THE HURONIAN ROCKS

OF

NORTHEASTERN ONTARIO

by

K.E. EADE

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INTRODUCTION

GENERAL STATEMENT:

Extending eastward from the Sault Ste. Marie area of Ontario, along the north shore of Lake Huron, thence northeastward through the Sudbury and Lake Wanapitei areas, to the Gowganda and Cobalt areas and on into the Province of Quebec, there is a belt of Algonkian rocks of Huronian age. They consist for the most part of clastic sediments, quartzites, arkoses, greywackes, conglomerates and possibly tillites, with minor amounts of limestone and volcanic extrusive rocks.

The rocks of this belt have been the subject of much study and many reports. Their accessibility, combined with their relatively undisturbed condition, compared to the early Precambrian sediments, and the interest in the mineral deposits they contain in the Cobalt and Gowganda areas, are inducements to investigation. In this thesis an attempt is made to correlate the available information about these rocks, and to compare them along their strike, and also to compare their stratigraphic development.

Particular attention has been paid to the lithologic types present in this series, and an attempt is made to secure a quantitative estimate of the relative amounts of each kind. Each formation of the Huronian present in this band is described in some detail. Variations from the normal character of a formation in the band are described whenever they occur. Naturally, since definite information is often scanty, a considerable element of personal judgment enters into such determinations, particularly in estimating quantities of rock.

It is hoped that such a quantitative study may lead to conclusions as to physiographic conditions and type of sedimentation characteristic of the time involved. It is also not unlikely that such a study may have a bearing upon larger problems such as the distribution of Precambrian orogenies.

The problems involved in such a study as this are apparent. The author is totally dependent for information on the published reports of others. These reports sometimes give a clear picture, while in other cases desirable and necessary details are vague and incomplete.

This study of a small section of Huronian rocks may serve as a starting point for research on other sections of Algonkian rocks in the Canadian Precambrian Shield.

METHOD OF PROCEDURE:

All available literature for the areas involved was read and summary notes were made for the more recent and more detailed reports. With these notes as a basis, and with constant reference to the original reports, the formations throughout the area were described. Intensive study of the published maps was necessary to gain an idea of the extent and distribution of the various formations.

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To the many authors, whose field work makes such a correlation possible, credit is given throughout the report.

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TABLE I

COLEMAN (1913)	LAWSON (1929)	BURROWS AND RICKABY (1934)	COLLINS (1937)	FAIRBAIRN (1941)
Lower Huronian	Huronian	Temiskaming (?)	Lower Huronian	Lower Huronian
	Not classified as Sudbury or Bruce:	Sudbury Series:	Bruce Series:	Sudbury-Bruce Series:
		Wanapitei (Mississagi)	Serpent	Serpent
Ramsey Lake	McKim	Ramsey Lake	Espanola	Espanola
	Ramsey Lake	McKim	Bruce	Bruce
		Copper Cliff	Mississagi	Mississagi
			Ramsey Lake	Ramsey Lake
		Greenstone-sediment complex (partly Keewatin)		McKim
				Copper Cliff
UNCONFORMITY	UNCONFORMITY		UNCONFORMITY	FAULT
Pre-Huronian	Mississagi		Pre-Huronian	Pre-Huronian
Sudbury Series:	Remainder not studied		Sudbury Series:	
Wanapitei (Mississagi)				
McKim			McKim	
Copper Cliff			Keewatin Series:	
Keewatin Series:			Copper Cliff	
Volcanic schists and sediments			Volcanic schists and sediments	Sediments and volcanic schists

THE SUDBURY SERIES

Coleman (1913) was the first to use the name "Sudbury Series" for a group of rocks extending southwestward from Sudbury, almost to Blind River. He regarded this series as much older than any of the Huronian formations, and placed it in the Archean era. The age relation of this series to the overlying Huronian, as well as what formations should be included with it, has caused controversy for a number of years. The table of formations given by various authors (table 1) shows the variety of interpretations of the geology in the Sudbury area. A discussion of these interpretations will reveal apparent misconceptions in some reports on this area.

The Wanapitei quartzite was placed by Coleman (1913) in the Sudbury Series, but it is now agreed that it is equivalent to the Mississagi quartzite mapped by Collins (1925) in adjacent areas to the west. The Mississagi is definitely part of the Huronian Series. More difficult to explain is the reason for Coleman's reversed order of the quartzite and the Ramsey Lake formation. Mapping definitely shows that the Ramsey Lake formation underlies the Wanapitei or Mississagi quartzite. It is true he interpreted breccia at the base of the quartzite as a true conglomerate, but this still does not explain the reversal of order for these formations.

Lawson (1929) likewise misinterpreted breccia as conglomerate, but was more consistent, and reversed the sequence to place the Wanapitei at the base overlain in turn by the Ramsey Lake and the McKim formations. The dip and tops determination of the beds of the formations prove this interpretation wrong.

The table of formations of Burrows and Rickaby (1934), Collins (1936), and Fairbairn (1941) are in agreement as to the relative ages of the McKim, Ramsey Lake and Mississagi (Wanapitei) formations. There is, however, disagreement as to the nature of the contact between them. On this point depends the existence of the Sudbury Series as separate from the Huronian.

Coleman (1914), originator of the term "Sudbury Series", postulated an unconformity between the Ramsey Lake and the Mississagi. Later investigation has shown no such unconformity exists, so this classification may be ruled out. Similarly, Lawson's unconformity between the same two formations, but with the McKim on top, is wrong.

Collins (1937), who made an intensive study of the Huronian, not only in the Sudbury area but also west of there, concluded the McKim belonged to the pre-Huronian. He based this conclusion on the following evidence: (1) The McKim exhibits somewhat more metamorphism than the Bruce, unexplainable on the basis of nearness to intrusives; (2) The McKim does not everywhere underlie the Ramsey Lake, being confined to a small area near Sudbury. This he apparently believed could be explained if the McKim is regarded as an older formation that suffered much erosion prior to deposition of the Ramsey Lake, and thus was preserved only in a small area; (3) The McKim, he believed, was conformable with the Copper Cliff rhyolite and the pre-Huronian schists; (4) Both conformable and unconformable relations between the McKim and Ramsey Lake were found by Collins. However, he thought the conformable relation was apparent rather than real, since he believed the Ramsey Lake was a regolithic formation. These features he felt overruled two others, indicating possible conformable relations. (1) Practically no pebbles of any rock occur in the Ramsey Lake that might be identified as derived from the McKim. If the McKim had been subject to a period of erosion, one would expect a conglomerate overlying it to contain derived pebbles. (2) The pre-Huronian granite gneiss, which cuts the Archean volcanic schists, does not intrude the McKim. This would indicate some break between the Archean schists and the McKim, although none was apparent to Collins. He states further in Memoir 143 that Eskola was of the opinion the Sudbury Series was conformable with and represented the lower part of the Huronian Series. In spite of this Collins placed an unconformity between the McKim and Ramsey Lake formations.

Burrows and Rickaby (1934) based their report on the Sudbury area alone. They found evidence of conformable relations between the Ramsey Lake and the McKim. They do not discuss any of Collins' evidence for an unconformity. A discrepancy is apparent in their classification of the Ramsey Lake and Mississagi as part of the Sudbury Series, although aware of the fact that Collins in the area to the west classified these formations as Bruce Series. They also knew Collins had mapped formations later than the Mississagi in townships close to the Sudbury area. It appears unreasonable, therefore, that they should place the Mississagi and Ramsey Lake formations with the McKim and Copper Cliff rhyolite as the Sudbury Series, classifying this series as Temiskaming (Late Archean) age.

The most recent works in the Sudbury area are those of Fairbairn (1941) and Cooke (1941), who agree on the contact relations of the McKim and the Ramsey Lake. The result of these discoveries will now be considered.

Cooke has shown that the Copper Cliff rhyolite is in faulted contact with the early Archean greenstones and volcanic schists. Where the rhyolite is not present the McKim is in faulted contact with the older underlying rock. Collins' contention that the McKim is transitional with the older Archean sedimentary and volcanic rocks is not confirmed in the Sudbury area.

The degree of metamorphism of the McKim formation, compared to younger formations as used by Collins (Memoir 143), is a hazardous criterion to use as chemical and mineralogical composition play such an important role in this regard. In addition, Fairbairn states that in the vicinity of Sudbury he found no evidence of more metamorphism in the McKim, except where due to intrusion of the much younger gabbro.

Collins (1937) interpreted the limited extent of the McKim as due to erosion. On the other hand, Fairbairn believed that the McKim was deposited only in a limited area, and that it is conformable with the later formations that were laid down over a wider area.

In the Sudbury region Fairbairn made an exhaustive study of the contact of the McKim and Ramsey Lake formations. He found no evidence at the contact which indicated anything different from other contacts for which non-regolithic origin was suggested. Further, he found alternations of the grit beds of the Ramsey Lake with the greywacke beds of the McKim, which suggests continuous and conformable deposition. Cooke also came to the same conclusion. This evidence then seems to invalidate Collins' reasons for placing an unconformity between the McKim and Ramsey Lake formations.

Cooke suggests that the term "Sudbury Series" has lost all meaning, and should be discarded entirely. Fairbairn, on the other hand, suggests that the name "Sudbury-Bruce Series" be applied to the series as it now stands.

THE COPPER CLIFF RHYOLITE:

The Copper Cliff rhyolite outcrops in the vicinity of Sudbury as a band striking approximately northeast, some 23 miles long and three-quarters of a mile wide as a maximum. This formation is the only volcanic extrusive that is definitely a part of the Huronian. The band of outcrop is not continuous, as it is cut by later igneous rocks, and also fails to outcrop in some places. It is the oldest Huronian rock in the Sudbury area.

Coleman (1913) regarded this rock as a recrystallized arkose when he mapped it. The slight banding of the rock suggested bedding to him. Burrows and Rickaby (1934), however, seem to have shown that most of the formation consists of rhyolite flow. Flow structures, spherulitic structures, and a few interbedded greenstone flows with pillows are definite evidence of the extrusive origin. The part of the formation that appears bedded is considered to be a rhyolite tuff.

The rock is light in colour, from white and grey to pink and red, with prominent bleached feldspars on the surface. It shows a lack of features suggesting sedimentary origin, usually has a rhyolitic or felsitic appearance. The tuff portion is made up of light greyish fragments of rhyolitic material up to 1 inch in length imbedded in finer material. Microscopic examination of the rhyolite reveals little, according to Burrows and Rickaby. It consists of interlocking grains of microcline, orthoclase, plagioclase, and quartz, with scattered biotite or hornblende and occasional large feldspar grains that might be phenocrysts. In spite of the definite evidence that most, if not all, of the Copper Cliff formation is rhyolite, Burrows and Rickaby suggested the continuance of the arkose term established by Coleman.

Coleman estimated the thickness of the formation at 2000 feet. Lack of distinctive horizons markers makes detection of folds or faults difficult, so this estimate may not be reliable.

THE McKIM FORMATION:

The McKim formation, subject of much controversy on the question of age relations, has a moderately wide areal distribution. It outcrops as a long narrow band trending northeast, extending from a point slightly east of Blind River on the north shore of Lake Huron, northeastward some 105 miles to the vicinity of Sudbury. The band has a maximum width of 2 miles at one point. On the north shore of Lake Huron the formation has been intruded by the Cutler granite. It also lies on the southwest side of the great Murray fault, so that it is bounded on the north by this fault, and on the south by Lake Huron and the Cutler granite.

Collins in Memoir 143 originally classified the section of this formation north of Lake Huron as pre-Huronian. However, the investigations of Fairbairn and Cooke, as outlined previously, seem to indicate the formation belongs to the Huronian, and that it is a continuation of the McKim formation at Sudbury. Originally the name "McKim" was applied to the formation only locally at Sudbury, but it is logical to extend this name to include the same formation elsewhere.

Generally speaking, the formation consists of a monotonous succession of greywacke with quartzite interbedded occasionally. The formation has suffered varying degrees of metamorphism. Typical occurrences in various areas will now be described.

In the southern part of Janes Township, some 26 miles east of Sudbury, Bruce (1932) mapped quartz-biotite schists as of Sudbury age, and it is possible that these may represent highly metamorphosed sediments equivalent to the McKim formation. They are now schists and gneisses, with most of the original sedimentary character destroyed. The proximity of the Killarnean granite possibly accounts for the metamorphism. Precise correlation of these rocks is impossible, but there is a suggestion they are equivalent in age to the McKim formation.

Occurrences of the McKim formation in the vicinity of Sudbury are fully described by Coleman (1913). On weathered surfaces beautiful sedimentary structures are exhibited, fine stratification, with small scale cross-bedding and ripple marks. Bands from one-half inch to two or three inches wide are made up of fine and coarse layers. The fine-grained parts are slatey, and often contain pseudomorphs after staurolite that may either be small like rice grains or five to six inches long and an inch across. The pseudomorphs now consist of fine-grained quartz and sericite. The petrographic character of the rock is vague, and composition varies a good deal, but it always has some gritty particles of quartz and feldspar in a grey ground-mass of fine material. Thin sections show the groundmass contains considerable chlorite and sericite, as well as obscure opaque material. Coleman (1905) estimated the thickness of the formation at 7000 feet, but again some doubt as to the accuracy arises because the lack of marker horizons precludes the detection of faults and folds. He also considered the rock as continuous in areas where only scattered outcrops occur.

Burrows and Rickaby (1934) in describing the formation around Sudbury stated that the beds are much disturbed and folded. The contact with the underlying rhyolite is quite steep. The beds of the McKim formation dip to the southeast and the beds also face this direction, indicating no overturning of the beds. They state that thin sections of these rocks show that recrystallization has occurred.

Fairbairn (1941) added to Coleman's original description the additional information that the lower beds are much thicker and more quartzose.

West and south of Sudbury the McKim Formation was described by Collins (1925) in the Lake Panache map area, and by Quirke (1917) in the Espanola map area. Both of these authors originally considered the formation to be pre-Huronian in age.

Collins (1925) stated that in the Lake Panache area the formation is represented by quartzites, argillites or greywackes, and intermediate rock types. The strata dip at steep angles, and the strike is not constant due to many small folds. In Hallam township a width across the strike of two miles is measurable, but in this distance there is no bed distinctive enough to serve as a horizon marker, and consequently it is not possible to say that repetition by folds has not occurred. Greywacke types predominate, showing continuous widths in places of hundreds of feet. The quartzite beds, six inches to ten feet in thickness, alternate with the darker beds. Only in a few places do thicker quartzite beds occur. All beds have been metamorphosed, though in variable degrees.

The quartzite beds, which are the least changed, range in colour from white to grey, depending on the amount of argillaceous material present. Under the microscope it is revealed that the clastic structure has been destroyed, and that the rock now consists of a mosaic of angular quartz grains with shreds of white mica. In some localities, for example in Baldwin Township, the quartzite has undergone extreme deformation, and the beds are highly contorted. Impure layers in the quartzite are here recrystallized to form hornblende schists. A more argillaceous variety of quartzite near Espanola Station shows good, vertical, slaty cleavage, at an angle of 60° to the bedding. It contains abundant flat crystals of mica in a finely crystalline groundmass. The groundmass consists of quartz grains and shreds of secondary mica. A highly metamorphosed variety of greywacke from Hallem Township appears now as a dark green schist that cleaves readily to reveal silvery micaceous surfaces, but has a gnarled appearance due to the formation of staurolite crystals up to two inches in length. The groundmass of this type has reached a more advanced stage of metamorphism than the preceding rock described, and here the quartz grains and mica shreds are coarse grained.

Quirke (1917), in describing the formation in the Espanola area, split it into four main types: micaceous slate or phyllite, micaceous schist or greywacke schist, staurolite schist and quartzitic schist.

The micaceous slate or phyllite is an even-grained siliceous rock, probably deposited as a mud. It fractures readily along schistosity planes, showing gleaming micaceous surfaces. Banding is evident, with bands about one-half inch wide. It is much crumpled and faulted where observed.

The micaceous schist or greywacke schist appears to be very similar to the above rock, but slightly more quartzitic. It has been intensely metamorphosed with the result that much sericite has developed. In some places phenocrysts of mica have developed.

The staurolitic schist seems to be a highly metamorphosed variety of the greywacke schist. Quirke believes the rock conforms closely to the description of staurolite schist given by Coleman for the Sudbury area. Under the microscope the rock is seen to consist of quartz grains, with secondary mica and amphibole developed around the grains.

The quartzitic schist is greenish gray in colour, and seems quite different from the other three types of rock. It is evidently quartzitic, but contains a great deal of secondary mica. It is highly schistose and breaks down easily into fragments. Microscopic work reveals that the quartz grains have crenulated margins and marked strained extinction, evidences of considerable metamorphism.

These descriptions of rock types by Quirke illustrate the variety of rock types present in the McKim of the Espanola area. The variety in composition of the original rocks, as well as the varying types and degree of metamorphism, are factors responsible for the divergent types of rocks.

Just east of the Espanola area, in the Blind River area, Collins (1925, p.24) stated that the sedimentary rocks are perceptibly more crystalline. Here the McKim formation consists of mica schists, fine to medium-grained rocks composed mainly of quartz, with some feldspar and biotite. There is apparently a gradual transition from the greywacke of the Espanola area to the mica schists of the Blind River area.

Near Smith Lake, Shedden Township, Collins described an interesting section of the formation. The mica schist becomes less crystalline, and grades into a greywacke. This, in turn, grades into a boulder conglomerate containing angular to rounded inclusions of granite gneiss and a few of greenstone. They have been somewhat flattened by pressure. The conglomerate is succeeded by 15 feet of quartzite and 100 feet of slatey greywacke. This is in faulted contact with the down-faulted Cobalt series on the north side of the Murray fault. This occurrence is of interest as it is the first variation in the McKim formation from the usual greywackes and quartzites.

Still farther west the rocks become more gneissic and highly crystalline. The original sedimentary character is almost destroyed, and the only indication of relation to the McKim is the fact that the rock is almost continuous. The Cutler granite bounds the formation on the south, and the Murray fault on the north, and it is thus confined to a narrow band from one-quarter to one-half mile wide.

Farther west the effect of the Cutler granite is less, and the sedimentary character of the rock is more apparent, with interbedded greywackes and quartzites, similar to those of the Espanola area, the common rock type. There is a gradual change though in the lithologic character near the western extremity of the band. Greywacke and greywacke conglomerate, much like that of the Gowganda formation occur in Striker Township. Beyond this point the band passes under drift and cannot be traced.

Collins questioned whether the rock throughout the length of this band - from near Blind River to the Sudbury area - may be regarded as all part of the same formation. The section west of the Cutler granite is particularly difficult to correlate, resembling as it does both the McKim formation and a part of the Cobalt series. Since the rock types appear to gradually grade from one to another, Collins favoured the hypothesis that they are a part of the pre-Mississagi formation.

The only estimate of thickness for the McKim formation is that of 7000 feet given by Coleman. As stated previously, any estimate of thickness for this formation is fraught with possible error. Fairbairn (1941) stated that in the Sudbury area the formation is at least of the magnitude of 7000 feet.

Summary of the McKim Formation:

The McKim formation consists, primarily, of greywacke with some interbedded quartzite layers. The amount of quartzite increases west of the Sudbury area in the Espanola district, but at the western extremity of the band the quartzite is nearly absent,and is replaced by greywacke conglomerate. The formation has undergone metamorphism, dynamic, thermal and, probably, metasomatic, which has produced much change in the original rock types. This metamorphism is strongest in the middle area of the band. It makes definite correlations throughout the length of the band impossible, but the continuity, coupled with the gradual changes of the rock, indicate that the rock is continuous.

The western part of the band lies on the upthrow side of the Murray fault, and has apparently been uncovered by erosion of the overlying series.

The original basin of deposition seems to have been a northeast trending narrow trough. The indicated thickness, some 7000 feet of sediments, suggested that it existed for some time. The material deposited could not have travelled far, as feldspar, and mafic minerals are present in nearly all parts in some quantity, although in most localities almost completely altered now to chlorite.

THE SOO SERIES

In the Sault Ste. Marie area, McConnell (1926) described a series of rocks, which he called the Soo, believed by him to form a basal Huronian series below the Bruce Series. It had not definitely been recognized east of the Sault Ste. Marie area he stated. It is bordered on the west by pre-Huronian granite and on the east by post-Huronian granite. The series is made up of three formations, in descending order, the Aweres formation, the Duncan greenstone, and the Driving Creek formation.

THE DRIVING CREEK FORMATION:

This formation has a very limited distribution, and consists of a few disconnected outcrops. Its fragmentary nature is due to its being overlain by the Duncan greenstone on the west and by the intrusion of post-Huronian granite on the east. It consists of medium-grained light greyish to whitish quartzite, passing downward into conglomerate. No argillite bands are interbedded with the quartzite. The quartzite consists of angular quartz and feldspar grains, with some sericite and less chlorite. The rock is comparatively fresh. The presence of more sericite than chlorite distinguishes it from the quartzites of the Bruce Series. The conglomerate, which has some coarse greywacke interbedded with it, contains pebbles and boulders up to 2 feet in diameter of grey granite, quartzite, quartz and greenstone, distributed irregularly through the coarse greywacke matrix. The well-rounded character of the boulders and pebbles, and the absence of red granite pebbles are distinguishing features.

The matrix consists of coarse angular quartz and feldspar grains, with sericite the chief alteration. McConnell estimates the quartzite to be 2000 feet thick and the conglomerate to be 400 feet thick.

THE DUNCAN GREENSTONE:

This formation is a hard, massive, fine-grained dark green to black, volcanic rock. It has undergone little alteration. There are some vesicules and amygdules filled with white quartz. Preservation of these original structures distinguishes it from the basement complex lavas of Keewatin age. At the contact with the underlying quartzites, there is some evidence of faulting. The overlying conglomerate and associated beds rest on a roughened surface of the greenstone.

THE AWERES FORMATION:

This formation consists of conglomerate and quartzites, chiefly with some greywacke and arkose free of pebbles. Some of the conglomerate has suffered much shearing. The quartzite is always more or less feldspathic. It is made up of very angular quartz and feldspar grains in a groundmass of the same minerals, with some chlorite and a little sericite. McConnell (1926) stated that this formation is probably a remnant not destroyed by erosion.

DISCUSSION OF THE SOO SERIES:

There is no reference to this series other than in the report of McConnell (1926). Some doubt arises as to whether it is proper to classify it as a separate series or whether it is of Huronian age. It has not definitely been recognized in any region to the east and, because of its isolated position, it may not be possible to correlate it with other rocks. McConnell stated that field evidence, while nowhere absolutely conclusive, indicated that the Soo Series is older than the Bruce Series, and, probably, underlies it unconformably. The general strike of the Soo Series, north to northwest, is nearly transverse to the east strike of the Cobalt and Bruce Series. This is not readily explainable, except by earlier folding of the Soo Series before deposition of the Bruce. The dips of the Soo Series seem everywhere to be steeper than those of the Bruce Series.

Beds of the Driving Creek formation are nowhere exposed in contact with the Bruce Series,and only at one point with the Duncan greenstone.

The Aweres formation adjoins the Mississagi formation near its southern termination on the northern boundary of the Garden River Indian Reserve. To quote McConnell: "At this point, two wedge-shaped areas of Mississagi quartzite, one, half a mile, the other 100 yards in length, project into the conglomerate of the Aweres formation. The exact contact was nowhere seen, but they are exposed within a few feet of each other. The strikes are similar, but the dips are divergent. The conglomerate is nearly vertical, while the latter wedge has dips of 40^{o} to 60^{o} north, and the former wedge 80^{o} north. There are no boulders or pebbles of quartzite in the conglomerate". He stated that there is possibly a fault between the two formations, but that any evidences are obscured.

The structural evidence in the area certainly does not warrant calling the Soo Series a part of the Huronian. In fact, if anything, it indicates that the Soo Series belongs to some earlier period, and that it suffered deformation before the deposition of the Bruce. The lack of definite contacts between the Soo and Bruce Series is a great handicap in determining their relationship.

The relatively unaltered state of the Soo Series rocks is certainly suggestive of the Algonkian rather than Archean rocks.

It has been suggested by Emmons (1926) that the Soo Series is a correlative of the Basal Mississagi formation in the Bruce Mines area. This idea is based on lithologic similarities alone, and there is no possibility of connecting the two areally due to intervening granite intrusions and faulting.

It must be with reserve, then, that the Soo Series be accepted as the lowermost Huronian series. If it is true, a basin of deposition must have been present here much earlier than elsewhere in the belt of Huronian rocks. This series would certainly represent a longer period of deposition than that of the Basal Mississagi in the northern Bruce Mines area or of the McKim at Sudbury.

THE BRUCE SERIES

THE RAMSEY LAKE FORMATION - BASAL MISSISSAGI:

Ramsey Lake formation is a name used by certain authors for rocks in the vicinity of Sudbury that are classed as Basal Mississagi elsewhere. The Basal Mississagi is particularly well developed around Sudbury, so Coleman (1913) felt that it deserved to be classed as a separate formation. The formation is particularly well exposed on the north shore of Ramsey Lake, near Sudbury, hence the name.

The thickness of the Basal Mississagi is extremely irregular, varying from a few feet in some places to over a thousand feet in certain localities. The beds are not at all continuous, although in lithologic character they are similar from area to area.

In the Bruce Mines map area, near Thessalon, Collins (1925) described a conglomerate at the base of the Mississagi formation. The underlying rock is granite gneiss, and a gradation from solid granite gneiss to conglomerate takes place over a thickness of from 3 to 4 feet. The conglomerate consists of large and small boulders of the granite gneiss in an arkosic matrix. The thickness of the conglomerate here is from 10 to 15 feet at the maximum. The conglomerate here is clearly derived from the underlying formation.

A remarkable development of the Basal Mississagi was described by Emmons, and quoted by Collins (1925) in the northern part of the Bruce Mines map area. The formation outcrops in central Morin Township, and west and northwest from there across

McMahon, Chesley additions and part of Kehoe and Chesley Townships. This forms a band trending east - west, some 18 miles long and one-and one-half miles wide. In northern Kehoe and Chesley additional townships it attains the greatest thickness, where it is 4700 feet thick. Southeastward it changes in character and thickness, until in Otter Township it is almost absent. In this Township there may be from 2 to 12 feet of boulder conglomerate, or the typical feldspathic quartzite of the Mississagi may rest on the underlying formation, with no basal phase.

The conglomerate is essentially flat-lying in this part of the basal Mississagi, and, from the differences in elevation of the contact of the formation with the underlying granite, it can be assumed that it was deposited on a surface of considerable relief. Steep inclination of the contact in some localities also suggests this.

Emmons divided the formation into five phases, although all are not present throughout.

(1) At the base is a coarse boulder conglomerate, with boulders chiefly of granite, more than 8 inches in diameter. It is seldom more than 20 feet thick, and in some localities is almost absent. It is similar to the conglomerate found at the base of the Mississagi elsewhere except that the matrix is less quartzitic and more greywacke-like, although the matrix is quite variable in composition locally. The matrix is composed of angular grains of quartz and feldspar, with considerable ferromagnesian minerals almost completely chloritized. The amount of chlorite decreases as the distance from the contact increases. The contact with the underlying rock is usually sharply defined, although

in a few localities a gradational contact exists.

(2) The basal boulder conglomerate passes by gradation above into arkosic quartzite conglomerate. Rapid and marked changes in the lithological character of the conglomerate, both along the strike and across it appears to be characteristic. The commonest variation is in the number of pebbles and their size. The matrix also changes in grain size and composition, being in various places an argillite, an arkose, a greywacke, or a quartzite. Small rounded granite pebbles are the common type of pebble. The commonest type of matrix is one composed of angular grains of quartz, feldspar and some hornblende, in a fine groundmass of the same minerals, along with much chlorite. The maximum thickness at any place of this phase is 620 feet.

(3) This is a transition zone from the pebble conglomerate below to the argillite above, and consists of interbedded quartzite, quartzite conglomerate and argillitic material. The amount of argillaceous material in the quartzite increases, and the number of pebbles decreases till the argillite phase alone is reached. This phase does not occur widely. The transition occurs over some 200 feet usually.

(4) This is the argillite member, which is developed best in Kehoe Township. Typically it is finely banded, and, in places, is quite slatey. Some banding, however, is quite coarse. Beds range from inches to tens of feet in thickness, with bedding brought out by textural or mineral composition differences. Thin sections show the argillite is extremely fine-grained, composed mainly of quartz, chlorite, mica, and some limonitic material. In places, beds of arkose occur within the argillite, with indefinite boundaries. The thickest section measured was 2600 feet,

but to the east of Kehoe Township the phase appears to be entirely absent. To the west much of it is conglomerate or quartzite.

(5) This represents the transition zone from the argillite member to the true Mississagi quartzite, and is usually some 275 feet thick. The transition occurs by an increasing number of quartzite beds, being intercalated with the argillite beds.

This section of Basal Mississagi rocks is quite remarkable, not only for its thickness, but also for the variety of rock types present. The rapid changes, both along and across the strike, are suggestive of deposition in numerous intermontane basins.

East of the Bruce Mines area, in the Wakomata Lake area, Emmons (1926) described further formations of Basal Mississagi, but with a decidedly different character. Emmons felt though that in spite of different characteristics there is some indication of continuity with the unique development in the northern Bruce Mines area. The Basal Mississagi consists of two main divisions, a white feldspathic quartzite overlain by a banded argillite. From the central part of Township 169 eastward, the quartzite increases from a thin formation with a conglomerate at its base to a thick extensive formation. The argillite overlying it is thickest in the central part of Township 169, and gradually thins to the east. The coarse-grained quartzite contains many conglomerate beds, with quartz and jasper pebbles. Eastward, there are many conglomerate bands near the base, with argillite matrices and granite pebbles. The matrix may either be massive or well banded. The argillite overlying the lower quartzite appears to be fairly continuous as far east as Township 157, where it grades into an impure type of quartzite. In one place in Township 157 it is 600 feet thick, and may even be at least 1000 feet thick east of here. Emmons stated that the beds are highly coloured, though no colours are given. They range from 1 inch to 1 foot in thickness, with laminations within the beds. The argillite passes by gradation into quartzite, above and below.

Although Emmons correlated the lower quartzite and argillite with the Basal Mississagi, some doubt arises as to the correctness of this. The normal Mississagi often contains argillite members, although perhaps none quite so thick as this argillite band. He stated that the lower quartzite resembles the quartzite of the Basal Mississagi in the northern Bruce Mines area. However, neither quartzite differs much from the normal Mississagi quartzite. There are no great conglomerate beds like those found in the Basal Mississagi to the west. Although this description is included with that of the Basal Mississagi, it should be noted that probably it is a part of the normal Mississagi, and only the lowermost conglomerate is true Basal Mississagi.

To the south in the Blind River map area the Basal Mississagi is negligible in quantity in most places. In Long Township, the Mississagi, (Collins, 1925), is in contact with granite gneiss. The gradation from fresh granite gneiss, through decayed granite gneiss and conglomeratic arkose to the typical feldspathic quartzite of the Mississagi formation proper, is complete in about 4 feet. In one locality in Striker Township there is a perfectly definite line between undecomposed granite gneiss and feldspathic quartzite, showing that any former soil must have been removed from here before deposition of the Mississagi. In Townships 150 and 154, on the north shore of Quirke Lake, the Mississagi again rests on granite gneiss. Here the gradation zone is from 10 to 50 feet thick, with a considerable amount of conglomerate containing boulders 8 to 10 inches in diameter, according to Collins. On the north shore of Tenmile Lake in Township 156, Collins described the transition zone from early pre-Cambrian schists to the Mississagi quartzite. The change is complete in from 3 to 4 feet. The transition zone comprises dark grey greywacke-like rock containing grains and pebbles of quartz.

From the mouth of Spanish River on the north shore of Lake Huron, to the vicinity of Sudbury, Collins' maps (155A, 1933, and Lake Panache, 1925) show the Basal Mississagi to be quite continuous. He states that in all this distance the basal member of the Mississagi is a conglomerate that grades upward into the feldspathic quartzite of the Mississagi proper. The matrix is invariably coarse grit or impure quartzite, somewhat lighter in colour than the matrices of the Bruce or Gowganda conglomerates. The matrix consists mostly of quartz and partly decayed feldspar grains, with some decomposition products. The boulder content is variable, in some localities only a few small pebbles are present, in others, boulders up to 5 feet in diameter constitute one-third of the total rock volume. They are fairly well rounded and represent a wide variety of rocks. Granite or granite gneiss are commonest, but several types of greenstone (basic igneous rock), green schists, and quartz pebbles occur also. Collins stated that no exact thickness measurements were made, although in several places it is several hundred feet thick.

Throughout this distance the formation lies between the quartzite of the Mississagi on the south and the greywacke and quartzite of the McKim on the north. Collins stated the contact with the underlying rock is indefinite and gradational, and that the two formations appear to be conformable. He suggested a regolithic contact here, and that actually they are unconformable. This appears unlikely now, as explained in the section on the age-relation of the Sudbury Series.

In the vicinity of Sudbury, where the Basal Mississagi is known as the Ramsey Lake formation, detailed descriptions of the formations are available, as in the reports of Coleman (1913) and of Burrows and Rickaby (1934). However, the recent study by Fairbairn (1941) of the Sudbury area is the most thorough, therefore much of the description is from that report.

Fairbairn stated that rather than being a conglomerate, the formation consists of three phases. These are, in order of decreasing abundance, grit, conglomerate, and quartzite. The grit is usually coarse-grained, massive, and a greyish colour. A distinguishing feature is the occurrence of numerous white quartz grains, slightly larger than average grain size, that stand out in relief on weathered surfaces. These white quartz grains, one-eighth of an inch or more in diameter, distinguish the formation from the Bruce conglomerate. Pebbles and boulders, chiefly of granite are scattered throughout the grit, but seem to be commonest toward the top of the formation. Lenses of massive grey-white quartzite are interbanded with the grit.

Fairbairn believed that some earlier reports included the Bruce conglomerate and breccia formed from the Mississagi as part of the Ramsey Lake formation in Dryden and Falconbridge Townships. The abundant white quartz eyes of the Ramsey Lake conglomerate, as well as its greyer colour on weathered surfaces, distinguish it from the Bruce. Also, the relatively few pebbles in the Ramsey Lake conglomerate, except near the top, differentiate it from the Bruce. To distinguish breccia formed from the Ramsey Lake from that in the Mississagi, the rounded and angular fragments in the breccia are mostly Mississagi quartzite. The Ramsey Lake grit does not contain pebbles or fragments of the Mississagi quartzite and any quartzite fragments in it are due to brecciation of quartzite lenses deposited within the grit. Also, the breccia matrix is finer grained than the Ramsey Lake grit, is more micaceous, and may show lineation due to its origin.

Collins (1937, p.1437) estimated a maximum thickness of 250 feet for the formation. Fairbairn stated that around Sudbury at least, a thickness of 450 feet is more likely.

East of Sudbury, in the Ashagami Lake area, Fairbairn (1939) described two occurrences of possible Basal Mississagi (Ramsey Lake) formation. In one place in Street Township Fairbairn described it as a conglomeratic grit. White quartz grains stand out conspicuously on the weathered surface, as with the Ramsey Lake grit near Sudbury. The second occurrence, in Scadding Township, is not at all typical, and the only reason for calling it Ramsey Lake formation is its position beneath 6000 feet of Mississagi quartzite. It may, however, only represent a conglomeratic phase in the quartzite. The conglomerate here contains many boulders and pebbles, but no white quartz grains. In neither case is the base of the conglomerate exposed, so no estimate of thickness is possible.

Northeast of Sudbury, Quirke (1921) described conglomerates at the base of the Mississagi formation in the central part of MacLennan Township, and at one locality in Scadding Township. In the former locality the conglomerate overlies the Keewatin schist complex, but no description is given beyond the statement, "a dark coloured quartzitic conglomerate". It is less than 50 feet thick. In the latter locality a total thickness could not be determined. It again overlies the Keewatin schist complex. It contains relatively few elongated pieces of schist, and relatively many rounded pebbles of dark schist, or smoky quartz. As the schist contains many smoky quartz veins, fragments of this material are to be expected in the overlying conglomerate. The basal conglomerate is 2½ feet thick, and is overlain by 6 feet of coarse arkose, followed by at least 7 feet of conglomerate containing many smoky quartz pebbles and cobbles, and a few boulders of granite up to 8 inches in diameter. The thickness is at least 15½ feet.

Lying about 30 miles northwest of Sudbury, the Geneva map area in Hess and Moncrief Townships is separated from all other areas of Huronian rocks. Quirke (1920) described Huronian rocks here that can be correlated with the area of the north shore of Lake Huron. Conglomerates, believed to be Basal Mississagi, are present in both townships. The outcrops are small and scattered, however, so correlation is difficult. In one place in Moncrief Township, though, a conglomerate 170 feet thick is found conformably overlain by quartzite. The conglomerate was described as dark in colour, massive in structure, heterogeneous in composition and lying unconformably on an older granite. In another place, where conglomerate lies on basic pyroclastic rocks, it is very dark coloured, and apparently derived from them. Quirke stated that the surface beneath the Basal Mississagi is very irregular. He believed that the basal conglomerate here is a continental deposit.

Summary of the Basal Mississagi:

The Basal Mississagi or Ramsey Lake formation is extremely variable throughout the area considered, both in the kind and amount of material that makes it up. In some localities it is almost entirely absent, with the Mississagi quartzite being deposited on the older rock, with practically no transitional stage. In other areas, as in the northern Bruce Mines area, or near Sudbury, the formation is extensive and varied.

Some parts of the formation consist only of the accumulation of weathered material on the old rock surface, and this shows a gradation from undecayed rock through various stages into the sedimentary conglomerate and into the true feldspathic quartzite of the Mississagi. In other localities the weathered material was apparently swept away before the introduction of new material took place to form the Basal Mississagi. Collins (1925, p.60) suggested that the surface it was deposited on must have had a low peneplane-like relief, and that it must have been a land surface for some time to give the bouldery soil of arkose and greywacke that makes up some parts of the Basal Mississagi. However, where the formation shows its greatest development, in the northern Bruce Mines area, the evidence indicates that the formation was laid down on a land of considerable relief, and that deposition occurred in intermontane basins. In other areas where the formation is quite thick, such as around Sudbury, it is likely that deposition occurred in local basins with material derived from adjacent areas of high land. The somewhat discontinuous nature of the formation lends support to such an idea.

The composition of the formation suggests that the material underwent only short transportation, but that it suffered a great deal of decay. In the thick sections of the formation, the lenses of quartzite indicate long transportation of that material.

For the most part, the formation appears to consist of a continental deposit. Where thick sections are developed, deposition occurred in local basins of quiet water.

THE MISSISSAGI FORMATION:

The Mississagi formation occurs widely in a belt from Sault Ste. Marie to a point some 40 miles east of Sudbury. It is remarkably regular in lithogic character over all this area, consisting of massive white feldspathic quartzite. The name Mississagui was first applied to the quartzite formation near the base of the Bruce Series by Alexander Winchell (1888). The spelling was changed to Mississagi by Collins (1914).

The most westerly known occurrences of Mississagi quartzite, that can be correlated with this band, are described by McConnell (1926), in the southeast part of the Sault Ste.Marie map area in the Garden River Indian Reserve, and parts of Duncan and Kehoe Townships. He described the rock as a medium grained feldspathic quartzite, greyish to light green in colour. It is composed of angular and sub-angular grains of quartz and feldspar in a groundmass of small angular grains of the same minerals, along with shreds of chlorite, colourless mica, and iron ore. In some samples the feldspar may exceed 30 percent. The heavy bedding is a prominent feature of the Mississagi, with planes 2 to 3 feet apart, though partings may be entirely absent, and the rock appear quite massive. Cross-bedding is common, and some ripple marks are seen. A few insignificant beds of greywacke 2 to 3 feet thick are interlaminated with the quartzite. They form discontinuous lenses. No pebble horizons are found near the top of the formation, as described by Collins (1925) in the area to the east. McConnell estimated a minimum thickness of 1500 feet for the formation. As it is overlain unconformably by the Cobalt Series in many places, it is likely that part of the Mississagi quartzite was removed by erosion.

East of the Sault Ste. Marie area the Mississagi outcrops extensively. It seems quite uniform for the most part, agreeing with the description given above for the quartzite. Emmons (1926) stated that it is a white to light grey colour, while the arkosic part of the formation is particularly feldspathic. Whether there is a gradual decrease in feldspar content from bottom to top was not positively determined, but such a tendency appears likely. From 100 to 200 feet from the base feldspar may make up a quarter, or even a third, of the rock, but near the top the formation is nearly pure quartz. The grains are sub-angular though secondary growth of the sand grains has obscured this in many places - sixty to ninety percent are quartz, with the remainder mostly orthoclase or microcline. Plagioclase grains are not common. Around the grains and filling the interstices is kaolinic matter, composed largely of colourless shreds presumably resulting from decay of the feldspars. The above descriptions apply generally to all of the Mississagi quartzite. Variation in the formation is found in the kind of beds that are interlaminated with the quartzite.

In Lefroy Township of the Bruce Mines map area, Collins (1925) stated that the pure quartzite near the top of the formation carries thin conglomeratic lenses of well-worn pebbles of white quartz and of banded gray silica, in a matrix of rather clean quartzite. The pebbles are notably uniform in size, from one-half to one and one-half inches in diameter, and are somewhat less in quantity than the quartzite. The well-rounded pebbles imply long transportation. No argillite bands are present in the quartzite of the Bruce Mines area according to Collins.

To the northeast of the Bruce Mines area, in Township 169, located in the Wokomata map area, Emmons (1926) found thin argillite bed irregularly distributed through the quartzite beds of the Mississagi. In the Blind River area to the south, Collins (1925) stated that the Mississagi contains argillite facies of different thickness, and at different horizons. They appear to be laterally discontinuous lenses within the quartzite, and not a single widespread formation. Lenses of argillite, at least 150 feet thick, are present in various localities at different distances from the base of the formation.

In the Panache Lake and Espanola map areas the argillite appears to be represented by about 20 feet of thinly bedded sediment which has, however, been metamorphosed to a hornblende schist, with the resultant loss of its original character. In the Espanola area Quirke (1917) believed the rusty argillitic partings in the quartzite are of the same nature as the thick argillite members elsewhere.

The argillite consists of regular layers from one-sixteenth to one-half inch thick, with the upper and lower parts of each layer slightly differing from each other in colour. This gives the rock a finely banded appearance. It is dark grey to dark brown in colour, and is exceptionally incompetent, which results in it being crumpled. Thin sections show that it is composed of an extremely fine-grained aggregate of colourless mica shreds and quartz grains. The lower part of each bed contains quartz particles, while the upper part is free of them.

Locally, there are conglomerate beds within the Mississagi quartzite. In Striker Township of the Blind River area, Collins (1925) described an exceptionally interesting occurrence. It is boulder conglomerate, 20 to 50 feet thick, composed of well-rounded boulders up to 18 inches in diameter. They are of a variety of rock types, granites, gneisses, greenstones, quartzites, conglomerates, a greywacke-like stratified material, and also angular blocks of friable brown quartzite, beds of which occur in the underlying Mississagi. The boulders are packed closely together, and the interstices are filled with a coarse grit. This conglomerate seems to represent a break in the Mississagi at this point as illustrated by the uneven quartzite surface, cutting bedding planes, on which the conglomerate rests. A few other small occurrences of conglomerate in the quartzite, in the Blind River and Panache Lake map area, were described by Collins (1926, p.43).

The Mississagi formation shows a great range in thickness, with what appears to be a fairly uniform increase from north to south in some parts of the Blind River sheet. In the northern part of Township 144 it is only some 1000 feet thick, but about 10 miles south, in Township 149, it is 1500 to 2000 feet thick. In Shedden and Victoria Townships, 12 miles further south, the estimated thickness is 3500 feet. Across the intervening Murray fault, and some 5 miles south, it does not seem to be less than 10,000 feet thick. South of the Murray fault, in the Panache Lake area and the Blind River area, the formation seems to maintain a thickness of 10,000 to 12,000 feet. All the thickness given above must be regarded as estimates only. Collins took into account the dips of the formation in arriving at these figures, but in some localities, where dips are flat, inaccuracies are possible.

The description of the Mississagi quartzite in the Espanola area by Quirke (1917) agreed with that of Collins for the rest of the north shore of Lake Huron area. Some minor variations are present, such as a purple tint along some of the bedding planes, due to the oxidation of hematite present there in small quantities. In this area, much of the formation has been dynamically metamorphosed, as shown by sericitic partings along the bedding planes separating the beds every 4 to 6 feet. The weathering of these sheared zones gives a rutted appearance to the outcrops. In some places deformation has been severe enough to fracture the quartzite, the resulting fracture often being filled by vein quartz. The same gradation exists in the area from feldspathic quartzite in the lower part of the formation to nearly pure quartz at the top. Argillitic or conglomeratic phases within the quartzite are not mentioned, though at one place in Foster Township the quartzite grades into a quartzitic greywacke near the contact with the overlying Bruce conglomerate. There are, however, well defined dark coloured bedding planes in some places that probably represent argillite bands of other areas. Quirke made an estimate of at least 4000 feet thickness for the quartzite part of the formation. However, due to lack of distinctive bedding planes, and much deformation, wide variation from this figure is possible.

In the vicinity of Sudbury, the Mississagi was originally called the Wanapitei quartzite by Coleman (1905), and classed as a member of the Sudbury Series. When Collins (1914) showed the formation near Sudbury was continuous with the Mississagi to the west, the latter, more general name, was adopted. Also, the name Wanapitei, as originally used by Coleman, included part of the Serpent quartzite also. The quartzite shows the same characteristics in this area. Burrows and Rickaby (1934) stated that dark coloured slatey greywacke usually separates the thick-bedded layers of quartzite, and that conglomerate lenses are distributed through the quartzite. Fairbairn (1941, p. 5) stated that some thin-bedded argillite in the Mississagi was confused with McKim greywacke by Burrows and Rickaby (1934). The two rocks are very similar, but can be distinguished by structural and stratigraphic means. Collins (1937) indicated a thickness of 8000 feet for the Mississagi of the Sudbury area.

East of Sudbury in the Wanapitei Lake area, Quirke (1921) described occurrences of the Mississagi formation. The quartzite here is quite feldspathic, with a greenish yellow colour on the weathered surface, and pink on the fresh surface. In places there are streaks of fine-grained siliceous greywacke in the quartzite, while elsewhere small inclusions of mudstone are present. The greywacke phase may show ripple marks, well marked dark bedding, and, less commonly, mud cracks or small sand lenses. Interbedded with the quartzite, in a few localities, are conglomerate bands consisting chiefly of quartz pebbles up to 3 inches in diameter in a highly siliceous matrix. He estimated the thickness of the formation in this area to be 5000 feet, including both the quartzite and the basal conglomerate.

Kindle (1932) refered to the Temiskaming-Bruce formation as the lowest member of the Huronian in the Moose Mountain - Wanapitei area. This is equivalent to the Mississagi formation. It consists of finely bedded white quartzite which, at one place in Parkin Township, he estimated to be 2000 feet thick if the dip is considered vertical. In Hutton Township conglomerates and argillites are present in the quartzite.

To the southeast, in the Ashagami Lake area, Fairbairn (1939) stated that the Mississagi outcrops extensively. Near Ashagami Lake, he estimated the thickness of the formation to be 6000 feet. Fairbairn's description of the formation corresponds with that given by Collins for areas to the west.

A few miles to the east, in the northeastern part of Janes Township, southeastern part of McNish and western part of Pardo Townships, Bruce (1932) mapped a quartzite as part of the Sudbury Series. It appears to be an extension of the Mississagi quartzite mapped by Fairbairn (1939), and probably should be correlated with the Mississagi. Except for a slightly more metamorphosed state, the formation is lithologically similar to the

Mississagi. The proximity of the Killarnean granite would account for the metamorphism. Bruce hesitated to call the quartzite Mississagi because of a marked unconformity between it and the overlying Gowganda Series. The closely folded nature of the rocks here, however, may explain the apparent unconformity. Because of the lack of the Bruce Series, the Mississagi had been subjected to erosion before the deposition of the Gowganda and, consequently, an unconformity is to be expected.

In the isolated Geneva map area, Quirke (1920) found occurrences of Mississagi formation in both Hess and Moncrief Townships. In one place a thickness of 350 feet of quartzite is apparent, but lack of continuous outcrop in the area prevents determination of thickness. It is probable, however, that the Mississagi does not develop any great thickness in this area.

Summary of the Mississagi Formation:

The Mississagi is a massive feldspathic quartzite, deposited extensively in a great trough, trending roughly east-west. The variations in the formation throughout the trough lie in beds of argillite or conglomerate that are found interbedded with the quartzite. These beds, occurring locally, mark slight changes in the conditions of deposition. These breaks did not extend over a wide area, for none of the facies are continuous for any distance. The argillite layers probably indicate more rapid accumulation, and less decay of the rock where it was accumulated. The conglomerates indicate a slight break in the deposition in several places where they lie on apparently eroded surfaces. In other cases they represent only a change in conditions, such as a shift in shoreline. For the most part, however, conditions must have been stable to give the thick beds of quartzite that occur.

The formation appears to have resulted from fairly complete decay of rock, particularly in the upper part of the formation, where practically pure quartz is present. Deposition under fairly shallow water conditions is suggested by the cross-bedding that is so common in many occurrences, and also the ripple marks found occasionally. The land area from which the material was derived probably had a considerable relief if one considers the great quantity of material deposited.

The variation in the thickness of the formation is not readily explainable. The greatest development is in the central part of the trough, along the north shore of Lake Huron. The thickness shows a marked increase from north to south across the trough as it is now preserved. The thickness diminishes at each end of the belt, as well as along the northern boundary.

Deformation of the formation is severe in at least two localities, in the Espanola area and the extreme eastern occurrences. In both cases the most apparent cause is the intrusion of granite nearby.

THE BRUCE CONGLOMERATE:

This conglomerate, lying next above the Mississagi quartzite, was first mapped by Logan and Murray (1848), who called the formation the Lower Slate conglomerate. Collins (1914) changed the name to Bruce conglomerate, by which name it is now known.

The formation does not occur as widely as the underlying Mississagi quartzite. Typically, it is a massive boulder conglomerate. In most localities it passes from the underlying Mississagi by gradation, while occasionally it rests on an apparently eroded surface of the Mississagi quartzite. The thickness of the formation shows great variation, but this variation has the same regularity shown by the Mississagi. Difficulties in distinguishing this formation from other conglomerates produced inaccuracies in some of the earlier reports.

McConnell (1926) stated that the Bruce conglomerate does not outcrop in the Sault Ste. Marie area except, possibly, for a few feet of pebble-bearing greywacke under the Bruce limestone at one locality. Collins (1925) reported its presence in the nearby Bruce Mines area, however. He gave a good general description of the formations for all the north shore of Lake Huron area. It is a massive boulder conglomerate, typically weathering to a buff colour, containing sub-angular to rounded boulders of granite, gneiss, dioritic rock, green schists of various sorts, and rarely a glassy sort of quartzite, unlike the Mississagi. They are of all sizes up to 3 feet in diameter, but are largest and most abundant in the lower part of the formation. Near the bottom they make up one-third to one-half of the whole rock mass, while in the upper part there may only be three or four pebbles to the square yard. At the top this nearly pebble-free greywacke grades into thinly stratified silicious silt, which forms the bottom of the overlying Bruce limestone. The matrix that holds the boulders for a short distance above the Mississagi quartzite has practically the same character as that formation. However, in from one to three or four feet, or locally up to 40 feet, the matrix changes to a greywacke.

Under the microscope, the matrix of the Bruce conglomerate is seen to be comprised of large sand grains scattered through a fine greywacke material. The angular to sub-angular sand grains, making up one-quarter to one-half of the whole, are up to 2 mm. in size, and consist chiefly of quartz with the remainder feldspar, both potash and plagioclase types. The finer material consists of chlorite and sericite shreds, epidote, minute grains of feldspar and quartz and indeterminable opaque material.

The matrix of the conglomerate is sufficiently different from that of the Cobalt boulder conglomerate so that the two can be distinguished, although in other ways they are remarkably alike. The matrix of the Cobalt conglomerate is a homogeneous slate-coloured material, which, under the microscope, proves to be pulverized rock material, quite unsorted and undecayed. The matrix of the Bruce conglomerate is apparently a reconsolidated rock flour that has suffered some decay and some assortment, which gives the higher percentage of sand grains. These glassy particles give the matrix a gritty appearance that distinguishes it from the more homogeneous matrix of the Cobalt conglomerate. Collins also stated that the Bruce matrix characteristically contain pyrite grains scattered through the matrix in irregular grains, and, particularly, in the narrow spaces where the matrix has been pulled away from the boulders and pebbles. He stated that the tendency of the matrix to draw away from the pebbles is more prevalent in the Bruce than in the Gowganda (Cobalt) boulder conglomerate. Quirke (1912) suggested that under impressed stress the more plastic groundmass flowed enough to leave a space around parts of the resistant pebbles.

The conglomerate itself shows no sign of stratification, but in a few places there are small amounts of well stratified material associated with it. At one place in the Blind River area, Collins described a well stratified succession consisting of, in ascending order, 35 feet of coarse boulder conglomerate; 6 feet of well stratified calcareous silt resembling Espanola greywacke, and, finally, 30 feet of boulder conglomerate that grades into the overlying formation. In the Panache Lake area, on the north side of Panache Lake, a similar alternation of stratified silty quartzite and massive boulder conglomerate is present.

Emmons (1927) stated that in the Wakomata Lake area the Bruce conglomerate outcrops in Townships 169 and 176. The formation is the same as described by Collins above. In both places the contact with the underlying Mississagi quartzite is gradational over a few feet. In Township 169 the formation is not more than 50 feet thick, and is thinner in several places. In the other locality no estimate is possible as the upper contact is not visible.

In the northwest part of the Bruce Mines sheet, near Echo Lake and in the Garden River Indian Reserve, the Mississagi formation passes conformably upward into the Bruce conglomerate over a distance of about two feet. The quartzite becomes coarser-grained and pebbles and boulders appear. The matrix of the conglomerate changes from feldspathic quartzite to greywacke in from 3 to 40 feet. Near Echo Lake the formation is only 20 feet thick, but near Bruce Mines, in the northern part of the sheet, it is probably twice as thick, although no actual measurement is possible.

Near Quirke Lake in the Blind River sheet, and near Panache Lake in the Panache Lake sheet, gradational contacts with the Mississagi formation are again found. In Township 138 in the Blind River sheet, and south of Espanola in the Panache Lake sheet, however, there is a sharply defined disconformity. The top of the Mississagi appears as a sharply defined wavy line. The conglomerate immediately above is in a feldspathic-quartzite matrix, resembling the Mississagi quartzite, but it rapidly changes to a greywacke matrix.

In Striker Township, in the southwest part of the Blind River sheet, the formation is 60 feet thick. In Townships 150 and 156, in the north central part of the same map area, it ranges from 90 to 125 feet in thickness. Further east, near Panache Lake, Collins stated that in spite of complex folding and faulting, an estimate of not less than 500 feet, and perhaps even 1000 feet, is reasonable.

The Bruce conglomerate of the Espanola area was described by Quirke (1917). The description agrees generally with that given by Collins for other areas. In the Espanola area, Quirke found in most cases an abrupt change, without gradation, from clear quartzite to very gritty pebble and cobble-rich conglomerate. He mentioned that there are places in which there is an appearance of alternations. Thus, it appears that both gradational and sharp contacts exist. At one place in Foster Township a discordance in dip between the Mississagi quartzite and the Bruce conglomerate of 22 degrees is reported.

Quartzite pebbles are present in the Bruce conglomerate, but Quirke stated that there is nothing to show that they are derived from the Mississagi quartzite.

An estimated thickness of 400 feet is given for the Bruce conglomerate in the Espanola area.

Collins (1914) first traced the Bruce conglomerate into the Sudbury area from the Espanola area. Previous to this time, all the conglomerate had been mapped as the Ramsey Lake formation (Coleman, 1905, 1913). It outcrops in Falconbridge and Dryden Townships. Fairbairn (1941, p. 4) stated the reasons for classing it as Bruce conglomerate and not Ramsey Lake conglomerate. These are, to quote: "(1) It lies stratigraphically above the Mississagi formation; (2) The Bruce contains abundant pebbles and boulders, these being commoner at the base than at the top; the Ramsey Lake formation contains relatively few pebbles except at the top, and does not merit the term 'conglomerate' for the formation as a whole; (3) The Bruce matrix consists of a fine greywacke containing conspicuous quartz eyes, which commonly appear black to the unaided eye; the Ramsey Lake matrix is more arkosic and typically contains conspicuous grains of white quartz; (4) The Bruce conglomerate weathers to a dull brown; the Ramsey Lake is greyer, and the abundant white quartz eyes of the matrix are conspicuous". Though these features seem distinctive enough, without careful mapping their significance could easily be overlooked.

In the Sudbury area, quartzite beds are commonly found interbedded throughout the Bruce conglomerate. This feature is not common in other areas. Superficially, these quartzite beds resemble the Mississagi quartzite. They lack cross-bedding, however, a common structure throughout the Mississagi. Fairbairn (1941) stated that in Dryden and Falconbridge Townships a thickness of at least 2000 feet is indicated, including quartzite horizons that total some 200 feet. There is no evidence that this figure can be reduced by folding and faulting. The contact between the Mississagi and the Bruce conglomerate is gradational over a zone of several hundreds of feet in the Sudbury area, according to Fairbairn (1941). Here conglomeratic quartzite and quartzite interbedded with conglomerate are found. It is difficult to draw a distinct line between the conglomeratic quartzite and the Bruce conglomerate. However, the matrices, which are quartzite and greywacke, respectively, give one the opportunity to distinguish between the formations.

In the Wanapitei Lake map area, Quirke (1921) found the Bruce conglomerate is apparently more than 1000 feet thick. It is no different from the rock previously described except that here it shows no bedding, that is, there are no stratified sections. The same typical feature of deformation in the conglomerate is present, with the matrix pulled away from the pebbles.

The Bruce conglomerate was not mapped separately by Kindle (1932) in the Moose Mountain - Wanapitei area. He referred to the Temiskaming-Bruce quartzite and conglomerate, which includes both the Mississago quartzite and the Bruce conglomerate. No estimate was given of the thickness of the Bruce conglomerate.

Fairbairn (1939) states that the Bruce conglomerate occurs in the western part of Scadding and Street Townships of the Ashagami Lake area. A few outcrops in the eastern part of the area in Davis Township were mapped as Bruce conglomerate on lithologic character alone, not being in contact with any other sedimentary formation. In one place, near Ashagami Lake, a maximum thickness of 600 feet is estimated for the formation. The distinctive features of the Bruce conglomerate, buff-coloured weathered surface and a dark matrix containing quartz eyes, are present. In some parts of the area, the exposures are highly sheared, so that distinction from the Gowganda conglomerate, that occurs nearby, is difficult.

Farther east, in the Townships of Janes, McNish and Pardo, there is no rock that can be correlated with the Bruce conglomerate. Similarly, in Hess and Moncrief Townships, northwest of Sudbury, Quirke (1920) stated the Bruce conglomerate is absent.

Summary of the Bruce Conglomerate:

The Bruce conglomerate was deposited in the same trough as the underlying Mississagi quartzite, but it appears not to have formed over so extensive an area, or else more of it has been completely removed by erosion from some areas. Its absence from the outlying Geneva map area possibly indicates that it did not extend as far north as the Mississagi formation. In some localities there has been a definite break in deposition; an angular discordance was reported at one place. In other places, however, deposition was continuous from the Mississagi formation to the Bruce conglomerate. The break could not have been for long as no fragments of Mississagi quartzite have been recognized in the Bruce conglomerate, and where there is no break, elsewhere, only enough time passed for deposition of from 5 to 30 feet of material.

The greywacke matrix of the conglomerate suggests that it has not undergone long transportation, although there has been some decay of the less resistant rock fragments. Unlike the Gowganda conglomerate matrix, some removal of fine material has occurred, so that there is an abundance of the coarser quartz and feldspar grains.

In localities where some stratification is visible there were changing conditions during deposition, resulting in the layers of quartzite in the conglomerate. Stratification is not general, so such changes are only local.

The character of the quartzite beds suggest that the formation was deposited in water, at least in part. The massive character of the formation and the heterogeneity of the inclusions suggest that sorting was lacking for the most part. Quirke (1917) believed that the formation is more likely continental than marine in origin. Coleman (1914 , p.221) thought the deposits are of glacial origin. He believed the conglomerate rests on a glaciated surface of quartzite. The lack of soled or facetted pebbles and boulders is strong evidence against the theory of glacial origin, as is also the lack of a definitely glaciated surface beneath the conglomerate.

Quirke (1917) suggested that it may be an alluvial deposit which accumulated at the base of a steep slope in a region of little rainfall. Any theory to explain the formation must take into account the heterogeneity of the boulders present. They must have been transported some distance for often they do not consist of rock types found nearby. The character of the formations above and below must also be considered.

A semi-glacial origin would easily explain the type of fragments found in the sediment, as they could be dropped from floating masses of ice. The presence of a conglomerate between such well-bedded formations as quartzite below and limestone above, also fits in with a glacial origin. There is an entire lack of direct evidence of glacial origin, however.

The fluvial origin proposed by Quirke might explain the formation. If uplift of the trough of deposition and the adjacent lands occurred so that the depth of water diminished and material was still being introduced by fast-flowing streams from the adjacent uplifted land, then a conglomerate might be expected. The relatively short transportation by streams of the fine material of the greywacke matrix would explain its composition. The sub-angular to rounded heterogeneous boulders and pebbles could be accounted for by stream transportation. A sudden influx of water due to downwarping would be necessary to give the change of conditions so that the overlying limestone would be deposited.

THE BRUCE LIMESTONE:

Although the Bruce limestone is not a thick formation, it is an important one, for, due to its distinctive characteristics, it serves as a marker horizon for determination of stratigraphy and structure. In many areas the underlying Bruce conglomerate is not bedded, and the overlying Serpent quartzite (where the Espanola formation is missing) is difficult to distinguish from the Mississagi quartzite. The limestone, where found, provides a key to the succession.

The name 'Bruce Limestone' was first applied by N.H. Winchell (1887), and has gained fairly wide usage. Some authors, however, - Fairbairn (1939), for example - include the limestone with the overlying greywacke, calling both together the 'Espanola Formation'. The limestone is such an important horizon it seems best to differentiate it as a separate formation.

Collins (1925) described very completely the Bruce limestone for the area north of Lake Huron. This description seems to fit almost all occurrences from the Sault Ste. Marie area to the Ashagami Lake area, east of Sudbury. The underlying Bruce conglomerate passes upward into several feet of thinly stratified siliceous dark grey material, which appears to be an indurated silt. Although not calcareous for from 5 to 15 feet from the bottom, it gradually shows thin intercalations of limestone that increase in number and thickness. On exposed surfaces, the limestone weathers out to produce a regularly and deeply corrugated surface. At the middle of the formation, the rock is about three-fourths limestone in beds of a foot or less in thickness, alternating with siliceous layers that are usually about one-quarter inch thick, although occasionally 1 to 2 feet. From the middle of the formation upward the condition is reversed, with a gradual decrease in the amount of limestone, until a banded siliceous rock remains near the top similar to that at the bottom of the formation.

The siliceous, thinly stratified material, under the microscope, is found to consist of angular to sub-angular sand grains of quartz and feldspar in a matrix of finer clayey material. An unusual feature is that from one-half to one-third more numerous than the quartz grains are the fresh plagioclase and orthoclase grains. The groundmass is a fine felt of chlorite, sericite and biotite shreds holding minute particles of quartz and feldspar. The amount of groundmass material is extremely variable from strata to strata, but is never less than one-half of the whole. Small grains of carbonate are present in the silty layers where they alternate with limestone layers, but, nevertheless, they are sharply defined from the limestone layers.

The limestone beds, bluish to grey in colour, are finely crystalline and practically devoid of silty material. The limestone is slightly dolomitic but Collins (1925, p.50) did not think the magnesia content has any consistent relationship to vertical position in the formation.

In the Sault Ste. Marie area, McConnell stated that the Bruce limestone has a very limited distribution, and exists only as erosional remnants that survived the pre-Cobalt erosions. In one place it occurs as a nearly flat-lying remnant some 100 feet thick. In the other occurrences in this area it lies in disturbed or faulted zones and thicknesses were not measured. The formation occurs only sparsely to the east in the Bruce Mines area. Still farther east, in the Wakomata Lake area, Emmons (1927) reported occurrences in several places. In this area it was mapped very carefully because it is the key formation. He estimated a thickness of 150 feet in one of the best exposures in the eastern part of Township 169, but the structure here precludes any reliable measurement.

In the Blind River area, south of the Wakomata Lake area, in Townships 149 and 155, there is a variation in the formation. Here the basal part of the Bruce limestone is a lean iron formation. The usual siliceous layers are interbedded with layers of fairly pure black iron oxide or siliceous material, sprinkled with black magnetite grains. This iron formation is nowhere more than 15 feet thick. Collins (1925) stated that the Bruce limestone maintains a thickness of 150 to 200 feet throughout the Bruce Mines, Blind River, and Panache Lake areas, unless thinned by pre-Cobalt erosion. Quirke (1917) likewise stated that in the Espanola area the formation is about 150 feet thick. In some places in this area the rock is a white marble, indicating that the limestone has undergone metamorphism.

In the Sudbury area, Fairbairn (1941) describes occurrences in Dryden and Falconbridge Townships. Because he did not state any thicknesses, it is presumed to be approximately the same as in areas to the west. It has suffered faulting in some localities, so the normal transition from Bruce conglomerate to limestone may not always be apparent.

To the east of Sudbury, in the Ashagami Lake area, Fairbairn (1939) stated that the limestone occurs frequently, often as excellent exposures. Thicknesses of 250 feet were noted in two localities along the Wanapitei River. Both dolomitic and non-dolomitic types of limestone are found. Similar occurrences of limestone are mentioned by Quirke (1921) in the adjoining Wanapitei map area. A thickness of 200 feet was noted at one place, but in many small disconnected outcrops it is seldom more than 100 feet thick.

Northeast of Sudbury, in Parkin Township, Kindle (1932) failed to distinguish between the Bruce limestone and the later Espanola limestone.

In the Geneva map area, northwest of Sudbury, the relations of the Bruce limestone are not clear, according to Quirke (1920). He doubted whether the Bruce limestone here exists as a separate formation. There is limestone present along with greywacke, and he thinks the two are the equivalent of the Bruce limestone, the Espanola greywacke and the Espanola limestone.

Summary of the Bruce Limestone:

The importance of the Bruce limestone, where it occurs, must be emphasized. It is often the key formation in determining structural and stratigraphical relations. It is remarkably constant in general character wherever it is found. The thickness is quite constant also, usually from about 150 feet to 250 feet. Many outcrops are only remnants that have survived the pre-Cobalt erosion. The distinctive weathered surface of the formation makes it readily recognizable in the field.

The alternation of siliceous beds with thin limestone beds suggests that the formation was deposited in shallow water, perhaps near a shore, where conditions changed from time to time.

Toward the centre of the formation, where the limestone beds are thicker and more numerous, deposition probably took place in deeper water. Collins (1925, p.62) suggested the alternation of silt layers with limestone implies alternating periods of turbid and clear water.

THE ESPANOLA GREYWACKE:

This formation was first described and named by Collins (1914, p.19), but the name greywacke is hardly appropriate. More correctly, the rock is the indurated equivalent of a calcareous silt. The formation, showing similar general characteristics wherever found, often accompanies the underlying Bruce limestone in occurrences.

Collins (1925) stated that the formation is closely allied to the underlying Bruce limestone. It consists of the same interlaminated silty material and limestone, except that the limestone constituent is scarce and irregular in distribution in layers. A variable amount of carbonate grains occur scattered through the silt. The formation is generally thin-bedded, with beds ranging from 1 inch to 1 foot in thickness, and most of them further separable into finer laminae. An uneven, corrugated weathered surface results from the differential weathering of the dark-coloured, resistant siliceous layers and the light-coloured calcareous layers. In composition the beds range from the almost pure siliceous type resembling a fine quartzite to some which are a crystalline limestone. The quartzitic layers consist of grains of quartz and fresh feldspar in a paste of secondary mica shreds cementing them together. The calcareous varieties have from a trace up to 30% of carbonate disseminated through the silt. It appears, then, the only difference between the Espanola greywacke and the Bruce limestone is in the amount of carbonate present.

Ripple marks are frequently found in this formation, and, less commonly, mud cracks. These cracks, about one-quarter inch wide at the top and two inches deep, cut silty beds at a normal angle, and are filled with the same material as overlying beds. Some of the thicker beds are wavy in outline and uneven in thickness, suggesting that the beds were subject to some erosion before the overlying beds were deposited.

The formation sometimes shows brecciation into angular blocks closely packed together in a matrix of ground up rock. It appears that the rock was consolidated when the breccia was formed but not under any great load, as the blocks show considerable rotation without being pulverized or schistified.

The Espanola greywacke does not occur in the Sault Ste. Marie area. In a few localities in the southern part of the Bruce Mines area there are occurrences, but the outcrops have been eroded or are unsatisfactory for thickness measurements.

Emmons (1927) described occurrences of the formation in the Wakomata Lake area. In one locality in Township 169 the lower part of the formation is extremely siliceous, and is very largely a dark red quartzite with intercalated argillite bands. This zone is about 100 feet thick. Because of its folded and faulted nature, Emmons was able to give no reliable estimate of the formation's thickness, although in the eastern part of Township 163 it appears to be about 400 feet thick.

To the south, in the Blind River area around Quirke Lake, in Townships 144 and 150, Collins estimated the thickness to be 350 feet, but to the west the apparent thickness diminishes, due either to faults or intraformational erosion. To the east in Panache Lake area it is from 300 to 400 feet thick.

In the Espanola area, Quirke (1917) stated the formation has suffered considerable deformation. Under compressive stress, the formation has been folded and the folding caused the siliceous layers to break into small pieces, and the calcareous layers to flow around the fragments. On the weathered surface, the more soluble calcareous parts weather out, leaving a pitted and cracked surface, with no alignment or orientation. A tentative estimate of a thickness of 280 feet for the formation is given.

In the Sudbury region, in Falconbridge and Dryden Townships, the formation is present, according to Fairbairn. In Dryden and Falconbridge Townships the estimated thickness is 500 feet, although actually it is probably less. The formation possesses the same characteristics here as described by Collins in areas to the west.

The formation is found well developed in two localities in the Ashagami Lake area, east of Sudbury. Fairbairn (1939) stated the formation shows a thickness of 300 feet or more in the western part of Scadding Township, and on Portage Island in the Wanapitei River. Quirke (1921), p.420) also described the occurrence on Portage Island. The formation occurs in the Moose Mountain-Wanapitei area, according to Kindle, but no details are given. In the Geneva area a greywacke occurs that is probably the equivalent of the Espanola greywacke, but here the Bruce limestone and Espanola greywacke and limestone cannot be separated from each other.

Summary of the Espanola Greywacke:

The Espanola greywacke appears to be closely related in character to the underlying Bruce limestone. They represent a continuous, though not uniform, process of deposition. In the Espanola greywacke formation there has been a decrease in the amount of carbonate deposited, and a relative increase in silty material. The character of the stratification and the fine lamination suggests deposition in shallow water, possibly as the result of gentle shifting currents. The presence of ripple marks and mud cracks implies shallow water deposition with brief emergences. The brecciated, and slightly eroded layers found in some places, support this idea.

Wherever found, the formation seems to have quite a constant thickness of from 200 to 350 feet. The scattered and eroded nature of the outcrops in many places prevent accurate measurement of thickness.

THE ESPANOLA LIMESTONE:

The Espanola limestone was first named by Collins (1914), the apparent reason being to call attention to the presence of limestone layers at different levels in the Huronian. This formation represents a limestone-rich continuation of the underlying Espanola greywacke. Errors in stratigraphy were made by some early workers, for they failed to differentiate this formation from the lower Bruce limestone. Both have similar characteristics. They must be separated, however, if they are to be used as horizon markers.

The Espanola greywacke grades upward into the limestone by an increasing number of thin limestone layers, until the limestone layers and silty layers are about equal in number. Towards the top of the formation the limestone layers again diminish in number and disappear, and the dark grey silty layers gradually merge into the quartzitic, thinly laminated base of the Serpent quartzite.

The Espanola limestone shows the same features under the microscope as those already described for the Bruce limestone and the Espanola greywacke. This emphasizes the conclusion that the three formations are the result of a continuous although not uniform process of deposition. One difference that is apparent between the Bruce limestone and the Espanola limestone is that the weathered surface of the latter is more of a brown colour, due to a higher iron content.

The formation is represented by only a few limestone layers in the southwest part of the Bruce Mines area, according to Collins, and does not occur elsewhere in this area. In Township 163 of the Wakomata Lake area, Emmons (1927) described a considerable amount of limestone with interbedded argillite lying above the Espanola greywacke. As the limestone layers constitute more than half the rock, he mapped it as part of the Espanola limestone. Here there is considerable iron carbonate present, which results in formation of limonite on the weathered surfaces. Only the lower 20 to 25 feet are visible, so the total thickness is unknown.

To the south, in the Blind River area, around Quirke Lake (Townships 144 and 150), the formation is from 50 to 75 feet thick, but diminishes in thickness to the west, where there are only a few thin limestone layers. In the Panache Lake area, near the west end of Panache Lake and around Espanola, Collins (1925) stated that the formation is from 50 to 75 feet thick. Quirke (1917) estimated thickness of the formation to be from 1 to 25 feet in his report on the Espanola map area.

South of Panache Lake, in the Panache sheet, Quirke and Collins (1930) stated that the Espanola limestone and greywacke and the Bruce limestone cannot be separated into individual formations. They have all undergone considerable metamorphism in this area.

East of the Espanola area, the Espanola limestone apparently does not occur in any quantity. The Espanola greywacke passes upward into the Serpent quartzite in Dryden and Falconbridge Townships, according to Fairbairn (1941), in places, but a thickness of 30 feet may be present.

In the Geneva map area, Quirke (1921) did not differentiate an Espanola limestone formation from the interbedded limestone and greywacke.

Summary of the Espanola Limestone:

The Espanola limestone represents the calcareous upper part of the Espanola formation, which is made up of the Bruce limestone, the Espanola greywacke, and the Espanola limestone. It is not a thick formation, apparently not exceeding 75 feet, and was not deposited over as wide an area as the two formations preceding it. In an east-west direction it extends only from the Bruce Mines area to the Sudbury area. To be of value as a horizon marker it must be distinguished from the Bruce limestone.

Quirke (1917, p.38) suggested that this more calcareous phase represents a slight retreat of the shoreline, although deposition still took place in relatively shallow, quiet waters.

THE SERPENT QUARTZITE:

This quartzite at the top of the Bruce Series was not named or generally recognized previous to 1914, when Collins (1919) named it the 'Serpent'. It is a thick and fairly widespread formation that has variable phases within it.

Collins (1925) described the Serpent quartzite as it occurs north of Lake Huron. The underlying Espanola formation passes into the quartzite in a distance of 15 feet by becoming more quartzitic and coarser grained. The fine lamination of the silt persists for a distance into the quartzite, then becomes less marked. The quartzite is close-grained and has a dead-white colour that suggests unglazed porcelain, which features are very characteristic of the lower part of the Serpent quartzite. The slight lamination may be expressed on the weathered surface by a delicate corrugation. The almost complete absence of bedding and conglomeratic phases distinguishes the Serpent from the Mississagi quartzite. This dead-white, laminated quartzite continues upward into a coarse grained, pink arkosic quartzite of great thickness. Except for fine lamination, this pink variety is massive, not being separated by bedding planes as the Mississagi is.

Collins (1925) stated the Serpent quartzite is made up of quartz and feldspar grains with a scanty amount of dusty kaolinic material, filling the angular interstices. The feldspar, which is quite fresh, consists of orthoclase, microcline, microperthite, and plagioclase, and makes up from one-fourth to one-half of the rock. The grains are angular to sub-angular in the lower part of the formation, but in the upper part the grains are more rounded. Carbonate is present in small quantities.

Approximately the first 1000 feet of the formation consists of the dead-white porcelain-like type of quartzite. The pink-coloured variety lies above this. In the Bruce Mines and Blind River map areas, Collins (1925) stated that only the lowest part of the formation is present, that is, the white-coloured type. On Quirke Lake, in the Blind River area, a thickness of 1100 feet was measured. In the Panache Lake area, on Lake Panache, 1500 feet of the dead white porcelain-like type is overlain by several thousand feet of the coarse pink quartzite.

In Aberdeen Township, in the Bruce Mines area, Collins (1925) described an important local break within the Bruce Series. In this locality some 60 to 80 feet of Bruce limestone is overlain disconformably by about 800 feet of quartzite. This quartzite was first called the 'Aberdeen' quartzite, but Collins (1925, p.58) believed it to be the equivalent of the Serpent quartzite. From the character of the Bruce limestone Collins concluded that only the lower half of that formation is represented. It appears possible then that a part of the Bruce limestone, and all the Espanola greywacke and limestone were removed by erosion in this locality prior to deposition of the Serpent quartzite. Due to heavy drift covering in this locality, the lateral extent of this disconformity is not known. It does not extend into the Panache Lake or Blind River map areas.

In the Wakomata Lake area, Emmons (1922) reported that in the western part of Township 163 there is at the bottom of the formation a quartzite-conglomerate of considerable thickness that grades down into the Espanola greywacke. The pebbles are mainly quartzite, and are confined to lenticular beds, most of which are sparsely distributed. This quartzite-conglomerate is about 100 feet thick, and merges upward into the quartzite. This may represent an equivalent break in deposition to that recorded in Aberdeen Township. Elsewhere in the Wakomata Lake area the Serpent quartzite is found only in patches on the Espanola limestone, having been mostly removed by erosion.

In the Espanola area, Quirke (1917) includes a greywacke type of member, some 250 feet thick, below the normal Serpent quartzite. He stated that it appears to be transitional between the calcareous formation below (Espanola limestone) and the overlying quartzite. The rock consists of bands of greywacke and of clean quartzite, which weather differentially, giving a corrugated weathered surface. The dark greywacke bands are from one inch to a fraction of an inch, while the quartzite bands are from 1 to 6 inches thick.

Above this greywacke member is a well bedded, fairly clean, and, for the most part, fine-grained quartzite, according to Quirke. This disagrees with Collins' statement that the quartzite lacks good bedding. The noticeable lamination is again present here. This author does not distinguish clearly between the dead-white porcelain-like variety of quartzite and the pink, coarse-grained type, although both are apparently present in Foster Township. He states that in Merritt Township the formation appears to be 1600 feet thick, but, as the overlying Gowganda formation rests on an erosion surface, an unknown amount has been removed. In Foster Township, where the pink coarse-grained variety of quartzite is present, as well as the white type, a possible thickness of 8000 feet is estimated, although the evidence, on which this large figure is based, is not given. In one locality in central Foster Township a band of conglomerate, 6 inches thick, containing small pebbles of granite and quartz and pieces of mudstone in arkosic matrix, is present. This indicates that a local break occurred here in the process of deposition.

The Serpent quartzite is present in Dryden and Falconbridge Townships of the Sudbury area, but no thicknesses are given. East of Sudbury, in the Ashagami Lake area, Fairbairn (1939) reported occurrences in the central part of Scadding Township and west of the Wanapitei River. The latter locality, according to Fairbairn, was incorrectly mapped as Mississagi quartzite by Quirke (1917). It is underlain by limestone, so there seems no alternative but to call it 'Serpent' quartzite. It has the fine banding and lacks cross-bedding, typical characteristics of the Serpent quartzite. Because the top of the formation is everywhere a surface of erosion, no estimate of thickness is given.

In the Wanapitei Lake area, Quirke described occurrences of the Serpent formation as dark quartzitic greywacke, characterized by streaks of ripple marked and mud cracked greywacke within beds of pale green quartzitic arkose.

Kindle (1931) described in the Moose Mountain - Wanapitei area occurrences of the Serpent quartzite at different localities in Parkin and Hutton Townships. Both the dark variety, like that described by Quirke in the Wanapitei area, and the pink arkose type, are present. No estimate of thickness is given.

In the outlying Geneva map area an unusual variety of the Serpent formation was described by Quirke (1920). The formation lies conformably on the Espanola formation, but is not only quartzitic, but markedly conglomeratic. The conglomerate phases are not persistent either laterally or stratigraphically, giving way to both quartzite and greywacke bands. The formation is here between 600 and 700 feet thick, and seems to be made up irregularly of conglomerate, greywacke and quartzite layers. Some of the quartzite layers resemble the typical Serpent quartzite described previously, either the pink arkosic type or the white porcelain-like variety. The formation here is quite unlike any other occurrences.

Summary of the Serpent Quartzite:

The thick Serpent quartzite formation indicates a gradual change in conditions as the calcareous silts of the Espanola formation gave way to the greywacke-quartzite of the Serpent. The Serpent formation shows variations in character from area to area, consequently, the conditions of deposition were not the same in all places. In the western part the quartzites are clean, while to the east there is more greywacke material intermixed, particularly in the lower part of the formation. The large amount of undecayed feldspar present in the Serpent formation indicates that transportation was short, and that accumulation was rapid, with little chance for decay. The rock eroded to produce material for this formation appears to have been extremely low in mafic minerals. In localities where greywacke is more prevalent, a different type of rock was broken down.

Breaks in deposition are indicated in some areas, as stated previously. They are, however, only local in character.

The character of the formation in the Geneva area, quite different from that found elsewhere, suggests that it lay near the edge of the depositional basin, and that the level of the basin was subject to fluctuation.

The fact that the Serpent is the last formation before the pre-Cobalt erosion interval means that a thickness for the formation is only an estimate of its present thickness. The original extent and thickness of the formation may never be known.

THE COBALT SERIES

The name 'Cobalt Series' was applied by Miller (1905) in the Cobalt district to a series of sedimentary rocks. Later these rocks were correlated with the Upper Huronian series of the area on the north shore of Lake Huron, and the name 'Cobalt Series' was adopted for all these rocks. It is not known definitely whether they correspond to the middle or upper Huronian Series on the south shore of Lake Superior. Cooke (1941) stated that the Cobalt must be assigned to the mid-Huronian on the basis of the time required to erode the sediments where the Whitewater Series are deposited.

The Cobalt Series outcrops widely in the area previously described as the location of the Bruce Series. It is found from Sault Ste. Marie in the west, through Bruce Mines, Blind River, Wakomata Lake to Panache Lake and to Espanola areas. In the Sudbury area itself, however, no rocks of this series are found. To the east, though, in the Wanapitei Lake and Ashagami Lake areas, the series again is present. This is part of the large mass of Cobalt rocks that extends to the north in a more or less circular shape, including the Gowganda, the South Lorrain, and the original Cobalt areas. Whether these were disconnected basins of deposition or not is unknown. The alternative is that there was one large basin, and that later erosion has removed the rock that would connect the two present masses.

The amazing feature of the Cobalt Series rocks is the general similarity in succession over the whole area, and the great variation on minor scale over very short distances. Even within one map area it is frequently difficult, as well as of little value, to separate out the different phases within the Cobalt Series. Yet, if one considers the rock types generally and their sequence, a singular regularity is apparent.

The Cobalt Series consists of two major widespread formations, the lower, Gowganda formation, overlain by the Lorrain quartzite. In some localities there are two further formations above this, the banded cherty quartzite, and the upper white quartzite with some cherty quartzite.

Some authors have further subdivided the Gowganda and Lorrain formations in certain areas. However, for this discussion these main divisions are adequate.

THE GOWGANDA FORMATION:

In the original Cobalt district, Miller (1905) divided the Huronian rocks into a lower Cobalt Series, consisting of boulder conglomerate, banded greywacke, impure quartzite, and so on, and an upper Lorrain Series of feldspathic quartzite. Subsequent work in adjacent areas showed that the unconformity on which he based the division was only local, and that in other areas the two are conformable formations. Later reports, therefore, included the Lorrain as a part of the Cobalt Series. Collins (1917), in the report on the Onaping map area, proposed the name 'Gowganda Formation' for the lower, boulder conglomerate, banded greywacke formation. This name has been quite widely adopted.

The Gowganda formation is a heterogeneous assemblage of conglomerates of various sorts, banded greywackes, greywackes, impure quartzite, and, rarely, a little siliceous limestone.

The formation varies so much from locality to locality that a detailed description to fit all areas is quite impossible. In fact the rock types merge so imperceptibly in most cases that only an arbitrary boundary line is possible. Easy and rapid gradation from one rock type to another is characteristic of the formation. Collins (1925, p.63) stated that most geologists think they have a common origin under frigid climatic conditions, consequently, in spite of diverse lithologic types, the whole assemblage can be treated as one formation.

The best generalized description of the Gowganda formation for the area north of Lake Huron is that by Collins (1925). It applies to no particular section, and any phase may be absent in a certain locality. Certain localities may have developed local phases that are entirely distinctive.

Conglomerates of diverse character are common in the Gowganda. In many places there is a basal conglomerate of from 5 to 25 feet thick, which is made up of closely packed pebbles, often less than 3 inches in diameter. They are sub-angular to well rounded, and are of a variety of rock types, granite, gneiss, greenstones, etc. The matrix in this conglomerate is sand and fine gravel almost free of argillitic material. This type of conglomerate is evidently a well washed water deposit, possibly a beach type, although the flat beach type pebbles are absent. Some thin beds of this pebble type conglomerate may occur higher up in the formation, but it is typical of the base.

This type of conglomerate almost always grades upward into a boulder conglomerate that may be from 20 to 500 feet thick. This type of conglomerate consists of pebbles and boulders of all shapes and sizes scattered rather sparingly through a relatively abundant matrix of fine grained, slate-coloured greywacke. The matrix nearly always makes up more than half the rock, and in many cases only an occasional pebble per square foot is found. The conglomerate itself shows no sign of stratification, but quartzite and boulderless greywacke within it may show stratification. Thinner boulder conglomerates are found higher up in the formation in some localities.

The inclusions may comprise a great variety of rock material, or sometimes they may be practically all of one kind. Granite, gneiss, amphilolites, fine-grained erruptives, and schists of many sorts, quartz and some sedimentary types, greywacke, quartzite and limestone may all be represented. The inclusions may be more or less resistant than the matrix, weathering into bosses or forming hollows on the surface, respectively. They commonly are rounded to sub-angular, although some may be quite angular, particularly those of Bruce limestone. Collins states that many of the sub-angular ones have the appearance of soled boulders, but only rarely have definite striations been found on any.

The matrix enclosing the boulders is slate or dark greenish coloured, fine to medium grained greywacke. It is a fine aggregate of quartz, feldspar, composite rock fragments, chlorite, opaque dust and some larger grains of quartz and fresh feldspar scattered through the paste. Chemical analysis indicates that it is relatively unweathered, as shown by the soda-potash and the ferrous-ferric ratios. This is in the relativ-ely unsorted types. Some other samples show more quartz and feldspar grains in the paste, indicating some transportation and sorting. By disappearance of the boulders and pebbles, this conglomerate grades into a massive greywacke.

Most typical of the Gowganda formation is conglomerate that has boulders and pebbles scattered sparingly through a matrix of thinly laminated greywacke. The boulders are seldom more than 1 foot in diameter, and the matrix is in regular layers about one-eighth inch thick, although they may be as thin as one-fortieth inch. Fine bands may alternate with coarse bands, but most commonly bands show a gradation from coarse at the bottom to fine at the top. This banded or laminated greywacke consists of imperfectly decomposed fragmental material of the same character as the greywacke matrix of the boulder conglomerate. There is a better degree of sorting in the laminated greywacke. Lamination around inclusions is of interest, for it appears that the pebbles dropped into the soft, finely stratified laminae, punching through several laminae. The laminae terminate abruptly at the lower sides of the pebble, but arch over the top part with only slight thinning. By disappearance of pebbles the laminated greywacke conglomerate grades into laminated greywacke. This laminated greywacke grades into the massive greywacke, which shows only slight stratification, and both types grade into impure feldspathic quartzite.

The quartzites range from the quartzitic greywacke to pure feldspathic quartzite. The latter are notably rich in fresh feldspar grains. The quartzites also show imperfect assortment.

Only in one locality of the north shore area, along Blind River, does a siliceous limestone occur in the Gowganda formation. It consists of thin highly siliceous layers alternating with thin limestone layers.

In the Sault Ste. Marie area, McConnell (1926) described two separate bands of Gowganda formation. The southern band, in the Garden River Indian Reserve, conforms to the above description by Collins. In Deroche, Vankoughnet and Havilland Townships are parts of a once continuous band that shows different characteristics. The predominant constituents are greywackes of various kinds, alternating in places with red and grey quartzites, and only rarely enclosing boulders. The only conglomerate present is in thin bands at the base. The greywacke far exceeds the quartzite in amount, although quartzite bands up to 50 feet thick are present. The correlation of this phase of the Gowganda, lacking in conglomerate, with the normal conglomerate rich type, is based on the fact that both pass into the same type of quartzite above by a gradually increasing quartz content. According to McConnell, the total thickness of the lower Cobalt is unknown in the Sault Ste. Marie area. In one place in the band, where conglomerate is missing, a thickness of over 5000 feet is indicated, disregarding faulting and folding. In other localities, the exposed thicknesses seldom exceed 1000 feet. In Aberdeen Township of the Bruce Mines area, Collins calculated a thickness of 3000 to 3500 feet. In the Panache Lake area it is estimated to be between 2000 and 3500 feet in thickness.

In the Wakomata Lake area, the Gowganda consists mainly of boulder conglomerate, according to Emmons (1927). No estimate of the thickness of the formation is given.

Harding (1939) described a belt of Cobalt Series rocks in the Flack Lake area, north of the Blind River area. The Gowganda formation outcrops in Township 1A and U. It overlies pre-Huronian rocks, which are in this area, of Keewatin and Algoman age. Harding believed the Cobalt rocks in this area were deposited in an oval-shaped, shallow lacustrine basin. He did not think the Gowganda underlies all the younger Huronian rocks for they do not occur all around the margins of the basin. Here the formation is made up almost entirely of coarse boulder-conglomerate. It has a maximum thickness of 300 feet in Township 1A.

In the Espanola map area, Quirke (1917) described two separate occurrences of the Gowganda formation, one in Merritt Township, and the other in Foster Township. In Foster Township the occurrence is a synclinal exposure, in which is exposed irregularly bedded conglomerate and quartzitic layers, greywacke, some of which is well bedded, massive boulder slate conglomerate topped by fine-grained pink arkose, totalling 1350 feet. The underlying rock here is the pink arkosic quartzite of the upper part of the Serpent formation. The occurrence in Merritt Township lies on the white porcelain-like type of Serpent quartzite characteristic of the lower part of the formation. Over the short distance separating these occurrences there must have been a considerable erosional relief.

South of Panache Lake, in the Panache area, Quirke and Collins (1930) described extensive areas of Gowganda formation. The same assemblage of boulder conglomerate, greywacke slate conglomerate, Greywackes and quartzites are present here. The formation appears to be between 2500 and 3000 feet thick in this locality.

The Cobalt Series does not occur for a distance of about 32 miles from Panache Lake, east through Sudbury, until it is again found in Scadding and Street Townships. The occurrences here are described by Fairbairn (1939) in the report on the Ashagami Lake area. Only the Gowganda formation occurs in this area. it consists of the usual greywacke boulder conglomerate and quartzite, in part well bedded, and in part structureless. No estimate of the thickness of the formation can be made from exposures in this area. These occurrences continue northward into the Wanapitei Lake area, where they are completely described by Quirke (1921, p.430). He separates the formation into its varied component parts, but the same general lithologic types are found here as described by Collins from the area north of Lake Huron. He estimates the thickness of the formation to be 3500 feet.

The Gowganda formation continues east of the Ashagami Lake area into Janes, McNish, Pardo and Dana Townships, where the occurrences were described by Bruce (1932). As in other areas, it is a heterogeneous group made up chiefly of conglomerates, with considerable amounts of quartzite and slate.

In the Moose Mountain - Wanapitei area, Kindle (1932) described the usual rock types found in the Gowganda, boulder conglomerate, greywackes and quartzites, but, in addition, limestone is found interbedded with siliceous greywacke. The limestone is buff in colour and contains numerous cherty layers. Occurrences of this type were noted in Hutton Township, while in Parkin Township an exposure of grey laminated limestone is reported. An estimate of the thickness of the formation is not given, although in one locality in Hutton Township the boulder conglomerate is over 1000 feet thick.

In the isolated Geneva map area, northwest of Sudbury, the Gowganda formation is some 1200 feet thick, according to Quirke (1920). The essential characteristics of the formation in this area are similar to those elsewhere. In this area, care must be taken to distinguish the Gowganda from the unusual conglomeratic type of Serpent formation found here. Careful and detailed study of a section of rocks is often required to distinguish them.

Extending northward from Lake Wanapitei there is a large area of Cobalt Series rocks that is roughly circular in shape. It is impossible to consider individually all the descriptions in reports on this area, but as such a similarity exists, only certain detailed reports on key areas will be dealt with.

The Onaping map area takes in a large area in the western part of the area of Cobalt rocks. It was from studies in this area that Collins (1912) first proposed the name 'Gowganda formation' for the lower part of the Cobalt Series. The Gowganda formation here shows the same heterogeneous assemblage of rock types that is typical of the formation. The basal, pebble, boulder, and laminated greywacke types of conglomerates are all represented. Both massive greywacke and the laminated greywacke that is diagnostic of the formation are present. In Demorest and Clary Townships, limestone is exposed in a number of places. It is the same type of rock as is found in certain other areas, with alternating limestone and siliceous layers.

It is from 10 to 15 feet thick usually. The lack of uniformity in the thickness and in the order of succession of the various materials was noted by Collins. The basal conglomerate may be several hundred feet thick, or it may be lacking, with greywacke resting on the pre-Huronian basement rocks. In Sweeny Township, through which passes the western boundary of the Cobalt rocks, much of the main part of the Gowganda is missing. In one locality there is a basal conglomerate followed by the Lorrain quartzite, with no greywacke at all present. A small outlier of the Gowganda formation in Botha Township shows only a thickness of 500 feet. This is slight compared with an occurrence in Selkirk Township to the northeast, where the formation consisting mostly of greywacke, with no basal conglomerate at all, is 2800 feet thick. Collins thought the formation might be 3000 or more feet thick in some parts of the Onaping area. Around Gowganda and Shiningtree Lakes, in the northern part of this map-area, the formation is quite thick.

Collins (1913), in the report on the Gowganda Mining Division, described occurrences of the Cobalt Series over a wide area in the northern part of the Cobalt section of rock. The same variety of rock types within the formation is met in this area, the basal, boulder and laminated greywacke conglomerates, arkose and quartzite. No limestone is present, however. He described a local brecciation and reconsolidation within the laminated greywacke in certain localities. The amazing feature is that bands above and below the disturbed ones are perfectly flat-lying and undisturbed. The dislocation apparently occurred before the strata were entirely hardened, yet the material was sufficiently consolidated to break into angular pieces without other deformation. A variety of laminated greywacke is present that is tinged a dull red by a large percentage of iron oxide present in it.

In the extreme northeastern occurrences of this band of Huronian rocks, in the Larder Lake area of Ontario, and adjoining Pontiac County of Quebec, there are numerous occurrences of the Gowganda formation. The same heterogeneous series of clastic sediments is found, but if minor variations are disregarded the same general succession is recognizable. Wilson (1912 and 1913), in two different reports, described the series as consisting of a basal conglomerate passing upward through greywacke into arkose, which, in turn, is overlain by an upper conglomerate. The same lithologic types as described previously, are found here. The greywacke, however, does not seem to have such prominent lamination, and arkose is somewhat commoner. The maximum thickness of the formation is estimated to be from 800 to 900 feet. This does not represent the total formation, Wilson stated, as undoubtedly much has been removed by denudation. To show, from locality to locality within the area, the variation in the amount of rock types at different places, Wilson (1913, p.87) presented a table of sections. Unfortunately, the sections are generally incomplete, due to lack of exposures. It is apparent, however, that the amount of any one rock type, such as conglomerate, is extremely variable from place to place over short distances.

The original area of Cobalt rocks, first described by Miller and Knight (1905), has been the subject of numerous reports. The same lithologic types are found here as are present in the Cobalt Series elsewhere. In this area, however, there appears to be some regularity in sequence, according to Miller. The sediments were laid down on a hilly surface, probably with higher hills and deeper valleys than found now on the present surface. The thickness of sediments, therefore, varies from place to place, but there is a pronounced definite order of deposition. The order seems to be a basal conglomerate that grades upward into a greywacke, which becomes finely laminated and slate-like. This, in turn, grades into an arkose or quartzite, which is overlain by an upper conglomerate. In some places one of these members may be absent, for example, the upper conglomerate may rest on the greywacke member. A feature here of the underlying surface is that it is not smooth, and there is a gradational transition from the old non-disintegrated Keewatin rocks upward into the distinctly fragmental member of the Cobalt Series. Around Cobalt, much of the material in the lower part of the basal conglomerate appears to have originated in place.

The descriptions of the different phases found in this area agrees with those given for the area north of Lake Huron. One minor feature noted in this area, not previously mentioned, is the occurrence of boulders of conglomerate, believed to be Temiskaming in age, within the Gowganda conglomerate. Miller (1913) estimated that in the Cobalt area the Gowganda formation now has a thickness of about 500 feet.

East of Lake Temiskaming and the Cobalt area, in Temiskaming County, Quebec, lies the eastern limit of the area of Cobalt rocks. Wilson (1918) described the same types of series as is found to the west in the Cobalt area. Here again, the extreme variability of the thickness of the formation and of different lithologic types is noted. The basal conglomerate is particularly variable. It is overlain by greywacke and argillite that varies from 0 feet to a maximum of 300 feet. Above this is arkose and quartzite that may be as much as 250 feet thick. The upper conglomerate seldom exceeds 90 feet in thickness.

A more detailed study of a part of this area is contained in the report of Henderson (1936) on the Ville Marie and Guillet Lake map areas. It covers the area directly east of Lake Temiskaming. He stated that the Gowganda, which does not exceed 400 feet in thickness, lacks the regular succession found at Cobalt. The same rock types are present, but their distribution throughout the formation is extremely irregular. In Ville Marie area the Gowganda rests on a relatively clean, unweathered pre-Huronian surface with no evidence of a residual soil or erosion surface. The overlying Lorrain, on the other hand, where in direct contact with the pre-Huronian, rests on a mantle of decomposed, deeply decayed bedrock regolith, Henderson states. He thinks the Gowganda did not form an evenly distributed mantle on the pre-Huronian surface prior to deposition of the Lorrain, but was in ridge-like deposits, which reached elevations of more than 200 feet. This is proven by the present level of the contacts between the Gowganda and the Lorrain in different localities. Henderson believed that there is a disconformity of some importance between the Gowganda and the Lorrain.

South of the Cobalt area, in the South Lorrain and

Matabitchuan areas, further occurrences of the Gowganda are described. The sequence is much the same as in the Cobalt area, except that the upper conglomerate is missing. There is a basal conglomerate grading up into greywacke and greywacke conglomerate, which becomes quite laminated, and the greywacke, in turn, by addition of quartzite bands, grades upward into the massive quartzite of the overlying Lorrain formation. Todd (1925 and 1926) described the formation in these areas, but no estimates of thickness are given.

Summary of the Gowganda Formation:

The Gowganda or lower Cobalt formation is complex if one considers its lithologic character. It varies rapidly, both laterally and stratigraphically in its rock types. Certain phases such as the laminated greywacke and the laminated greywacke conglomerate, however, are typical of this formation, and are key horizons for purposes of identification.

The type of surface the formation was deposited on is variable. In the western part, along the north shore of Lake Huron, the underlying Serpent formation had suffered some erosion, but not a great amount. Farther east, in the Espanola area, the Serpent, in places, had been considerably eroded prior to deposition of the Cobalt Series. In the Gowganda area the formation was deposited on a more or less peneplained surface with a few hills of old rock sticking through. In the Cobalt area the surface was deeply dissected into hills and valleys. In many cases, the Gowganda grades into the underlying rock, whether it is the Serpent quartzite, as along the north shore of Lake

Huron, or the old Keewatin rocks, as at Cobalt. However, in certain areas, such as the Onaping map area or the Ville Marie area in Quebec, the Gowganda formation was deposited on a smooth and polished surface.

The origin of some parts of the Gowganda formation has been the cause of much controversy and literature. The present consensus seems to be that part of the formation at least was deposited under moist frigid, perhaps glacial, conditions. The laminated greywacke resembles to a marked degree the varved layers of the Pleistocene glacial lake clays, the only difference being in degree of induration. It seems likely that they had similar origins. The pebbles and boulders that occur here and there in the laminated greywacke are believed to have dropped into the soft silt-like sediment from floating ice. This seems the only possible way to account for some of the extremely large granite boulders that are found in well laminated greywacke. If strong currents or fast flowing streams were responsible, the delicate lamination would be disturbed,

A logical-appearing explanation for the brecciated layers found occasionally within the laminated greywacke is that the bands were frozen solid and then broken up, perhaps by moving ice. This would account for the undisturbed state of the layers below, and satisfies the condition that deformation occurred when the layers were solid but not under a burden of overlying layers. The discovery of striated boulders in the conglomerate is positive corroboration of the idea of a glacial origin for part of the formation.

The evidence for a glacial origin appears to be conclusive. The arguments for and against it are so clearly and thoroughly stated in various reports that they will not be repeated here. A glacial origin satisfies more of the characteristics of the formation than any other origin.

Along the north shore of Lake Huron practically every member of the formation is well stratified, and apparently water laid, except the boulder conglomerate - massive greywacke phase. Shallow, localized submergences, with changing conditions, seem to have been a common feature. The Onaping area also appears to have a large portion of water deposited material in the Gowganda formation. In the eastern part, around Lake Temiskaming and the Gowganda area, however, the formation lacks stratification, and apparently a great part was deposited under continental conditions.

Whatever the origin of the formation it can be said that processes of disintegration rather than decomposition were most active.

The Gowganda has the same general characteristics wherever it occurs. The only differences are in the thicknesses of the different phases and the total thickness in the various occurrences.

THE LORRAIN QUARTZITE:

The Lorrain quartzite, overlying the Gowganda formation, was named after the Township of Lorrain in the Cobalt area by Miller (1905) in an early report on this area, where it occurs extensively. It has been correlated with the quartzite that overlies the Gowganda in the area north of Lake Huron. Murray

(1849), the first worker in this area, divided the formation into a lower red quartzite, a middle red jasper conglomerate, and an upper white quartzite, each of about equal thickness. However, since these phases are only local, occurring only in the Bruce Mines area, and have imperceptible, gradational contacts, this separation is no longer in use. Because there are some differences in the formation in various areas, the typical occurrences will each be considered.

In the Sault Ste. Marie area, the Lorrain formation outcrops in a band across the northern part of the area. It is a quartzite formation throughout, with the exception of a few small pebble beds. It has a maximum thickness of about 1800 feet in this area, according to McConnell (1926), made up of 400 feet of greyish and greenish quartzites below an intermediate band of reddish quartzite 700 feet thick, with an upper band 700 feet thick of white quartzite, occasionally tinged reddish. The formation is conformable with the Gowganda below, and passes by gradation with an increasing number of quartzite beds alternating with greywacke bands. The quartzites are heavily bedded, sometimes appearing massive, with obscure parting planes 8 to 10 feet apart. This is particularly marked in the upper white quartzite. In the lower part, the quartzite is feldspathic, but in the upper parts the feldspar and other less resistant minerals are gone before deposition, leaving an almost pure quartzite. Thin sections of the pure quartzite show even-sized angular quartz grains surrounded by narrow rims of colourless mica. Some of the Lorrain quartzite of this area is much altered by intrusions of younger granite and by structural deformation, such as faulting. This produces hard, glassy, completely cemented rocks in the first case, and highly shattered quartzites in the case of faulting.

In the adjacent Bruce Mines area the formation, as described by Collins (1925) is slightly different. The lowermost 200 or 300 feet is a fine-grained dark reddish quartzite, which is apparently a transition from the Gowganda below to the clear quartzite of the upper part of the Lorrain. This phase, under the microscope, is found to consist of an aggregate of quartz, feldspar, mica, hornblende and other fragments in a dark paste of decomposition products. The mica and hornblende are partly decomposed, but the feldspar is fresh. Angular quartz grains form about half of the material. In the next few hundred feet the impure phase changes to a light pink quartzite composed almost wholly of quartz and feldspar grains. Then it grows less feldspathic, so that the upper third of the formation is from 95 to 99 percent silica. The quartzite has been so completely cemented that it appears to be a mosaic of interlocking grains, but close inspection shows the outline of the original rounded quartz grains. Near the middle of the formation are bands of conglomerate made up of pebbles, of white quartz and red jasper, abundantly distributed through a matrix of fairly coarse white quartzite. The pebbles, not over 2 inches in diameter, are sub-angular to rounded. The quartzite is in massive beds 2 to 8 feet thick, with cross-bedding and symmetrical ripple marks common except near the base. Characteristic of the area are occurrences in the white quartzite of thin-bedded streaks and disseminated particles of specular iron ore.

In the Blind River area, according to Collins (1925) the Lorrain occurs in Township 162, where it is a white to pale green feldspathic variety.

Emmons (1927) found the Lorrain to occur widely in the Wakomata Lake area. It is a coarse-bedded white quartzite, often cross bedded, frequently carrying pebbles of white quartzite and jasper. A finely banded, dark cherty quartzite is a distinctive member found in this area.

The formation is similar in the Flack Lake area, to the north, according to the description by Harding (1939). He estimates the the thickness of the formation in Townships 1A and U at between 2000 and 4000 feet.

The Lorrain of the Panache Lake area, in the La Cloche Mountains, has its basal part neither so dark nor impure as in the Bruce Mines area, according to Collins (1925). It is coarse-grained pink to pale green quartzite, composed about equally of quartz and feldspar. Neither the quartz nor feldspar grains show any sign of rounding. The passage from the poorly assorted feldspathic to the pure quartzite is less noticeable here, because of the slight change in colour. Slightly above the middle of the formation is a conglomerate zone a few hundred feet thick. It here contains practically no jasper pebbles, being mostly white and grey quartz. Specular hematite bands occur infrequently in it. In this area the Lorrain passes gradationally into the Gowganda formation below.

Slightly to the north of the Panache Lake area, in the Espanola area, Quirke found no occurrences of the Lorrain, except a pink arkosic band at the top of the Gowganda in one locality that may be a part of the Lorrain.

In Hess and Moncrief Townships of the outlying Geneva map area, northwest of Sudbury, Quirke (1921) reported the Lorrain quartzite to be 1700 feet thick, with an unknown amount removed by erosion. The formation is here a pale green quartzite, carrying, in the upper part particularly, streaks of white quartz and pink jasper pebbles.

The Lorrain quartzite outcrops just north of Lake Wanapitei, in Parkin, Aylmer and MacLellan Townships, and extends northward from there. The southern part of this occurrence is described by Quirke (1921) in the report on the Wanapitei Lake map area. The formation is estimated to be as much as 5000 feet thick in this area. It passes by gradation from the Gowganda formation into the typical pale green quartzite. It contains streaks of small quartz and jasper pebbles, which are another typical feature. The jasper pebbles, are not as common in this area as in certain other localities.

Just to the west of this occurrence, in Hutton and Parkin Townships, a distinctly arkosic white, green or salmon-pink variety of the Lorrain has been reported by Kindle (1932).

To the north, in the Onaping map area, Collins estimated the Lorrain quartzite to have a thickness of at least 2000 feet, and, more probably, 3000 feet. The same characteristic features are found in this area, with the exception that the conglomerate bands contain no pebbles of red jasper. In one locality, a distinctive feature is the presence of constituent grains of feldspar up to one-half inch in diameter, a departure from the usual medium to fine grained character. In the Onaping map area the contact of the Lorrain with the underlying rock is of three different types. In the eastern third of the Onaping area, and in the adjacent Gowganda area, the Lorrain is conformable upon stratified greywacke, the top of the Gowganda formation. The passage from greywacke to quartzite takes place within 20 to 30 feet of well stratified greywacke and quartzite. Deposition was apparently continuous throughout. In the southern part of Lampman Township, stratified Lorrain quartzite rests upon an uneven surface of greywacke, representing the upper part of the Gowganda formation. In both, the bedding planes are nearly horizontal. There is no gradation from one formation to the other. The contact is uneven and slightly discordant, consequently the greywacke must have been subjected to mild erosion before the quartzite was deposited upon it. Not far west of here the Lorrain rests directly on the pre-Huronian granite-gneiss. Such occurrences are found in Sweeney, Rhodes, Ogilvie and Lawson Townships, where the Gowganda is either absent or a very minor factor in rock distribution. Thus, the Lorrain may be waterlaid on the Gowganda formation or the pre-Huronian surface, or it may rest on an erosion surface of the Gowganda. This local unconformity appears to be discontinuous in Onaping map area.

In the report on the Gowganda Mining Division, Collins' (1913) description of the Lorrain agrees with those already given. There is no mention of jasper pebbles in the conglomerate bands. The contact in the Gowganda area may be either gradational or may be an unconformity with angular fragments of the Gowganda greywacke in a matrix of the Lorrain quartzite. Here again the unconformable contact appears to be only local. The author stated that the formation is known to have a thickness of 600 feet, and probably is a great deal more. Burrows (1926), in his report on the Gowganda Silver area, gave a thickness of 1100 feet for the Lorrain at Maple Mountain in the Township of Whitson.

To the east of Gowganda, in the Larder Lake area and Temiskaming County, Quebec, Wilson (1912 and 1913) reports the presence of green sericitic quartzite that carries a few small pebbles of quartz and jasper in lenticular aggregates. In this area it was named the Ville Marie quartzite, but it is similar in lithology and stratigraphic position to the Lorrain of the Cobalt area.

The Lorrain of the Cobalt area rests either on the Gowganda greywacke or the pre-Huronian granite. In some cases it shows unconformable relations with the greywacke, but in other localities no break in deposition is evident. Miller (1913) stated that where it is in contact with the granite there is a gradual transition from undecomposed granite to the arkose. The arkose, in turn, grades into an impure quartzite, and later into purer quartzite that may contain conglomerate bands composed chiefly of quartz pebbles.

Just to the west of Cobalt, in the Anima-Nipissing Lake area, Todd (1926) stated the greatest thickness of the formation, 250 feet, is preserved in the southern part of Dane Township.

East of Cobalt and Lake Temiskaming, the Lorrain outcrops prominently as hills, according to Henderson (1936).

South of the Cobalt area the Lorrain continues into the

Matabitchuan area. No estimate of its thickness is given by Todd (1925). The Lorrain here has a gradational contact with the underlying Gowganda greywacke. The conglomerate bands occur near the top of the formation, as it is now preserved, and the quartzite is feldspathic throughout. These facts suggest that the upper part of the formation is absent here.

Summary of the Lorrain Quartzite:

Certain features of the Lorrain are common to almost every occurrence of the formation. There is a gradation from feldspathic quartzite at the bottom to almost pure quartzite at the top. The grains are angular in the lower part of the formation and quite well rounded at the top. This suggests that the degree of sorting increases upward in the formation. The feldspar in the lower part often gives the quartzite a greenish or pinkish tinge, while in the upper part it is a brilliant white. Conglomerate bands are common near the middle of the formation. From the Sault Ste. Marie area eastward to the Onaping area they carry typical jasper pebbles. In the eastern part, however, these are absent.

The character of the Lorrain suggests that it is a water laid deposit which probably accumulated in shallow marine waters. There must have been a great area of Ontario under shallow submergence at this time as the Lorrain is such a widespread formation. In the eastern section of the region there are Cobalt rocks which are believed to have formed under continental conditions in Gowganda time. In Lorrain time, however, the area was submerged.

The cold moist conditions suggested for the Gowganda may have prevailed in the early part of the Lorrain, for the amount of mica and feldspar in the lower part, as well as the coarse angular character of the sand grains, suggests rock disintegration was more active than chemical decomposition.

The thickness of the formation varies a great deal, but it appears to have its greatest development in the western section. There is a considerable thickness in the Onaping-Gowganda area, but this thins out to the east in the Cobalt area.

THE BANDED CHERTY QUARTZITE:

Overlying the Lorrain in a few areas there is a formation called the 'Banded Cherty Quartzite'. It is described fully by Collins (1925) for the north shore of Lake Huron area. The Lorrain passes gradationally into this thin-bedded formation, made up of layers from one-fourth of an inch to 1 foot in thickness. In composition the layers vary from a very finely clastic quartzite to one that is so fine it cannot be distinguished from chert. The different layers range in colour through light shades of grey, buff, and green, giving the formation a distinctly banded appearance. In appearance it superficially may resemble the pre-Huronian iron formations. Well up in the formation a few layers of siliceous limestone, 2 to 3 inches thick, are interbedded with the chert-like quartzite. Ripple marks are common throughout the formation.

Under the microscope even the chert-like varieties prove to have clastic texture, according to Collins. They consist of a felted aggregate of shreds and scales of colourless mica (possibly kaolin) and chlorite, with occasional grains of quartz. The coarser varieties consist of angular particles of quartz and feldspar and partly decayed ferro-magnesian minerals with a tendency for the grains to vary from coarse at the bottom to fine at the top.

In Plummer Township, of the Bruce Mines area, the formation is estimated by Collins to be 700 feet thick. Logan and Murray (1863) estimated a thickness of 400 feet in one locality of the Bruce Mines area. In the Flack Lake area, Harding (1939) noted thin beds of greenish white and buff cherty quartzite, chiefly in Townships 1A and 157. The finely banded dark cherty quartzite, described by Emmons (1927), in Township 163 of the Wakomata Lake area, may actually belong to the banded cherty quartzite formation. The author stated that it grades both above and below, within 6 to 8 feet into white quartzite. In the report it was included with the Lorrain quartzite.

The formation is present in the Panache area, according to Quirke and Collins (1930), but here it is so highly disturbed that the thickness cannot be determined. In the Onaping area, much farther east, Collins (1917) mapped an ultra-fine-grained quartzite resembling chert. It is a banded rock that shows ripple marks in many places. A partial thickness of 100 feet is present in McGiffin Township, but the total thickness is probably twice as great.

Summary of the Banded Cherty Quartzite:

The banded cherty quartzite bears a remarkable resemblance to the Espanola formation. The fineness and regularity of the bedding and the occasional presence of limestone layers, indicate deposition of the formation in water. The gradation within the layers of coarse to fine material implies a rhythmic process of deposition, possibly by current action, suggested Collins (1925, p.70). The formation nowhere attains any great thickness.

THE UPPER WHITE QUARTZITE AND CHERTY QUARTZITE:

Collins (1925) stated that in the northwest corner of Plummer Township of the Bruce Mines area, the banded cherty quartzite is overlain by a white quartzite similar to the upper part of the Lorrain formation. Logan and Murray (1863) estimated this formation to be 1500 feet thick and overlain, in turn, by 200 feet of yellowish chert and impure limestone, similar to the previous chert band, and over this is more white quartzite.

In Townships 151 and 157 of the Flack Lake area, Harding (1939) reported the banded cherty quartzite to be overlain by a massive white quartzite, very similar to the upper part of the Lorrain. He stated it is the youngest Huronian rock present in this map area. In a contact, at Flack Lake, the white quartzite is found to lie unconformably on the banded cherty quartzite.

In the Onaping area, Collins (1917) stated the thickness of the white quartzite overlying the banded cherty quartzite is measurable in hundreds of feet.

RELATIVE AMOUNT OF ROCK TYPES

To secure some idea of the relative amounts of each rock type, the thickness of formations is extremely important, and also the area covered by formations. The problems involved in such calculations are serious and should be considered in weighing the accuracy of the results. Because of this a great deal of the foregoing discussion has been devoted to area and thickness.

Although these Huronian rocks are relatively undisturbed, compared to many Precambrian sedimentary rocks, still, they are folded and faulted in many localities. To determine the volume of rock in such a zone requires considerable data. This area has been the object of much investigation, yet our knowledge of the extent of these rocks is fragmentary in many cases. In part, this is due to heavy drift covering, and in part to lack of sufficiently detailed work.

Having been subject to erosion during the great length of time since the Precambrian, the uppermost members have been partially removed, so that the original thickness is unknown. Similarly, the Serpent formation was subject to erosion during the pre-Cobalt interval and its thickness is a problem. Thus, erosion is another feature that prevents the measurement of complete sections of these rocks.

In determining the relative quantities of the different rock types another problem is encountered. Some formations show great variation in lithologic character, both stratigraphically and along the strike. The Bruce conglomerate and the Gowganda formation are examples. To determine with any accuracy the amount of each rock type would require numerous closely spaced sections across the formation, which are not available.

Lack of internal structure may complicate the determination of thickness. In formations that lack stratification or bedding or distinctive horizon markers it is difficult to determine the dip of the formation in an outcrop.

The preparation of isopach maps to show the extent and thickness of the formations is not possible, for the information is insufficient. It is only in a limited number of localities that detailed sections are available. Instead, for the different map areas a simple table of formations of the Huronian rocks present is reproduced. Wherever possible, the measured or estimated thickness is given.

It is virtually impossible to get an accurate picture of the area covered by each formation. There are not sufficient detailed maps of localities covered by these Huronian rocks. To secure some idea of the general distribution of the formations, the Lake Huron Sheet (Map 155A) of the Geological Survey of Canada is invaluable. Since the area of each formation cannot be determined with any accuracy, only the thicknesses will be considered in calculating relative quantities of the rock types. This, of course, implies an incorrect assumption that the basin of deposition was much the same for each formation. There appears to be no means of avoiding this in the present state of limited information.

The following sections of Huronian rocks, from different areas, are taken from the various reports. In certain cases where exact thicknesses are not given of the rock types, an arbitrary estimate, based on the text, is given. In determining the percentages of rock types, arkose is grouped with quartzite and argillite with greywacke. This is necessitated by the failure of some reports to separate them.

SAULT STE. MARIE AREA

Upper Cobalt	-	700 feet white pure quartzite
		700 feet reddish quartzite
		400 feet greyish and greenish quartzite
Lower Cobalt (Gowganda)	-	120 feet quartzite
		150 feet boulder conglomerate
		200 feet slaty greywacke
		130 feet boulder conglomerate
Unconformity		
Bruce Limestone	-	100 feet or less (an erosion remnant)
Bruce Conglomerate	-	A few feet
Mississagi Quartzite	-	1500 feet, minimum (incomplete section)
Basal Mississagi	-	Absent ?
Probable Unconformity		
Aweres formation	-	2000 feet quartzite
		?? feet conglomerate and greywacke
		2000 feet quartzite
Duncan Greenstone	-	No estimate
Driving Creek Formation	-	2000 feet quartzite
		400 feet conglomerate

The approximate percentages of rock types, not including the doubtful Soo Series, are:-

Conglomerate	7%	Greywacke	5%
Quartzite	85%	Limestone	3%

BRUCE MINES AREA

Upper White Quartzite and Cherty Quartzite -

1500 feet (Plummer Township)

Banded cherty quartzite	- 700 feet
Lorrain quartzite	- 5500-6000 feet (northern part of area)
Gowganda Formation	- 3000-3500 feet - Estimated- 1800 feet greywacke 1500 feet conglomerate 200 feet quartzite
<u>Unconformity</u>	
Serpent quartzite	- 1000 feet or less
Espanola limestone	- A few feet
Espanola greywacke	- Unknown - perhaps 250 to 400 feet
Bruce limestone	- 150 - 200 feet
Bruce conglomerate	- 20 feet northern part, 40 feet southern part
Mississagi quartzite	- 1060 feet quartzite, a few feet of conglomerate
Basal Mississagi	- Impure quartzite and argillite - 275 feet Argillite -2600 feet Argillite conglomerate - 620 feet

Approximate percentages of rock types:-

Conglomerate	14%	Greywacke	30%
Quartzite	55%	Limestone	1%

One reason for the relative increase in greywacke (including argillite) is the development in this area of a great thickness of the Basal Mississagi.

WAKOMATA LAKE AREA

Lorrain	- No estimate
Gowganda	- No estimate
<u>Unconformity</u>	
Serpent Quartzite	- Thickness of main body unknown, although in one locality 100 feet of quartzitic conglomerate

Espanola limestone	- 20 - 25 feet, upper part not visible
Espanola greywacke	- 400 feet, approximately
Bruce limestone	- 150 feet (unreliable)
Bruce conglomerate	- 50 feet or less
Mississagi	- present, but no estimate
Basal Mississagi	- 600 - 1000 feet argillite, quartzite; - 100 feet quartzitic matrix conglomerate (eastern part of area)
	- 10 - 50 feet basal conglomerate - western part

Insufficient data to estimate the approximate percentages of rock types.

FLACK LAKE AREA

Upper white quartzite	- present
Unconformity	
Cherty quartzite	- present
Lorrain	- 2000 - 4000 feet
Gowganda	- 300 feet
Unconformity	
Bruce Series	- Conglomerates, greywackes, arkoses, quartzites not separated into formations

Insufficient data to estimate the approximate percentages of rock types.

BLIND RIVER AREA

Lorrain	- 6000 feet (estimate)
Gowganda	- 2500 - 3500 feet. Estimated - 300 feet quartzite, 1800 feet greywacke, 1000 feet conglomerate, 20 feet limestone

Unconformity

Serpent quartzite	- 1100 feet
Espanola limestone	- 0-50-75 feet
Espanola greywacke	- 250 - 350 feet
Bruce limestone	- 150 - 200 feet
Bruce conglomerate	- 30 feet boulder conglomerate
	6 feet calcareous silt
	35 feet coarse boulder conglomerate
	8 feet silty quartzite
	4 feet pebble conglomerate
Mississagi quartzite	- 1000 - 3000 feet (northern part)
	100 - 150 feet of argillite, 20 feet conglomerate within the quartzite
Basal Mississagi	- 10 - 50 feet conglomerate
McKim	- Undeterminable

Approximate percentages of rock types:-

Conglomerate	9%	Greywacke	17%
Quartzite	71%	Limestone	3%

The relative percentage of greywacke would be much greater if it were possible to obtain a thickness for the McKim formation.

LAKE PANACHE AREA

Banded cherty quartzite	- No estimate	
Lorrain	- 6500 feet	
Gowganda	- 2000 - 3500 feet.	Estimated - 1500 feet greywacke 1100 feet conglomerate

Unconformity

Serpent quartzite	- 1500 - 2500 feet
Espanola limestone	- 50 - 75 feet

Espanola greywacke	- 300 - 400 feet
Bruce limestone	- 150 - 200 feet
Bruce conglomerate	- 500 feet at least, perhaps 1000 feet
Mississagi quartzite	- 10,000 feet, including 20 feet of argillite
Basal Mississagi	- Several hundred feet of conglomerate
McKim	- Indeterminable

Approximate percentages of rock types:-

Conglomerate	8.5%	Greywacke	8%
Quartzite	83%	Limestone	0.5%

The greatly increased thickness of the Mississagi quartzite is accountable for the large increase in quartzite percentage.

ESPANOLA DISTRICT

Gowganda - 650 feet bedded conglomerate
400 feet greywacke and slate
400 feet slate conglomerate

Unconformity

Serpent quartzite	- 8000 feet ? 250 feet greywacke
Espanola limestone	- 25 feet
Espanola greywacke	- 280 feet
Bruce limestone	- 150 feet
Bruce conglomerate	- 400 feet - 28 feet quartzite

Slight Unconformity

Mississagi quartzite	- 4000 feet
McKim	- Undeterminable

Approximate percentages of rock types:-

Conglomerate	10%	Greywacke	6%
Quartzite	83%	Limestone	1%

The increase of conglomerate over greywacke may be partly due to terminology. Some material classed as slate conglomerate by one author might be called slate or argillite by another.

SUDBURY AREA

DRYDEN AND FALCONBRIDGE TOWNSHIPS

Serpent quartzite	- less than 3000 feet
Bruce and Espanola limestone	- 30 feet
Espanola greywacke	- 500 feet
Bruce conglomerate	- at least 2000 feet, including 200 feet of quartzite
Mississagi quartzite	- 8000 feet of quartzite and some argillite
Ramsey Lake Formation	- 450 feet, grit, conglomerate, quartzite
McKim Formation	- 7000 feet greywacke, chiefly

Approximate percentages of rock types:-

Conglomerate	10%	Greywacke	36%
Quartzite	54%	Limestone	negligable

The large increase in the relative percentage of greywacke is due to the inclusion of the McKim greywacke in this area.

ASHAGAMI LAKE AREA

Gowganda	- No estimate
Unconformity	
Serpent quartzite	- No estimate
Espanola limestone	- Absent
Espanola greywacke	- 300 feet
Bruce limestone	- 250 feet
Bruce conglomerate	- 600 feet
Mississagi quartzite	- 6000 feet
Ramsey Lake Formation	- No estimate
McKim Formation	- Absent

Insufficient data to estimate the approximate percentages of rock types.

WANAPITEI LAKE AREA

Lorrain	- 5000 feet
Gowganda	- 3500 feet. Estimate - 2000 feet greywacke, 1500 feet conglomerate

Uncomformity

Serpent quartzite	- 800 feet (erosion remnant)
Espanola limestone	- Absent
Espanola greywacke	- 400 feet
Bruce limestone	- 200 - 600 feet
Bruce conglomerate	- 800 - 1000 feet
Mississagi quartzite	- 3000 - 5000 feet
Basal Mississagi	- 50 feet conglomerate

Approximate percentages of rock types:-

Conglomerate	16%	Greywacke	16%
Quartzite	65%	Limestone	3%

MOOSE MOUNTAIN - WANAPITEI AREA

Lorrain	- No estimate
Gowganda	- 1000 feet conglomerate, 1000 feet greywacke quartzite and limestone

Unconformity

Serpent	- No estimate
Espanola limestone	- May be present
Espanola greywacke	- No estimate
Bruce limestone	- No estimate
Bruce conglomerate	- Probably present
Mississagi quartzite	- 2000 feet

Insufficient data to estimate the approximate percentages of rock types.

GENEVA MAP AREA

Lorrain	- 1700 feet
Gowganda	- 1200 feet conglomerate and greywacke
Unconformity	
Serpent	- 600 - 700 feet, greywacke, conglomerate and quartzite
Espanola Formation	- (Bruce limestone, Espanola greywacke and limestone 90 - 120 feet
Bruce conglomerate	- Absent
Mississagi quartzite	- 300 feet
Basal Mississagi	- 170 feet conglomerate

Approximate percentages of rock types:-

Conglomerate	15%	Greywacke	29%
Quartzite	56%	Limestone	negligible

Information is not detailed for this area, but the above figures are believed to be approximately correct.

ONAPING MAP AREA

White quartzite	- Several hundred feet
Banded cherty quartzite	- 100 feet at least
Lorrain	- 2000 feet, more likely 3000 feet
Gowganda	- 10 - 200 feet conglomerate
	0 - 2800 feet greywacke
	20 feet limestone

Approximate percentages of rock types:-

Conglomerate	3%	Greywacke	45%
Quartzite	52%	Limestone	negligible

The high percentage of greywacke in this case is due to the use of the maximum amount of greywacke in the Gowganda for the calculation.

GOWGANDA MINING DIVISION

Lorrain	- 600 feet known, probably much more
Gowganda	- 500 - 1000 feet. 0 - 200 feet conglomerate Remainder greywacke, argillite, quartzite and arkose

Approximate percentages of rock types:-

Conglomerate	10%	Greywacke	29%
Quartzite	61%	Limestone	nil

These are only estimates as the figures are very incomplete.

KEWAGAMA LAKE AREA, QUEBEC

Gowganda - 750 feet conglomerate (Kekeko Hills)

90 feet conglomerate; 150 feet arkose;

250 feet argillite (Mount Shimnis)

70 feet conglomerate - ?? 365 feet;

250 feet arkose (Swinging Hills)

These figures are too incomplete to give any idea of approximate percentage of rock types.

COBALT AREA

Lorrain) - 300 feet Maple Mountain, Whitson Township
)550 feet
) at
Gowganda)Cobalt - 300 feet, (Midlothian Township)

100 feet conglomerate

315 feet greywacke

135 feet quartzite (Mount Chemaniss)

Approximate estimate of percentages of rock types:-

Conglomerate	7%	Greywacke	22%
Quartzite	71%		

TEMISKAMING COUNTY, QUEBEC

Lorrain or Ville Marie quartzite - No estimate

Gowganda - ? feet conglomerate

0 - 300 feet argillite

0 - 250 feet quartzite arkose

0 - 90 feet conglomerate

Figures are too limited to determine approximate percentages of rock types.

ANIMA-NIPISSING LAKE AREA

Lorrain - 100 - 250 feet

Gowganda - Conglomerate (erosion remnant), greywacke and a little quartzite

Insufficient data.

MATABITCHUAN AREA

Lorrain - No estimate

Gowganda - 70 - 80 feet conglomerate

90 - 100 feet greywacke

20 - 35 feet quartzite

90 feet conglomerate

Insufficient data.

SUMMARY TABLE

AREA	PERCENTAGES			
	CONGLOMERATE	QUARTZITE	GREYWACKE	LIMESTONE
Sault Ste. Marie	7	85	5	3
Bruce Mines	14	55	30	1
Blind River	9	71	17	3
Lake Panache	8.5	83	8	0.5
Espanola	10	83	6	1
Dryden and Falconbridge Townships	10	54	36	--
Wanapitei Lake	16	65	16	3
Geneva	15	56	29	--
Onaping	3	52	45	--
Gowganda Mining Division	10	61	29	--
Cobalt	7	71	22	--
TOTAL, as percentages	10%	67%	22%	1%

From an examination of these figures, it is evident that quartzite is by far the most abundant rock type. From the estimates given here it seems that about 67% of these Huronian rocks are quartzite. Greywacke, forming about 22% of the whole, is the next largest group. This is followed by conglomerate, which forms about 10% of the whole - actually an exceptionally large percentage for any group of rocks. Limestone, a very minor rock type, totals only about 1% of these Huronian rocks.

In the following table the percent of rock types in each area is multiplied by the thickness. The totals give values which are the weighted percent of the rock types in the areas for which sufficient information is available.

AREA	CONGLOMERATE	QUARTZITE	GREYWACKE	LIMESTONE
Sault Ste. Marie	1,960	290,500	1,000	300
Bruce Mines	30,400	473,000	141,900	180
Blind River	11,160	667,500	37,900	1,035
Lake Panache	17,000	1,533,000	14,800	125
Espanola	14,500	996,000	5,580	175
Dryden and Falconbridge Townships	21,500	610,000	270,000	--
Wanapitei	39,200	636,000	38,400	1,200
Geneva	9,300	128,800	34,560	--
Onaping	600	171,500	126,000	--
Gowganda Mining Division	2,200	67,100	14,000	--
Cobalt	700	73,500	6,930	--
	148,520	5,646,900	691,070	3,015
Weighted percent of rock types	2.3%	87%	10.7%	Negligible

The weighted percents indicate a still greater proportion of quartzite than do the simple average percents.

Geological Implication:

In a normal sedimentary sequence the rocks composed of mud material are a great deal more abundant than rocks formed from sand, i.e. quartzite or sandstone. Yet the previous tables show the tremendous emphasis on sand-type rocks in this area. The locus of deposition is evidently one of the major points involved in any explanation of this anomaly. Three localities of deposition should be considered; 1. in a geosynclinal trough, 2. under terrestrial conditions, and 3. in an epicontinental sea. In this area the third one may be ruled out for the thickness of the sediments deposited is too great for deposition to have occurred in an epicontinental sea. There are then two choices of deposition of these sediments. From the foregoing descriptions of the various formations it appears very likely that a combination of terrestrial and geosynclinal sediments is present.

Indications are that the geosyncline had an approximately east-west trend. It would seem that much of the material for the sediments was derived from high land that lay north of the trough. The increasing thickness of the Mississagi quartzite from north to south supports this idea.

Terrestrial conditions of deposition are suggested by some parts of the Gowganda and Cobalt formations in the northern parts of the area. Various evidences of this type of deposition are mentioned in the summaries of the formations.

In considering the absence of the mud there are two possibilities - either it was made but has since disappeared, or it was never present. If it was made the logical place for it to appear would be south of the sand type rocks of the geosyncline. However, this part of the trough is not available for study. What caused the disappearance of a part of the trough can only be conjectured, but it is likely some great diastrophic disturbance was responsible.

If the mud was never formed an explanation must be sought in the type of environment in which the sediments were deposited. A process of disintegration under arctic conditions is one which gives a minimum of mud. Desert disintegration also gives great amounts of sand with little mud. Some parts of the Gowganda formation may have been produced under arctic conditions, and Miller has suggested some parts of the Lorrain quartzite near Cobalt were formed under desert conditions.

It appears likely that the preponderance of sand over mud is due to a combination of several factors - environment of the sediments and disappearance of a part of the trough.

The limestone percentage is extremely meagre in all these rocks. It may be that conditions were not favourable for its production or that any large quantity of limestone produced was deposited in a part of the trough since swallowed up. Normally, if the source was to the north, the succession from south to north would be limestone, shale, sandstone. If the shale member is mostly missing, so much more the limestone.

CRITICISM OF THE LITERATURE UTILIZED

After reading some sixty-five reports, not only on this group of Huronian rocks but also others of the Canadian Shield, it was apparent that some suggestions could be made for their improvement. Whereas some authors are notably complete in their reports, others tend to overlook certain features.

The description of rock types in some reports leaves something to be desired. This is particularly true in the case of greywacke and argillite. The variety in the definitions of these terms is wide, and few of the authors state the definition they follow. Seldom are sufficient details given about the rock to enable the reader to draw his own conclusions. More detailed microscopic descriptions would be valuable in some cases in determining the origin of the rock. An opposite extreme is met in cases where an area of rocks has suffered extreme metamorphism. Very detailed descriptions of such rocks, where a slight change in chemical composition affects the appearance of the resultant rock so much, are of slight value. Unless the differences in composition can be traced back to the original rocks, extremely detailed descriptions are not worthwhile.

One of the problems met with constantly in the compilation of data in this thesis was lack of information about the thickness and extent of formations. It is realized that in many localities, due to lack of outcrop, it is not possible to get such information. If an estimate is made, possible limits of variation should be included so that some idea of the accuracy is given.

The structure of the formations is often quite neglected in the reports, or only sketchily described. This is to be expected in some cases where large areas were mapped in short periods of time. In the more detailed reports, however, more detailed studies of the structure might prove rewarding.

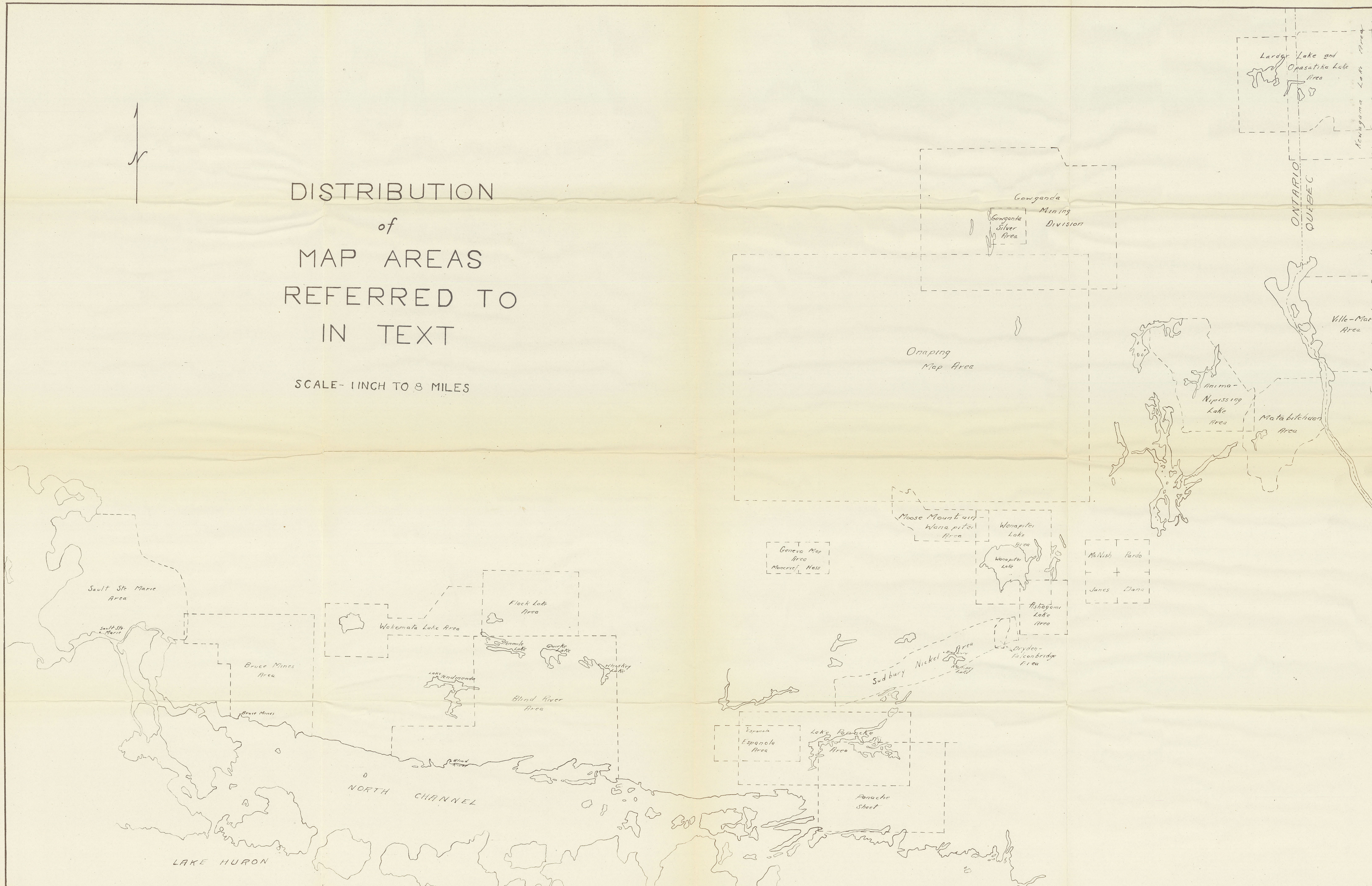
In nearly all cases unconformities are well described in the reports. Some of the earlier reports placed too much emphasis on local unconformities, a natural mistake when work is in the early stages. This led to confusion in the correlation from area to area in certain cases, and caused the introduction of local formation names, such as Aberdeen quartzite, now no longer used.

Correlation is a difficult problem unless there is a distinctive stratigraphic succession. Some authors simply describe the formations found in an area, but do not discuss the possible correlation of the rocks with those of adjacent areas. It is easier for the writer, who has seen the rock in the field, to suggest such a correlation than for a reader, who only has the reports to follow.

The origin of certain formations is an extremely controversial subject, and some reports present complete discussions of the problems involved. On the other hand, certain authors tend to overlook facts in order to favour a certain theory of origin. It is possible, though, by reading a number of reports to assess all the arguments. It is a noticeable weakness that, while the origin of certain distinctive formations is discussed at length, the origin of the more commonplace types is scarcely mentioned. Whether the authors feel that the origin is obvious or the facts are insufficient, is not clear.

For this area of Huronian rocks it is difficult to pick out any areas that would yield valuable new data concerning these rocks. Very thorough work has been done in the key areas of this band of sedimentary rocks, particularly by W.H. Collins. One locality that might be worth further study is that between the Bruce Mines area and the Sault Ste. Marie area. New facts that might lead to a recognition of a possible relationship between the Soo Series and the Basal Mississagi formation, might be revealed by intensive study in this area. More detailed work in practically any of the areas would probably add to the accuracy of estimates of the extent and the thickness of the formations. However, unless some distinct and practical advantage would be forthcoming from such a study, it seems unlikely that such work would be undertaken on a large scale by any government or private organization. One possible result might be the establishment on a firm footing of the existence of placer deposits on some of the unconformities. Gold and diamonds might suitably be looked for there. The type of weathering of the uplands might favor or preclude the search for kaolin, bauxite and other materials.


AREA IN RELATION
to
the CANADIAN SHIELD
Scale -
0 50 100 200
Miles
HUDSON
BAY
THE CANADIAN SHIELD
AREA
DISCUSSED
UNITED STATES
of
AMERICA


DISTRIBUTION
of
MAP AREAS
REFERRED TO
IN TEXT
SCALE- 1 INCH TO 8 MILES
N
Larder Lake and Opasatika Lake Area
ONTARIO
QUEBEC
Gowganda Mining Division
Gowganda Silver Area
Onaping Map Area
Ville-Marie Area
Anima-Nipissing Lake Area
Matabitchuan Area
Moose Mountain-Wanapitei Area
Wanapitei Lake Area
Wanapitei Lake
Geneva Map Area
Moncrief
Hess
McNish
Pardo
Janes
Dana
Pishagomi Lake Area
Dryden-Falconbridge Area
Sudbury Nickel Area
Sault Ste Marie Area
Sault Ste Marie
Bruce Mines Area
Bruce Mines
Wakemata Lake Area
Flack Lake Area
Blind River Area
Blind River
Quirke Lake
Whiskey Lake
Espanola Area
Espanola
Lake Panache Area
Panache Sheet
NORTH CHANNEL
LAKE HURON