GENERAL GEOLOGY

J. L. Jambor
Geological Survey of Canada, Ottawa

Introduction

That portion of the Superior structural province of the Canadian Shield which is dealt with here as the "Cobalt-Gowganda region" is shown in Fig. 7. With the exception of a relatively small Paleozoic outlier near the north end of Lake Timiskaming, the region is underlain wholly by Precambrian rocks. The basic structural pattern is made up of a steeply-dipping Archean volcanic basement uncomformably overlain by flat-lying Proterozoic sediments. Both were intruded by undulating sill-like sheets of diabase. Tectonic stability in the region has persisted since the early Proterozoic.

The more detailed geological subdivisions for the region are given in Table 1. Keewatin, Timiskaming, and similar names have an extensive local usage, but have at this stage been largely abandoned in province-wide correlations and in local mapping by the Ontario Department of Mines.

Archean

The basement rocks in the region are predominantly fine-grained, green, intermediate to mafic flow rocks characterized by steep to vertical dips due to folding. The flows are massive to pillowform and locally contain interflow cherty sediments and intercalated pyroclastics. Intrusions of felsite and quartz and feldspar porphyries are present in some places.

The Archean volcanics in the area around Cobalt have been grouped by Thomson (1961) into two units, a younger one in which fragmental tuffaceous sediments are abundant and locally well-bedded, and an older unit in which intermediate (andesitic) lavas predominate. In some places beds of chert, tuff, and greywacke having a combined thickness of up to 50 feet (15m) occur between the andesitic flows. Some of these interflow bands are rich in pyrite, pyrrhotite, chalcopyrite, sphalerite, and galena.

The area between Cobalt and Gowganda is almost devoid of Archean exposures. At Gowganda, about 55 miles northwest of Cobalt, a two-fold subdivision of the Archean volcanics is also recognizable. Mafic to intermediate lavas and pyroclastics, in places schistose, have been suggested

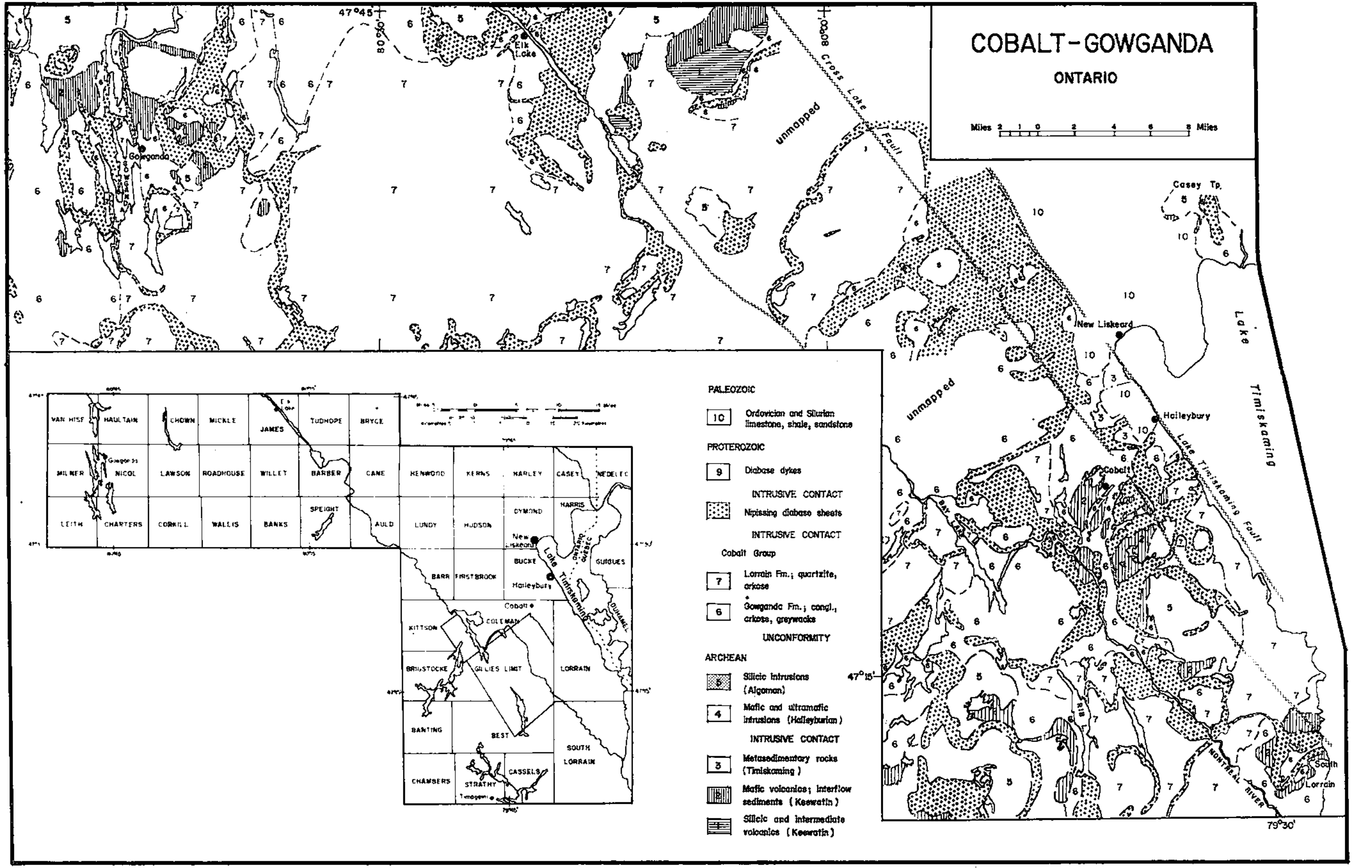

FIG. 7. General geology and township locations in the Cobalt-Gowganda region. A more detailed legend is given in Table I. (Compiled from maps by the Ontario Department of Mines)

TABLE 1. GEOLOGICAL COLUMN FOR THE COBALT — GOWGANDA REGION.

EON	TIME AND ROCK UNITS				
PHANEROZOIC	Cenozoic Era	Recent			Soils, lake and stream deposits
		Pleistocene			Glacial sand, gravel, bedded clay
				unconformity	
	Paleozoic Era	Silurian		Lockport Formation	Dolomite, limestone, sandstone
				Wabi Formation	Limestone, shale; disconformity at top
				disconformity	(?)
		Ordovician	Liskeard Group	Farr Formation	Limestone
				Bucke Formation	Shale
				Guiges Formation	Sandstone
				unconformity	
PROTEROZOIC	(Keweenawan)			Olivine and quartz diabase dykes	
				intrusive contact	
				Nipissing diabase sheets	
				intrusive contact	
	(Huronian)		Cobalt Group	Lorrain Formation	Arkose, quartzite
				Gowganda Formation	
				Firstbrook Member	Mainly bedded argillite
				Coleman Member	Conglomerate, greywacke quartzite, arkose
				Kenoran Orogeny, 2490 m.y.	
ARCHEAN	(Matachewan)			Dykes of diabase, minor lamprophyre	
				intrusive contact	
	(Algoman)			Large salic intrusions, Lorrain Granite, Round Lake Batholith	
				intrusive contact	
	(Haileyburian)			Minor dykes and sills of mafic rocks; lamprophyre, serpentinite	
				intrusive contact	
	(Timiskaming)			Mainly greywacke and conglomerate	
				unconformity	
	(Keewatin)			Mainly intermediate to mafic flows; some pyroclastics and acid volcanics, minor interflow sediments with chert, sulphides; iron formation; schist.	

by Moore (1956) to be an older sequence overlain by acid rocks, predominantly felsite, rhyolite, quartz porphyry, and minor iron formation and cherty interflow sediment.

Throughout the Cobalt-Gowganda region the volcanics were intruded by a few lamprophyre dykes and bodies of mafic and ultramafic rock. They are for the most part of small dimensions, though a few elongate bodies are about 500 feet (150m) thick. Some of these intrusions pre-date, and others apparently post-date the deposition of Archean conglomerates, greywackes, and slates which predominate in what are referred to as "Timiskaming" sediments. In common with other Archean rocks, the sediments have almost vertical dips and are therefore in some cases difficult to distinguish from the fine-grained interflow sediments in the largely volcanic "Keewatin" sequence. The stratigraphic relationships of "Timiskaming" rocks are also obscure in that they uncomformably rest on Keewatin rocks at some localities, but are elsewhere apparently interbedded with them. As far as is known, the Timiskaming rocks in this region are exposed only in a small area to the north of Cobalt (Fig. 7).

All the afore-mentioned rocks underwent regional metamorphism and deformation to their present attitudes during the Kenoran orogeny, dated at about 2.5 b.y. Metamorphism was generally of low grade, with most of the rocks being converted to the greenschist facies. Though the detailed structural features of the Archean rocks have not been unravelled, folding throughout the region appears to have occurred predominantly along northwest to west fold axes. In the Cobalt area the strike of the Archean rocks is predominantly northwest. Thomson (1961a) has recognized the presence of a major anticline with its axis near the centre of the New Lake diabase basin (Fig. 8) and striking N60°W. Several smaller isoclinal folds having a similar strike have been recognized near Cobalt. In the Timiskaming sediments north of Cobalt, Boutcher *et al.* (1966) also detected isoclinical folding along west to northwest axes. In Gowganda, Moore (1956) has tentatively suggested that an east-west Archean trough or fold axis passes through the Miller Lake basin.

As part of the Kenoran orogenic cycle, granitic rocks of batholithic proportions were intruded into the metasediments and metavolcanics. The intrusions differ in composition from place to place, the range extending from syenites and granites to quartz diorites and granodiorites. Porphyritic and foliated varieties occur in some areas. The granitic mass south of Cobalt (Fig. 7) is locally referred to as the Lorrain granite. It is pinkish, coarse-grained, uniformly massive, and economically barren. Several arcuate quartz veins in the adjacent metavolcanics follow the northwestern margin of the pluton and are believed to be genetically related to the intrusion.

The granitic mass near Elk Lake, northwest of Cobalt, is considered to be the southern exposed edge of the Round Lake Batholith, dated at 2605 m.y. (Lowdon *et al.* 1963). All the granitic plutons throughout the Cobalt-Gowganda region are sometimes referred to as being Algoman in age. Post-Algoman igneous activity in the Archean is limited to the intrusion of lamprophyre and diabase dykes. Only a few of these occur in the eastern part of the region, but in the west, near Gowganda, swarms of quartz diabase dykes occur in such profusion that Hester (1967) estimated a tensional crustal shortening of about 10 per cent was necessary for their accommodation. The dykes, which are usually referred to as "Matachewan", are characterized by remarkably uniform northerly strikes and by plagioclase phenocrysts several centimeters in length. Dyke widths of up to 400 feet (120m) have been noted (Hester 1967), but most are less than 100 feet (30m). Dykes, both pre-and post-Algoman, are a minor but important structural feature because in a few places, particularly at Cobalt, they appear to have been loci at which fracturing and silver mineralization occurred much later in the geological history.

Proterozoic

An extensive period of erosion of the upturned Archean metavolcanics and batholithic intrusions preceded and accompanied the deposition of Proterozoic sediments. The erosion levelled some areas and in others formed a hilly topography having a relief of several hundred feet. The first Proterozoic sediments were deposited in the erosional valleys as nearly horizontal beds atop the steeply-dipping Archean. This pronounced difference in attitude is a useful criterion for distinguishing between Archean and Proterozoic sediments both in the field and in drill cores.

The Proterozoic sediments belong to the Cobalt Group, which is generally designated as being Huronian, or lower Aphebian in the terminology of Stockwell (1964). Possible revision of the term "Huronian" is currently under active discussion (Robertson *et al.* 1969 a,b ; Church & Young 1970).

In the Cobalt-Gowganda region the Cobalt Group is almost totally represented by two formations, the Gowganda, and the overlying Lorrain. They are relatively undeformed and are mostly in the chlorite grade of metamorphism. The Gowganda Formation thickens and is underlain by older sediments to the south, but in the region dealt with here the underlying formations are missing and the Gowganda unconformably overlies the Archean. (The exception is an anomalous thickness of sediments intersected in a deep drill hole in Henwood township; the correlation of these with pre-Gowganda formations farther to the south is uncertain).

Near Cobalt it has been possible to subdivide the Gowganda Formation into two units (Thomson 1957a), and here the member names Coleman and Firstbrook are applicable as follows:

Local	*Regional*
Lorrain Formation	Lorrain Formation
Firstbrook Member Coleman Member	Gowganda Formation

The Coleman Member of the Gowganda consists largely of conglomerate, with variable amounts of argillite, quartzite, and arkose occurring at several horizons in the conglomerate. The thickness is highly variable; in places the member is absent, deposition having depended on the local topography of the pre-Huronian basement. Card (1969) has suggested that part of the irregular topographic surface of the basement in the western part of the Cobalt region probably formed by horst and graben faulting.

The maximum thickness of the Coleman Member near Cobalt is about 600 feet (180m), with the argillitic portion being up to 100 feet (30m) thick. The conglomerates vary greatly in the size, variety, angularity, and proportion of boulders, some of which are several feet in diameter and without a local source. Passing from the basal conglomerate, the general upward succession is through greywacke, quartzite, and an upper conglomerate unit having a thickness of 50 to 60 feet (15-18m).

Overlying the Coleman is the Firstbrook Member, consisting of well-bedded, fine-grained sediments generally called greywacke or argillite. The sediments are low-grade metapelites in which reddish, greenish, and greyish beds from about 0.1mm to 1cm thick commonly alternate. Member thicknesses of 700 to 1,000 feet (210-305m) have been recorded in several places near Cobalt. In Henwood township, about 20 miles (32km) northwest of Cobalt, Thomson (1968) reported that a vertical drill hole intersected over 2,000 feet (610m) of Firstbrook sediments.

The Gowganda Formation is believed to be glacial in origin. Johnston (1954) and others have noted that a thin, well-marked regolith is present at the base of the Formation in some places, but Grant (1964) and Schenk (1965) have observed pre-Huronian glacial striae near the south end of Lake Timagami. The detailed sedimentological studies of the Gowganda Formation by Lindsey (1967, 1969), Young (1968), and Lindsay *et al.* (1970) include some exposures from the Cobalt region. Most writers appear to agree with Lindsay's conclusion that the evidence for a continental glacial environment is compelling. Pebble fabric and ripple cross-lamination data indicate north-to-south glacial movement, with the dominant source of the sediments being the plutonic terrain underlying the northern part of the Formation.

The presence of a high Na_2O/K_2O ratio in Gowganda Formation argillites was pointed out by Pettijohn & Bastron (1959), who concluded that post-depositional albitization of the detrital plagioclase had occurred. Since that time, Thomson (1966) has obtained 2 analyses of Firstbrook argillite from Henwood township, McIlwaine (1969) has reported an analysis of Gowganda Formation feldspathic siltstone from Leith township, Gowganda, and Dass (1970) has reported 4 analyses of greywacke from the 400 level of the Silverfields mine, Cobalt. For the Henwood argillites, the Na_2O/K_2O values are 1.41/2.63 and 2.74/3.05, neither of which is particularly anomalous. The Leith township feldspathic sandstone contains 6.47 per cent Na_2O and only 0.28 per cent K_2O ; the Silverfields greywackes contain 0.1 to 0.2 per cent K_2O and 4.5 to 6.0 per cent Na_2O. Nine samples of tillite (conglomerate) matrix were analyzed by Young (1969), who also reported the average for an equal number of Gowganda Formation argillites. These results are summarized in Table 2. Young concluded (1969, p. 489) that "while the amount of sodium in the Gowganda samples is high for sedimentary rocks, it is comparable with that in the [Archean] basement rocks and merely indicates an absence of chemical weathering processes."

TABLE 2. AVERAGE CHEMICAL COMPOSITION OF GOWGANDA FORMATION AND ARCHEAN ROCKS (after Young 1969).

	Laminated argillite[1]	Tillite matrix[2]	Archean av.[3]
SiO_2	57.76	62.43	66.30
Al_2O_3	17.82	15.27	15.37
Fe_2O_3	2.87	2.38	1.26
FeO	4.96	3.83	2.85
MgO	4.16	3.82	2.05
CaO	1.22	2.15	3.97
Na_2O	3.15	4.07	3.87
K_2O	3.36	1.77	2.25
H_2O	3.19	3.02	0.87
TiO_2	0.75	0.65	0.47
P_2O_5	0.23	0.18	0.13
MnO	0.00	0.08	0.07

[1] Average of 9 samples.

[2] Average of 9 samples from the Cobalt-Gowganda region.

[3] Average Archean of N.W. Ontario (Shaw *et al.* 1967, in Young 1969).

The Gowganda Formation is overlain by arkoses and quartzites of the Lorrain Formation. In some places the Lorrain rests directly on the basement rocks; in others there are indications of an erosional interval in which only parts of the underlying Gowganda Formation were absent or removed, and in several places the contact between the Lorrain and Gowganda formations is a gradational one. Thus, the indications are that there was in Lorrain time a relatively low topographic relief, with the depressed areas gradually being filled.

The Lorrain Formation is the most abundant rock exposed in the Cobalt-Gowganda region. Most of the Formation is pinkish arkose which grades upwards into greenish white quartzites. Dips of 15° to 20° are common, but in general all the Proterozoic sediments can be considered as flat-lying. The thickness of the Lorrain is not known; throughout the Cobalt-Gowganda region the top part of the Formation has been eroded. The 1,045 foot (319m) vertical section intersected in the drilling in Henwood township (Thomson 1966) represents only the lower arkosic part of the Formation.

The sedimentology of the Lorrain has been studied in detail by Hadley (1968), who concluded that the basal arkosic part of the Formation was deposited in a shallow marine environment. The source rocks consisted predominantly of granites and granitic gneisses derived from an area to the north-northwest of Cobalt. The upper quartzite portion of the Formation may have had a similar source, but the abundance of common quartz is indicative of extensively re-worked granitic source rocks. Deposition seems to have occurred in an efficient beach environment.

Although major faulting has occurred in some areas, the approximately horizontal attitude of the Proterozoic sediments is an indication of the relatively stable tectonic environment which has since prevailed. The Huronian and older rocks were, however, intruded by sheets of diabase several hundred feet thick. Miller (1911) named these massive tholeiitic intrusions the "Nipissing diabase". The intrusions are of paramount importance in the region because silver deposits occur only in association with the diabase.

Earlier workers in the area, such as Burrows (1926) and Campbell (1930), assumed that the Nipissing diabase originated in the Cobalt area and spread as a single great sheet which extended westward to Gowganda and southward beyond Lake Timagami, thus covering an area of several thousand square miles. There is evidence at Cobalt of a local movement of diabase magma to the northwest, but it is interesting to speculate whether the historical exploitation of silver deposits in a progressively western direction unconsciously influenced thoughts on the westerly movement of diabase magma on a regional scale.

Neither sedimentary bedding nor the Proterozoic-Archean unconformity appears to have had a profound influence on the plane of intrusion. In many areas the diabase has gentle dips, but there are few places where either the unconformity or bedding was followed for any distance. Undulations in the sheets produced a series of basins and domes or arches. Subsequent erosion presumably removed the higher domes and arches, and preserved the lower parts as isolated basins. It is thus possible to hypothesize either that the Nipissing diabase exposures are remnants of a very extensive sheet intruded from a single source, or that the diabase spread into sheets from widely-distributed feeders. Moore (1956) specifically advocated the latter hypothesis, and proposed that the Nipissing diabase

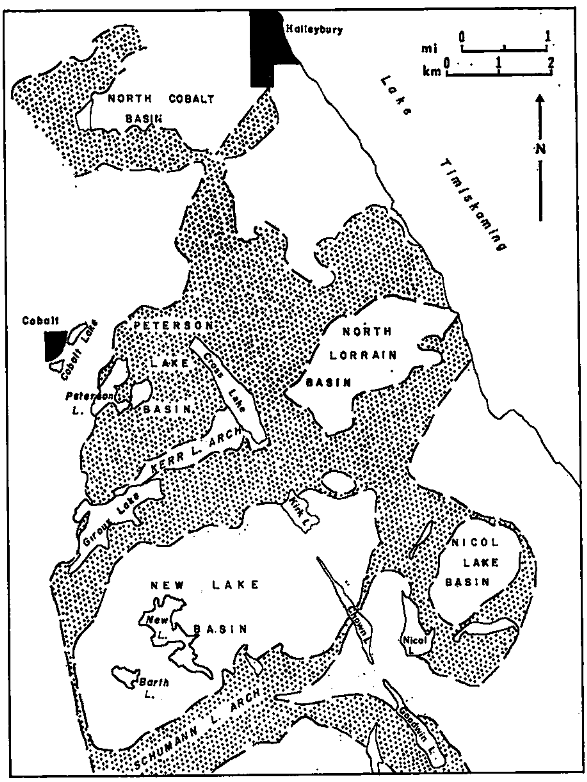

FIG. 8. Diabase basins in the Cobalt area (with diabase shown in stipple).

in the Miller Lake basin at Gowganda is the locus of the extensive diabase sheets in the adjacent area. From mapping the area between Gowganda and Elk Lake at ¼ mile intervals, MacKean concluded (1968, p. 13) that the Nipissing diabase "is not just a sill, but a complex intrusion intruded along feeder dikes into sill-like structures".

Large areas of diabase are exposed throughout the whole of the Cobalt-Gowganda region (Fig. 7). The configuration of the bottom contact of the diabase is a convenient criterion for defining the shapes of the intrusions. Several diabase basins have been named on this basis ; those near Cobalt are shown in Fig. 8.

The maximum thickness of the diabase sheets in the region is of the order of 1,100 feet (335m). Gentle dips predominate, but in some places the dips are very steep, and a few are vertical. In such places the thickness of the intrusion generally decreases and the diabase has the appearance of a large dyke rather than being sill-like. Although Lovell & Caine (1970) found indications of a possible feeder dyke under Cross Lake at Cobalt, dyke-like diabases in other places have been found to flatten at depth into sill-like sheets. In Henwood township two diabase sheets, each more than 200 meters thick, were intersected in a vertical drill hole. This is the only known occurrence of two sheets, one above the other, in the Timiskaming area.

The Nipissing diabase is most important from the economic point of view because the occurrence of silver ores appears to be generally restricted to the diabase and to country rocks of all types within about 700 feet of the diabase contacts. Several authors, such as Whitehead (1920), Whitman (1922), and Knight (1924) have suggested that the diabase sheets were folded after intrusion, but detailed mapping indicates that the dips of the diabase are primary. Paleomagnetic work by Symons (1970) is in agreement with the conclusion that not even gentle folding has occurred.

All the Nipissing diabase sheets are differentiated. Their petrological and chemical character is dealt with in detail in a subsequent paper and will not be repeated here.

Post-Nipissing igneous activity is restricted to the intrusion of a few quartz diabase and rare olivine diabase dykes.

Paleozoic

The Paleozoic rocks in the northeastern part of the region are part of an outlier unconformably overlying the Huronian. The rocks are shales, sandstones, and limestones of Ordovician and Silurian age. They are described in detail by Thomson (1965) and Sinclair (1965). Their maximum thickness near the north end of Lake Timiskaming is about 840 feet (256m).

Cenozoic

The Cobalt-Gowganda region was affected by Pleistocene glaciation. Many of the lower and flat-lying areas are covered by glacial deposits; less than 10 per cent of the surface area of the region consists of rock outcrops. Brief descriptions of the Pleistocene and Recent deposits are given in many geological reports, with those by Thomson (1965) and Boyle *et al.* (1969) being the most comprehensive. Boissonneau (1965, 1968) has described the glacial history and deposits of the region in some detail.

Faults

Miller (1906) and Todd (1926) drew attention to the arrangement of the drainage patterns into a northwest-southeast system, and a northeast-southwest system. These have been discussed most recently by Wilson

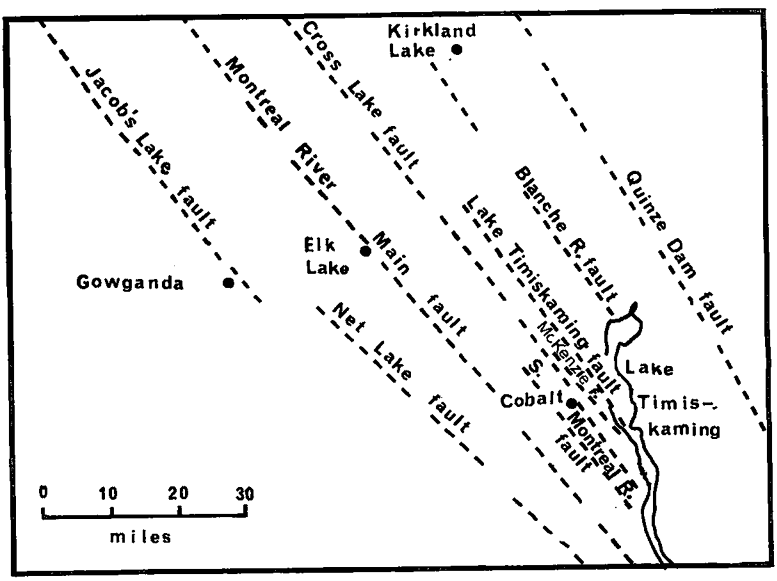

FIG. 9. Part of the Timiskaming rift valley system (after Lovell & Caine, 1970).

(1956). The marked linearity and parallelism of the northwestern pattern is especially prominent, and has been related by Lovell & Caine (1970) to a rift valley system (Fig. 9). Although the ages of the relevant faults are difficult to ascertain, substantial post-Silurian movement has been documented for the McKenzie and Lake Timiskaming faults near Cobalt. In both the northeast side has dropped, with the displacement along the Lake Timiskaming fault being as much as 1,000 feet (305m). Evidence of Precambrian movement is more difficult to obtain, but the occurrence of a post-Nipissing diabase dyke parallel to the Cross Lake fault at Cobalt is indicative of a line of weakness along the fault dating back to Precambrian times. The unusual thicknesses of Proterozoic sediments underlying the Lorrain Formation in Henwood township northwest of Lake Timiskaming may be an indication that subsidence occurred along and near the Cross and Lake Timiskaming faults early in the Proterozoic.

The much less prominently-developed northeastern set of faults is exemplified at Cobalt by the Cobalt Lake fault, and the nearby Valley, Trethewey, and related faults (Fig. 10). The silver-cobalt ore veins cut

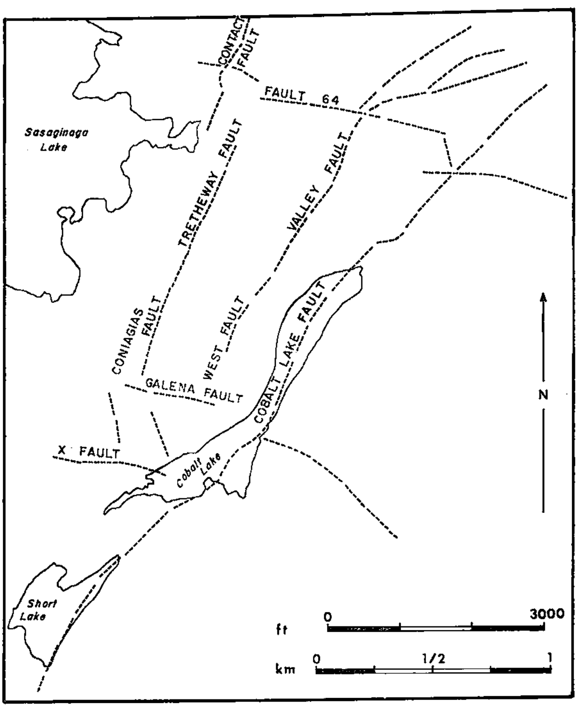

FIG. 10. Principal faults near Cobalt Lake.

the faults, and their Precambrian age is thus well-established. The Cobalt Lake fault has particular significance because, aside from being the largest northeasterly fault at Cobalt, Thomson (1967) has shown it as having offset the Nipissing diabase prior to the deposition of the silver ores. This aspect is discussed further in the section dealing with the age of silver deposition. It should be noted, however, that regional faults do not control the distribution of the silver veins and nearly all large faults are barren. There is a feeling among some of the mine geologists in the region that medium-sized faults or fault zones may have played a role in the development of the small fractures and fissures in which the veins occur. These faults or fault zones do not parallel the regional faults.

Mineralized Zones and Veins

Two distinct suites of minerals and ages of mineralization occur throughout the region. The older of these consists of base metal sulphides associated with the Archean volcanics and interflow sediments ; the younger consists of the silver-cobalt-nickel-arsenic assemblages that constitute the ore.

Pyrite, chalcopyrite, pyrrhotite, sphalerite, and galena are the principal sulphides occurring in the Archean rocks. Arsenopyrite, marcasite, tetrahedrite (and probably several other minerals) are present in small amounts in the flow rocks, but rich concentrations are largely confined to sediments, usually cherty and commonly carbonaceous, which occur as bands in the (Keewatin) volcanic sequence. Most of the bands are relatively narrow ; they are rarely as much as 50 feet (15m) thick, but many contain abundant sulphides and in some the sulphides constitute several per cent of the band and adjacent flows. These deposits apparently are of the stratiform type associated with Archean volcanism. The deposits were intruded by minor mafic-rich dykes, folded into their upright positions, and intruded by the salic plutons associated with the Kenoran orogeny. Movement of the sulphides has been both minor and confined with the bands ; their essentially stratiform character has not been altered.

Erosion of the Archean has dispersed the base metal sulphides into the lower portion of the Huronian sedimentary sequence, especially in basal strata adjacent to the Archean-Proterozoic unconformity. In some places the sulphides are of local derivation and have moved only a few feet from higher points toward depressions in the irregular Archean surface. Sulphides in the laminated sediments (Fig. 11) show a distinct monomineralic trend in that some groups of laminae in hand specimens contain only sphalerite, some only galena, and in others the yellow sulphides predominate. Large clasts and dropped pebbles commonly contain a heterogeneous sulphide assemblage which differs from the predominant sulphides in the enclosing laminae (Fig. 11). The amounts of sulphides in the Huronian sediments decrease upwards from the unconformity, and in most places only sparsely disseminated grains are found. The sulphides are clearly syngenetic, but the proportion deposited through chemical action rather than as discrete clastic grains is not known. Clastic accumulation in pebbles is evident, but chemical deposition can only be inferred because the finer sulphides have been recrystallized. However, the trend toward monomineral layering is not easily explained either by gravity winnowing or source rock variation, and it seems likely that significant chemical transport and deposition has been operative.

The degree of enrichment of the sulphide-rich basal Huronian described above is exceptional. This type of occurrence does, however, provide a simple and logical explanation for the occurrence of sparsely disseminated base metal sulphides in the Huronian.

The Archean and Huronian rocks were intruded by the Nipissing diabase sheets, and the silver ore veins were formed in small fractures, faults, and joints that cut the Archean, Huronian, and Nipissing. Although all may serve as host rocks for rich veins, production at Cobalt has been greatest where the host rocks are Huronian sediments. At Gowganda, production has been almost exclusively from the Nipissing diabase host.

Native silver is the chief ore mineral. It occurs with a complex assemblage of cobalt-nickel-iron arsenides and a variety of less abundant sulphides in a gangue consisting predominantly of dolomite and calcite. The ore veins are steeply-dipping to vertical and vary in width from a fraction of an inch to over a foot, with the average throughout the camp undoubtedly being considerably less than 2 inches (5cm). As Thomson (1957b, p. 378) has pointed out "What may be a good vein structure at Cobalt and worth considerable exploratory effort often seems to be of no consequence to one unfamiliar with the camp."

Some veins are over a thousand feet (305m) long, but in all veins the ore is localized in shoots. A length of 200 feet (60m) and a depth of 100 feet would usually be considered as a very good ore shoot. High grade shoots may contain thousands of ounces of silver per ton. Thus, the small size is partly compensated by the extreme richness; as Hellens (1962) has pointed out, a 4 inch wide shoot assaying 5,000 ounces per ton for a hundred foot length and a fifty foot depth would yield over a million ounces of silver. As might be anticipated, however, veins of this quality ore not often found. Commonly, two or more roughly parallel narrow veins

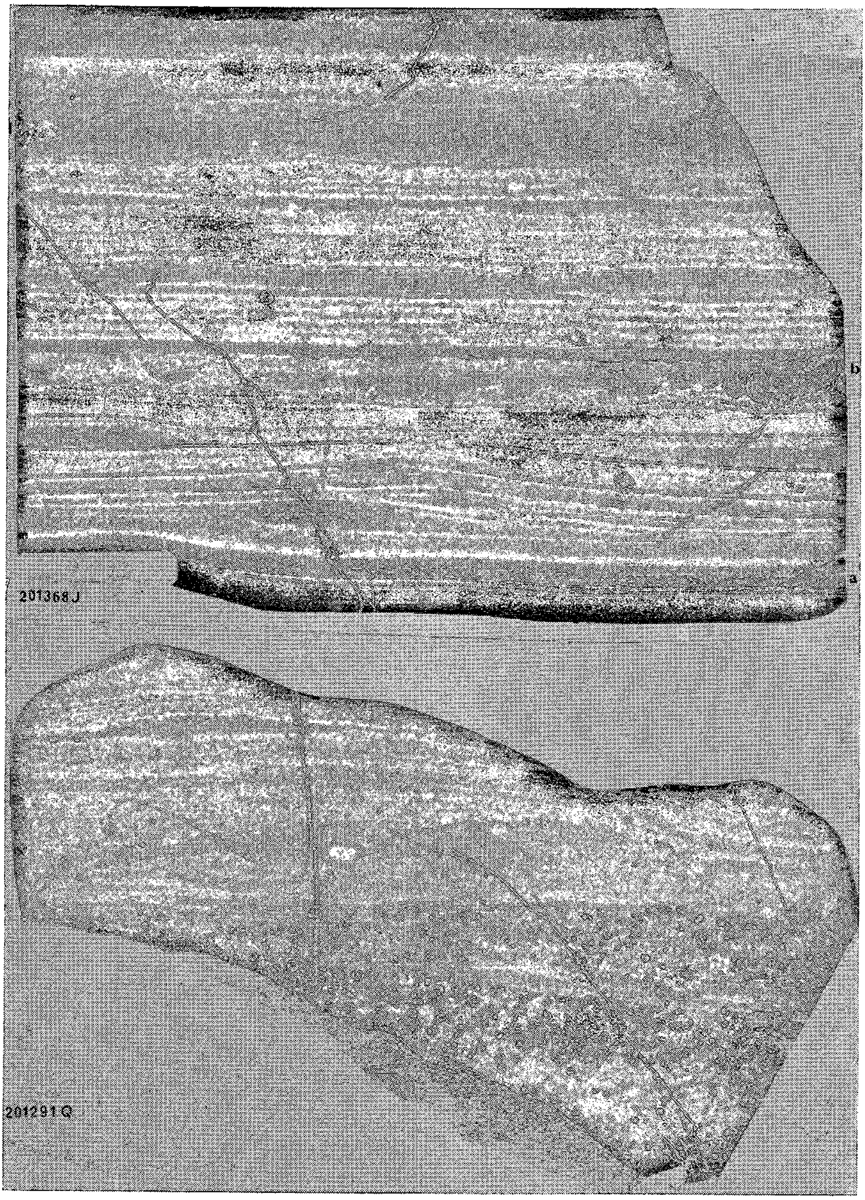

FIG. 11. Base metal sulphides in the Gowganda Formation sediments at the Archean-Proterozoic unconformity.

A. (Top) Sulphide-rich sediment from the 5th level of the Silverfields mine, Cobalt. Sphalerite is disseminated throughout the rock and is also concentrated in certain beds,

(Continued on next page)

make up an orebody, but both the veins and their contained oreshoots pinch and swell, the results being that a relatively low-grade mill rock is obtained. Nearly all veins are accompanied by subordinate fractures and joints in the adjacent wall rock, and these too may be coated with thin films of native silver. The Huronian sediments have been the most susceptible to this type of impregnation; a very few vein lodes accompanied by subsidiary fractures have yielded stope widths of 50 to 75 feet (15-23m), these being the largest attained in the camp.

Geochronology and Ore Deposition

Rock units and ore veins

The time and rock units applicable to the Cobalt-Gowganda region are given in Table 1. Potassium-argon and rubidium-strontium data for the Precambrian rocks are given in Table 3. The oldest ages, greater than 2,500 m.y., are from the "Algoman" salic intrusions. One new determination, on a pluton about 8 miles (13km) north of the Grenville Front in South Lorrain, gives an age of 2525 ± 72 m.y. This is similar to ages of 2,570 m.y. (Aldrich & Wetherill 1960), and 2,605 m.y. (Lowdon *et al.* 1963) obtained from the Round Lake Batholith between Cobalt and Kirkland Lake. Although not from within the region, one of the post-Algoman, northerly-striking "Matachewan" diabase dykes has been dated at 2,485 m.y. (Fahrig & Wanless 1963; Wanless *et al.* 1965). Age data on the remainder of the Archean in the region are sparse. Aldrich & Wetherill (1960) obtained a potassium-argon age of 1,990 m.y. and a rubidium-strontium age of 2,230 m.y. for a biotite-rich "Haileyburian" metamorphic rock from Coleman township. The assumption is made here that the sample is a biotite lamprophyre dyke, with the ages obtained being a result of isotopic adjustment to thermal metamorphism from the Nipissing diabase.

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the most visible being *a* and *b*. In these, the grey material is sphalerite, which shows particularly well in the load casts to the right. Cross-bedding in lenses in the bottom third of the specimen indicate current movement was from left to right. Black pebbles scattered throughout the specimen are commonly barren, but some consist largely of sulphides. The large pebble (1) at top left contains some galena and chalcopyrite as well as sphalerite; the lower central pebble below (2) is almost massive sphalerite.

B. Sulphide-rich sediment from the same locality as above showing several barren pebbles (black) and abundant sulphide-rich pebbles in the lower half of the specimen (grey to white). Sphalerite, galena, chalcopyrite, pyrrhotite, pyrite, and traces of tetrahedrite occur in the pebbles; the proportions of these minerals differ from pebble to pebble, with the amount of galena in each being approximately indicated by the variable whiteness. (Length of specimen 13 cm).

The boundary between the Archean and Proterozoic is marked by the Kenoran orogeny, which in the Superior province has a mean age of 2,490 m.y. (Stockwell 1964), and a range extending from 2,230 to 2,730 m.y. The Gowganda Formation has been dated at 2,288 ± 87 m.y. by Fairbairn *et al.* (1969). The Nipissing diabase was established by Lowdon *et al.* (1963) and Van Schmus (1965) as being approximately 2,150 m.y. old. A Rb-Sr isochron age of 2,162 ± 27 m.y. was obtained by Fairbairn *et al.* (1969) from 11 samples from a drill core through the sheet in the Miller Lake basin, Gowganda. This firmly establishes the oldest possible age of silver deposition, as the veins cut the Nipissing diabase.

TABLE 3. RADIOMETRIC AGES IN THE COBALT — GOWGANDA REGION.

Location	Rock Unit	Age (m.y.)	Method	Reference
Gowganda	Actinolite in post-ore fault	1400 ± 116	K-Ar	This paper
Gowganda	Post-Nipissing quartz diabase dyke	1465 ± 168	K-Ar	This paper
Gowganda	Nipissing diabase (isochron)	2162 ± 27	Rb-Sr	Fairbairn *et al.* (1969)
Cobalt	Nipissing diabase; biotite	2095	K-Ar	Lowdon *et al.* (1963)
Various	Nipissing diabase (isochron)	2155 ± 80	Rb-Sr	Van Schmus (1965)
Gowganda	Gowganda Formation, Miller Lake basin	2288 ± 87	Rb-Sr	Fairbairn *et al.* (1969)
Cobalt	Biotite-rich rock; post-Timiskaming, pre-Huronian "Haileyburian" formation	1900 2230	K-Ar Rb-Sr	Aldrich & Wetherill (1960)
S. Lorrain	McIlwaine (1968) quartz monzonite unit 3e	2525 ± 72	K-Ar	This paper
Savard tp. (north of region)	(Algoman) Round Lake Batholith	2570 2550	K-Ar Rb-Sr	Aldrich & Wetherill (1960)

The ore veins also apparently cut a 100-120 foot wide (30-37m) quartz diabase dyke on the Agaunico property on the shore of Lake Timiskaming at Cobalt. The dyke has been assumed to be younger than the Nipissing diabase, but nowhere have the two been seen in contact. It was stated by Thomson (1964, p. 100) that "One or two silver-cobalt bearing veins were in the Agaunico diabase dike but production from these where contained in the dike was negligible. These veins indicate however that all the silver-cobalt mineralization on the property was introduced after the intrusion of the dike." Detailed descriptions of the occurrences are not available; the most specific is as follows (Thomson 1964, p. 100) :

"The southwest extension of vein No. 1 on the 200 foot level into the Agaunico dike (here 120 feet wide) is the merest fracture, without gangue or metallic mineral; at this place the erroneous impression is given that the dike is younger than the vein."

Several quartz diabase dykes cut the Nipissing diabase in the Miller Lake basin at Gowganda. These are shown on maps by Moore (1956), and McIlwaine (1966, 1969). The dyke which passes close to the No. 6 shaft of the Siscoe mine was considered by Scott (1964) to be pre-ore. On the assumption that the dyke is of the Abitibi-type (and age) as described by Fahrig & Wanless (1963), the period of silver ore mineralization therefore occurred less than 1,230 m.y. ago (and over 900 m.y. after crystallization of the Nipissing diabase).

Scott (1964) observed that the early dark calcite veins do not transect the dyke and its apophyses as do the later quartz and white calcite veins. On the 525 level, he noted that the younger (quartz-calcite) veins constrict upon entering the dyke but pass completely through it. To the present writer, the above observations do not indicate that the dyke is pre-ore. The early dark calcite veins are typical ore-bearing veins; in detail the calcite is clear and transparent, with the dark colour resulting from myriads of finely disseminated arsenide inclusions. The later quartz-calcite veins are typically barren; their post-ore age as indicated by cross-cutting relationships is evident in many occurrences. Thus, the fact that centimeter-wide quartz-calcite veinlets cut the quartz diabase dyke is not considered by the present writer to be of critical significance.

In a presently inaccessible part of the 1,000 foot level, Scott (1964) had observed that diopside veins carrying cobaltite and pyrite occur in an apophysis 2 feet wide. Also in this vicinity, magnetite, believed by Scott to have been derived from the dykelet, was found in the veins. Scott's observation was verified by the present writer on the 850 level, where numerous apophyses of the dyke occur close to and in contact with the silver-cobalt ore veins. The ore veins do not fully enter the dyke (or vice versa); the cross-cutting is restricted to narrow veinlets which are usually less than a centimeter and generally no more than 1 or 2mm wide. Detailed studies indicate that the veinlets are material remobilized from the ore veins (Fig. 12). This conclusion is based on the following: (1) Well-developed wall rock alteration accompanies the main ore vein where it is in contact with Nipissing diabase, but such alteration is absent in the quartz diabase dyke. The plagioclase laths in the chilled edge of the dyke have been converted to albite, presumably by a diffusion process as the texture has not been changed; this is not typical of the normal wall rock alteration along ore veins. Clinopyroxene phenocrysts

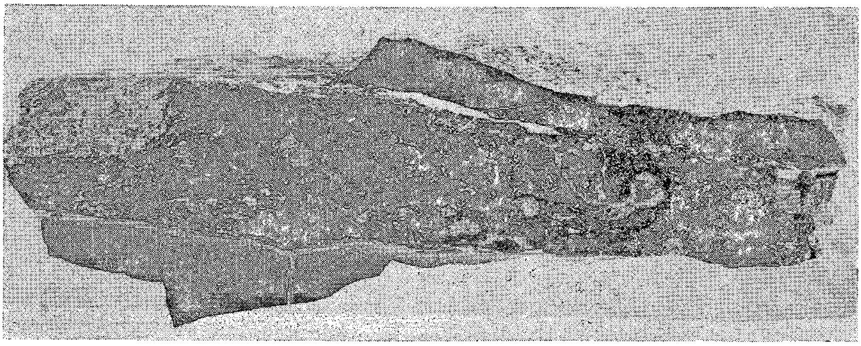

FIG. 12. Silver-cobalt vein from Siscoe 850 level, Gowganda. The wall rock at the top is Nipissing diabase and that at the bottom is the chilled edge of a post-ore quartz diabase dyke. The thin veinlet cutting the dyke consists mostly of actinolite and arsenopyrite. (Length of specimen 32 cm).

atypically persist to be chilled edge, and chloritization associated with normal wall rock alteration is absent. (2) There is no change in the appearance of the edge of the dyke, regardless of whether it abuts the ore vein or Nipissing diabase. It is reasonable to assume that this would not be the case if the dyke was pre-ore. (3) The dyke has thermally metamorphosed the gangue minerals in the ore vein : (a) the occurrence of clinopyroxene and amphibole in microscopic spherulites is a texture not seen in any other ore veins in the Cobalt-Gowganda region ; (b) diopside is not a gangue mineral in any vein in the region, but the diopside veins reported by Scott (1964) are a reasonable expectation from contact metamorphism. Their origin by a process analogous to skarn formation was also suggested by Scott.

A potassium-argon age of 1,465 ± 168 m.y. was obtained from the chilled edge of the diabase dyke from another locality on the 850 level. On the 1,000 foot level, a 2-5cm thick sample of actinolite, epidote, and pink axinite which forms a compact, slickenside gouge in the Glory Hole fault was also dated. The fault is a post-ore reverse one which strikes N25°W, dips 40°E, and has a known vertical displacement of about 35 feet (11m). The sample was selected for dating in order to obtain a minimum age for the silver-cobalt veins. The 1,400 ± 166 m.y. result overlaps the age of the quartz diabase dyke, suggesting that a roughly coincident period of post-ore faulting and dyke intrusion occurred.

The above data place the time of silver ore deposition as being between 1450 and 2162 m.y., the latter being the age of the Nipissing diabase. Lead isotope studies (Farquhar & Russell 1957 ; Kanasewich & Farquhar 1965 ; Kanasewich 1968) on ores from the Cobalt region indicate that a period of sulphide deposition occurred 2,300 ± 150 m.y. ago. Not all the analyzed leads are from vein-type deposits, though this is obviously the case where Nipissing diabase is cited as the host rock.

All the above data suggest that ore deposition occurred shortly after intrusion of the Nipissing diabase, with a subsialic source being indicated by the lead isotope ratios. Cooling of the diabase to a competency where jointing and fracturing could be sustained prior to ore deposition is an unquestionable fact. Whether the metals which filled the fractures and joints were derived from the Archean rocks, the diabase, or the deeper parent magma of the diabase is another matter; needless to say, each theory has been championed from time to time.

The Cobalt Lake fault

The Cobalt Lake, Trethewey, and related faults (Fig. 10) constitute a northeast-striking zone of reverse faulting in which there is a progressive decrease in dip and displacement towards the northwest. Many papers dealing with Cobalt have shown Knight's (1924) cross-section of this zone, which is reproduced here as Fig. 13. Silver-cobalt veins cut through the Valley and Trethewey faults, and abut the gouge in the Cobalt Lake fault; the pre-ore nature of the faults is thus clearly indicated. Thomson (1967) has further concluded that the Nipissing diabase sheet was offset by the Cobalt Lake fault prior to ore deposition. Thus he states (1967, p. 139): "Movement on the fault appears to be largely pre-ore as shown by the occurrence of silver-cobalt veins in the fault... To some extent this gives the time relationship of the silver-cobalt veins relative to the emplacement of the Nipissing diabase, inasmuch as the fault is younger than the diabase (which presumably was completely solidified at the time of faulting)."

That the ore veins were emplaced after solidification of the diabase is irrefutable. The main problem discussed here is therefore not concerned with the age of silver deposition, but relates to the age of movements along the Cobalt Lake fault. The vertical displacement by the fault is approximately 240 feet (73 m) at the northeastern end of Cobalt Lake, and approximately twice this at the southwestern end. How much of this movement occurred prior to the intrusion of the Nipissing diabase is not known. The displacements referred to above are based on offsets of the pre-Nipissing rocks, but the extent to which the diabase was faulted is based on an assumed configuration for the sheet. Without this assumption, the diabase could have been displaced less than 100 feet.

How much of the movement along the fault occurred after the deposition of the ore veins is not known. Knight (1924) saw little evidence

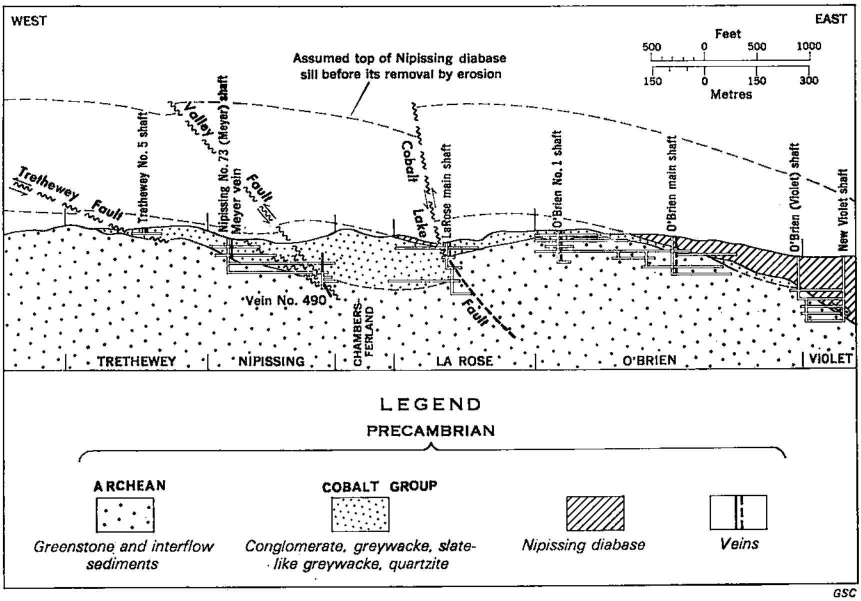

FIG. 13. The Trethewey, Valley, and Cobalt Lake faults at Cobalt. The configuration of the eroded part of the Nipissing diabase is conjectural.

that major post-ore movement had occurred, but the validity of this judgment is difficult to assess. The fault at both the north and south ends of Cobalt Lake consists of breakage zones rather than a single planar surface and it is possible that adjustment could have taken place along more than one plane. Moreover, the fault lacks any kind of vein material over much of its length and is barren of ore over nearly all its length. The character of the vein material, where it occurred in the fault, must have strongly influenced Knight's (1924) conclusion that no major post-ore movement had occurred. In places a calcite vein commonly up to 3 feet wide occurs in the fault. Whether much or most of this material is post-ore is not known, but this possibility appears to have been considered only by Miller (1913). Most of the vein is barren, but Knight mentions (1924, p. 77) that "One of the lenses is of extraordinary width, namely 4 feet at the widest place; this lens is about 65 feet long and consists mostly of calcite, but shows in places 9 inches of pure niccolite. The characteristic feature of the lens is that it is banded." To this writer, the banding is characteristic of two stages of deposition. Both Miller (1913) and Knight (1924) also pointed out that ore in the fault at the south end of Cobalt Lake was brecciated, and in one case was crushed to slickensided roundish balls.

The major displacement along the Cobalt Lake fault is thus not necessarily post-diabase and pre-ore.

Finally, the distribution of ore deposits with respect to the bottom contact of the Nipissing diabase throughout the Cobalt camp (page 80) may be construed as an indication that significant post-diabase movement did occur along the Cobalt Lake fault. Near the southern end of Cobalt Lake, the productive zone west of the fault is some 200 to 300 feet (60 to 90 m) lower than the productive zone on the eastern (hanging wall) side of the fault. This may have resulted from post-diabase reverse faulting which elevated the hanging wall; subsequent erosion cut deeply into the block and its contained veins, leaving only their roots near the fault.