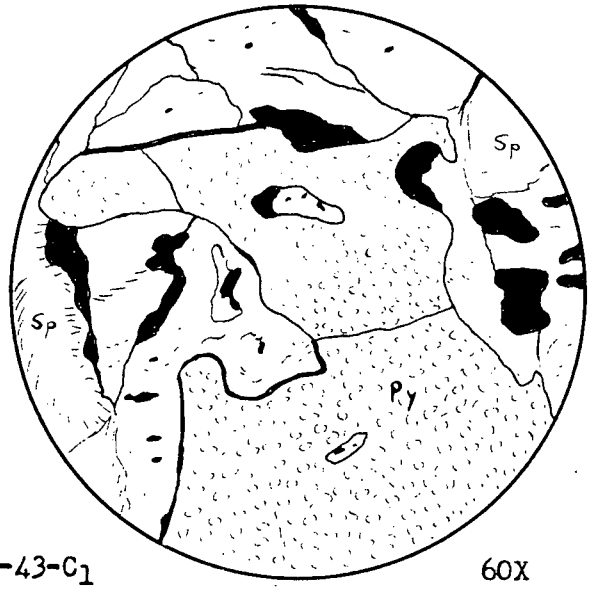

N
Slim Lake
Willroy Fault
Slim Lake Fault
Strike Lake
Willroy Lake
STRUCTURAL ELEMENTS
OF THE
WILLROY PROPERTY
Diabase dyke
Pegmatite dyke
Quartz muscovite schist
Iron formation
Fault
Axial planes of small folds
Gneissosity
Dip of dyke
SCALE
0
1000 ft

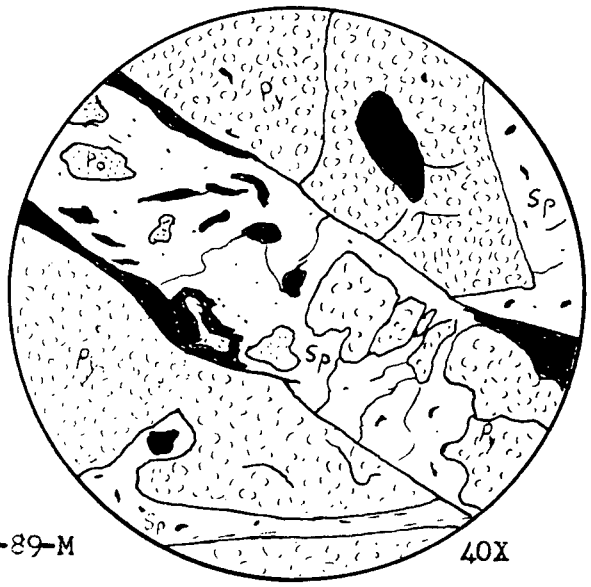
FIGURE II

FIGURE III



W-43-C_1 60X

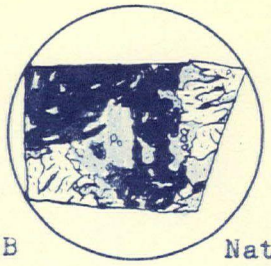
A Pyrite cube partially replaced by sphalerite



W-89-M 40X

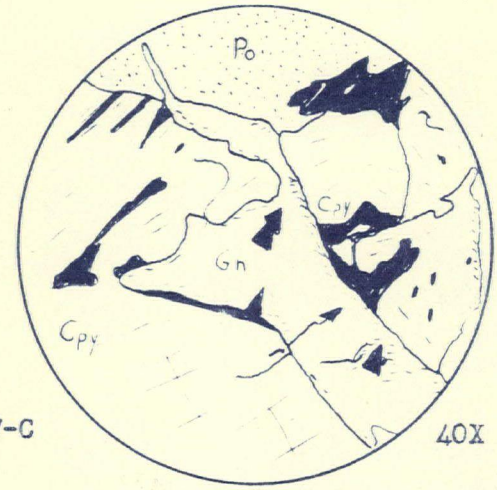
B Quartz veinlet containing pyrite fragments, pyrrhotite, and sphalerite cuts across a pyrite cube.

FIGURE IV



W-43-B Natural size

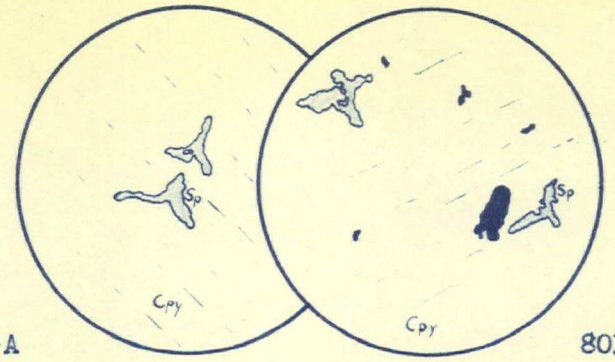
A Brecciated pyrite replaced by pyrrhotite



W-97-C 40X

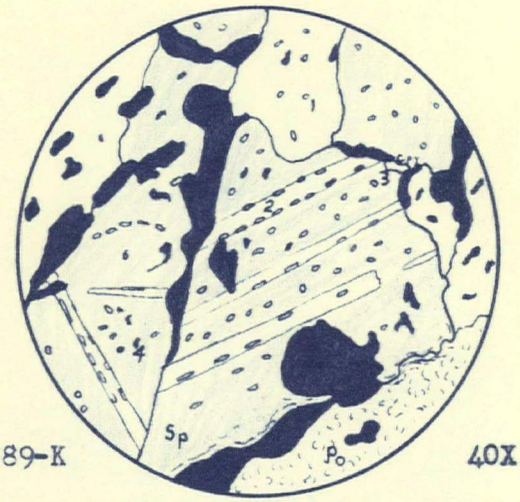
A Galena vein cutting across chalcopyrite and pyrrhotite

FIGURE V



W-7-A 80X

A Exsolution dendrites of sphalerite in chalcopyrite



W-89-K 40X

B Sphalerite stained to show twinning chalcopyrite occurring as;

1) Exsolution inclusions, unoriented
2) Exsolution inclusions, along twin planes
3) Exsolution inclusions, along grain boundaries
4) Exsolution inclusions, along cleavage planes