THE GEOLOGY
OF THE
SAULT STE. MARIE MAP-AREA

BY

R. E. HAY

A Thesis Submitted to the Department of Geological Sciences at McGill University in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy.

McGill University, December 1963

Montreal, P.Q.

TABLE OF CONTENTS

PAGE

PAGE

PAGE

LIST OF PLATES

PAGE

LIST OF TABLES

LIST OF FIGURES

PAGE

ACKNOWLEDGEMENTS

The writer is greatly indebted to the Geological Survey of Canada for the opportunity to map the Sault Ste. Marie area as a thesis project. The author is especially grateful to M.J. Frarey of the Geological Survey of Canada for his many helpful suggestions in the field. Dr. Frarey personally spent many hours showing the author type sections in the area east of Sault Ste. Marie.

Dr. P.R. Eakins supervised the research at McGill, and to him many thanks are in order. R. Dean, a fellow student at McGill, is thanked for his help in the refractive x ray work on the clay constituents of the Gowganda argillite.

The field assistants during mapping were G. Maclean, G. Koleszar, W. Kisluk, E. Zodrow, and L. Moxham. The writer was fortunate to have such able assistants. During the field mapping, the local residents proved very helpful. Amongst these, A.B. Smith, D. Pine, M. Pine, J. Wilson, and J. Beleau deserve special mention. Many interesting hours were spent in conversation with H.G. Morris; Mr. Morris had worked as a guide for McConnell during the 1925 mapping project, and also has prospected throughout

most of the Sault Ste. Marie map-area.

The writer was supported by a Shell Oil Fellowship, and by the LeRoy Fellowship while at McGill.

FRONTISPIECE

Plate 1: Late pegmatite dyke cutting diabase dyke and early granite and gneiss complex. South of Elizabeth Lake, Duncan Township.

CHAPTER 1

INTRODUCTION

INTRODUCTION

GENERAL STATEMENT

The Sault Ste. Marie map-area lies at the western end of the Huronian belt along the north shore of Lake Huron. It includes rock formations that range in age from highly metamorphosed early Precambrian basement rocks to unmetamorphosed, flat-lying Cambrian sediments and unconsolidated Pleistocene glacial materials.

The rock formations of the Sault Ste. Marie area have been arranged by earlier workers (McConnell 1926) into five major structural and stratigraphic elements, each quite distinct in age and character. These five divisions are, from the oldest to the youngest:

(1) Early Precambrian or basement rocks, consisting of granite and granite gneiss intruding amphibolite and metasediments.

(2) A local sedimentary series termed the Soo Series consisting of andesitic lavas associated with large thicknesses of clastic sediments.

(3) A thick series of Huronian sediments overlying the Soo Series with large angular unconformity and consisting largely of clastic sediments. This group of Huronian rocks is further subdivided into an older Bruce Group, and a younger Cobalt Group, the Cobalt overlying the Bruce with

slight angular unconformity. These rocks are intruded by granite batholiths of Killarney age and by smaller basic intrusives of Keweenawan age.

(4) Palaeozoic sedimentary formations which rest with profound unconformity on the Huronian and earlier rocks.

(5) Unconsolidated Pleistocene glacial sediments and lake sediments.

The relationships of these groups are illustrated on McConnell's map (Fig. 1) of the Ontario Department of Mines (McConnell 1926).

Pre-Huronian basement rocks underlie about one half of the map-area and consist of a highly metamorphosed series of lavas, tuffs, and sediments. It represents an assemblage of rocks similar in many respects to the Keewatin rocks of northwestern Ontario (Lawson 1885) but of too indefinite correlation to name it anything but "pre-Huronian". During mountain building large batholiths of granite were intruded into the overlying lavas and sediments, resulting in widespread metamorphism and deformation. With deep erosion of the pre-Huronian mountains granite and granite gneiss were exposed over large areas and the volcanic materials and sediments remained only as minor infolded remnants.

From 10,000 to 30,000 feet of Huronian sediments were deposited with great unconformity on the pre-Huronian planated surface. The 3000 to 4000 feet of Soo Series sediments which were previously grouped as pre-Huronian by McConnell (1926) or perhaps early Huronian are here grouped with the lower Huronian. The Huronian sediments are divided into two major groups, the Bruce Group consisting of quartzite, conglomerate, limestone, and minor volcanic material and including rocks of the Mississagi, Duncan, Bruce, Aweres, Espanola, and Serpent formations and the Cobalt Group consisting of argillite, greywacke, and polymictic conglomerate and including rocks of the Gowganda and Lorrain formations. The Cobalt Group overlies the Bruce Group with slight angular unconformity and extends north of the Bruce, where it overlies the basement rocks directly.

Cobalt and Bruce rocks have been intruded by sills and dykes of diabase and related rocks, which are regarded as equivalent in age to the Keweenawan rocks south of Lake Superior. A second stage of granite, intruded in Killarney time, cuts the diabase and Huronian sediments and has caused local metamorphism in the sediments (McConnell 1926). In the Sault Ste. Marie map-area this granite, originally classified as Killarney, or at least as post-Huronian, is now included with the basement complex. Late olivine-diabase dykes cut all earlier rocks.

Following folding and faulting of the Huronian sediments and later planation, Palaeozoic seas encroached upon the land and deposition of Cambrian sandstones and Ordovician limestones occurred. These lie with large angular unconformity on the Huronian and basement rocks. If late Palaeozoic or Mesozoic rocks were deposited in the area they have been removed by erosion.

Unconsolidated Pleistocene glacial materials and lake sediments cover the lowlands, especially in the area immediate to the north shore of Lake Huron and on the east coast of Lake Superior. Over twenty different glacial lake stages are illustrated in the Sault Ste. Marie area alone.

Current mapping shows the major geological problems of the area to be:

(1) The relation of the Soo Series to the Huronian and to the basement rocks.

(2) Separation of the Mississagi and Serpent quartzites, which are quite similar in lithology and composition.

(3) The relation of the Aweres formation to the Mississagi and Serpent formations.

(4) The age of the granite batholiths within the area.

(5) The origin of the Gowganda "tillites" and bedded argillites.

(6) The nature of the contact between the Bruce Group and the Cobalt Group.

(7) The nature of the contact between the Palaeozoic rocks and the Precambrian rocks along the escarpment north of the St. Mary's River.

FIELD METHODS

Mapping was carried out using standard techniques of the Geological Survey of Canada for whom the work was being done. Enlargements of one-mile topographic sheets of the National Topographic series were used as base maps. Field work was plotted directly on vertical air photographs on a scale of 1000 feet to the inch. Location of points on the photographs was made by either pace and compass traverses from known points, or by direct visual examination of the photographs. Information was transferred from the photographs by means of a vertical sketchmaster. Mapping for final publication was done on a scale of one mile to the inch.

Transportation facilities used during mapping included a hydroplane, jeep, and canoe.

LOCATION AND ACCESS

The Sault Ste. Marie map-area is located in the District of Algoma of North Central Ontario, between latitudes 46°30' and 46°45', and longitudes 84°00' and 84°30'. It constitutes map-area 41 K/9 of the National Topographic Series. The area is bounded on the west by Lake Superior and on the south by the St. Mary's River. The north end of Lake Huron lies approximately thirty miles to the east. Sault Ste. Marie, Ontario, a city of 43,000 population and the judicial seat for the District of Algoma, lies along the St. Mary's River in the south part of the area. The International Boundary between Canada and the United States follows the channel of the St. Mary's River.

The Ile Parisienne map-area was completed in conjunction with the Sault Ste. Marie map-area. It lies immediately west of the Sault Ste. Marie map-area and is bounded by latitudes 46°30' and 46°45', and longitudes 84°30' and 85°00'. Much of the area represented on this map-sheet is covered by the waters of Lake Superior. It is map-sheet 41 K/10 of the National Topographic Series.

Various transportation facilities are available to the area. The Canadian Pacific railway connects Sault Ste. Marie with the large nickel-copper mining district of Sudbury, approximately 179 miles to the east, and with the railway network of Southern Ontario. Railway service to the north is provided by the Algoma

Central railway which joins Sault Ste. Marie with the Algoma Steel Corporation Mines at Michipicoten and with the transcontinental line of the Canadian National Railway. Several railways to Sault Ste. Marie, Michigan, connect the area to the United States' railway network.

The new Trans-Canada Highway (Ontario Number 17) follows the north shore of Lake Huron and the St. Mary's River from Sudbury, Through Blind River to Sault Ste. Marie, where it turns north and follows the shore of Lake Superior to Port Arthur, Ontario. Highway connection to the south is provided by the highway system of the State of Michigan. A ferry service now connects Sault Ste. Marie, Michigan, and Sault Ste. Marie, Ontario, but construction of a high-level bridge commenced in the fall of 1960. A railway bridge was in operation for some time but service is now discontinued. The construction of the Michilimackinac bridge across the mouth of Lake Michigan has connected the area more closely to the heavily industrialized section of Southern Michigan.

Docking facilities for all ships, except the large ocean freighters, are available along the St. Mary's River in the vicinity of Sault Ste. Marie. The ore docks of the Algoma Steel Corporation, alone, handle several million tons of material annually. The "Soo Canals" in the St. Mary's River enable large lake freighters to pass from Lake Superior to the lower lakes.

A Federal Department of Transport Airport and Terminal near Sault Ste. Marie is in the final stages of completion. Regular Trans-Canada Airline service is provided for the area. Smaller craft and hydroplanes are able to land at the seaplane base and airfield at Leigh Bay, two miles west of Sault Ste. Marie, or at the Department of Lands and Forests' docks in Sault Ste. Marie, Ontario. Kincheloe Airforce Base, a strategic air command base of the United States Airforce, is located in Michigan, just south of Sault Ste. Marie.

AREA

The Sault Ste. Marie map-area encloses an area of about 400 square miles with dimensions of 17.5 miles in a north-south direction, and 23.5 miles in an east-west direction. Several areas of the United States, including parts of the city of Sault Ste. Marie, Michigan, and Sugar Island, Michigan, project into the southern part of the map-area, but these are not included in the present mapping.

The Garden River Indian Reserve, an area of forty-five square miles, occupies the southeast part of the map-area. About twenty square miles in the northwest part of the area is covered by the waters of Goulais Bay. Possibly as much as 100 square miles of the 400 square miles is overlain by Late Pleistocene lake sediments.

The Ile Parisienne map-sheet encloses a land area of about twenty square miles, while the rest of the area is covered by the waters of Lake Superior.

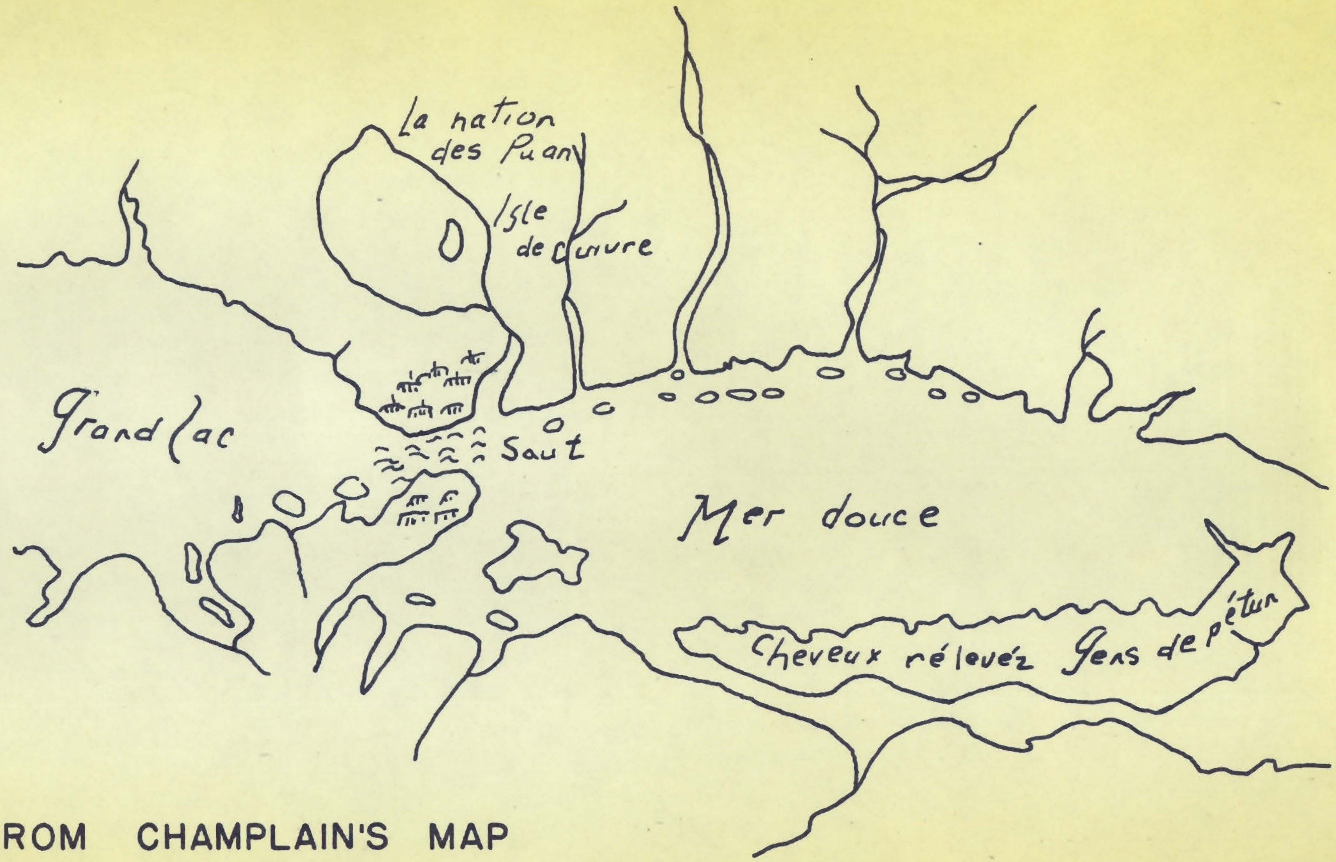
HISTORY

The Objibwa Indians, a branch of the Algonkin Nation, were the first inhabitants of Algoma. Henry Rowe Schoolcraft, American ethnologist and explorer, coined the word 'Algoma', which he advocated as the name for Lake Superior in recognition of the Objibwa claim to it as the Algonkin Sea. He obtained 'Al' from Algonkin, and 'goma' as a variant of gum-ee or go-m-ee, meaning waters. The rapids in the river marked a gathering spot for Indian tribes. Here, because of open water all year round, they could take the giant whitefish. They named it Pauwating or Bawating, the "place of the water over the stones". This is the area of the Objibwa hunting and fishing ground which is immortalized by Longfellow in his poem "Hiawatha".

The theory that the Norsemen were the first white men to visit the area is supported by the finding of a Norse spearhead, in the 1930's, at Gros Cap on Lake Superior.

The recorded history of the city of Sault Ste. Marie dates back as early as the 17th century, to the days of the great Canadian explorer and colonizer, Samuel de Champlain. In 1622, two French explorers, Etienne Brule and Grenolle visited the rapids at Sault Ste. Marie and gave them the name "Sault du Gaston" in honour of a younger brother of Louis X111 of France. Champlain marked it on his map of Canada in 1632 (Figure 2). As early as 1665, reports of copper-finds were sent out from the Lake Superior area by the Jesuit missionary-explorers.The first permanent settlement was made, on the south bank of the river, by Father Marquette, a Jesuit explorer, who established the mission of Ste. Marie du Sault in 1668.

Shortly after 1689, when the mission was abandoned because of an Iroquois invasion, a French fort was built on the north bank of the river. The site of this fort later became the base of operations of the Northwest Fur Trading Company, and still later, of the Hudson Bay Company. During the "hey-day" of the fur trade, Sault Ste. Marie was the central mart for the whole northwest. In 1762 a British garrison took possession of the fort. The region was under British rule until 1867 when confederation of the provinces created the Dominion of Canada.



FROM CHAMPLAIN'S MAP OF NEW FRANCE 1632

FIGURE 2

In 1797-1798 the first canal was excavated on the north shore to facilitate the movement of the heavily-laden bateaux to and from Lake Superior. In 1813 the settlement was completely destroyed by American naval forces.

In 1858 Algoma became a judicial district with Sault Ste. Marie as its headquarters. In 1871 it was incorporated as a village, and in 1887, as a town. At this time the line of the Canadian Pacific Railway to Sault Ste. Marie was constructed. In 1895 the Canadian lock of the "Soo Canals" was built. Sault Ste. Marie became a city in 1912. In the sixty years between 1858 and 1918 Sault Ste. Marie's population increased from 300 to over 21,000, with the major increase taking place after 1900.

INDUSTRY

During the 1840's mining interest commenced with the opening of the copper deposits at Bruce Mines, which is about forty miles east of Sault Ste. Marie. Sir William Logan and Alexander Murray made the first geological interpretation of the area in 1842. Industrial development began around 1890 with the establishment of the Algoma Steel Corporation mills in Sault Ste. Marie, Ontario. Since then, industry and settlement have increased to the point where now the area is heavily industrialized with a population of about 60,000.

Sault Ste. Marie is situated on the St. Mary's River at the very heart of the world's greatest inland waterway system, the St. Lawrence Seaway. The first lock was built in 1876, and since that time four additional locks have been constructed so that now five parallel locks pass more tonnage in nine months than the Suez and Panama Canals, combined, pass in one year. Iron ores from Minnesota, and wheat from Western Canada are the main commodities shipped through the canals.

The Algoma Steel Company mills commenced production in 1900 as a small plant to smelt the soft hematite ores from the Old Helen Mine in the Michipicoten area. Since then, with the opening of new mines, and with the increasing production from the steel mills, the company has grown to be the second largest producer of iron and steel products in Canada, being exceeded only by the Stelco Plant in Hamilton, Ontario. The Sault Ste. Marie mill is the only furnace in the world which recovers iron from siderite-type ores. When it is in full operation the mill employs about 8,600 men.

The worldwide Mannesman A.G. recently constructed a twenty million dollar seamless tube mill in Sault Ste. Marie. The plant normally employs about 500 men, but during the summer of 1960 the company shut down because of lack of market for their products. Production was resumed in the fall of 1960.

The Dominion Bridge Company steel-fabricating plant was located in Sault Ste. Marie because of the proximity of the Algoma Steel Corporation. A chromium smelter was operated in Sault Ste. Marie for several years, but it has been closed for about the past ten years. Raw materials were being transported from several small chromite mines in Eastern Quebec. The product was used by the Steel Company for the manufacture of alloys.

Lumbering is the second major industry in the area. The Abitibi Pulp and Paper Company produces numerous types of paper products. The Roddis Lumber Company operates a veneer and lumber mill. Logging operations are carried on in the dense bushland, north of Sault Ste. Marie.

The tourist industry has brought many millions of dollars to the area. The proximity of good fishing and hunting grounds has attracted American visitors in large numbers. The opening of the Trans-Canada Highway should increase this trade considerably.

Low cost hydro-electric power is supplied by two generating stations of the Great Lakes Power Company.

One station is located at Sault Ste. Marie, on the St. Mary's River rapids, and a second station is located in the Montreal River Canyon, 92 miles north of Sault Ste. Marie.

Sault Ste. Marie is the headquarters for the Provincial Air Service of the Department of Lands and Forests. In conjunction with this, two research stations, the Forest Insect Laboratory and the Laboratory of Insect Pathology, are operated by the Federal Department of Agriculture in co-operation with the Provincial Department of Lands and Forests.

HISTORY OF GEOLOGICAL INVESTIGATION

The north shore area of Lake Huron has been of interest to geologists since the first discoveries of copper in the Bruce Mines area in 1842. Since then, hundreds of geologists have visited the area and numerous correlations and stratigraphic sequences have resulted from their work.

Sir William Logan, first director of the newly formed Geological Survey of Canada, with the assistance of Alexander Murray, made several reconnaissance surveys through the north shore area to investigate and report on the copper occurrences in the Bruce Mines region. Logan had just completed surveys in the complex Grenville rocks along the St. Lawrence River, and he believed the relatively unmetamorphosed Huronian rocks of the north shore to be of a considerably younger age than the Grenville rocks. Although they were completely unfossiliferous, he placed the Huronian in the Lower Palaeozoic (Logan 1851). Logan described a sequence of rocks below the Huronian rocks, and these he termed the "Lower Copper-Bearing Series", placing the sequence equivalent to the Timiskaming Series.

Logan (1851) classified the Huronian rocks as follows:

"On Lake Huron the Lower Silurian group rests unconformably upon a silicious series, with only one known band of limestone, 150 feet thick, with leaves of chert in abundance but as yet without discovered fossils. This series is supposed to be of the Cambrian epoch. It comprehends the copper-bearing rocks of that district, and with its igneous, interstratified masses has a thickness of at least 10,000 feet."

Murray failed to recognize Logan's younger unconformity and correlated all the relatively unmetamorphosed sediments with Logan's Timiskaming type. Murray (1853-54) was the first to employ the term "Huronian" although he used it, apparently, in a geographical sense only, as did T.S. Hunt (1855). By the time of publication of Logan's "Geology of Canada" the term Huronian was widely accepted in geological literature.

Murray (1848) presented the first detailed description of Huronian and older rocks in the north shore area. Excerpts from his description are as follows:

"The older groups observed consist firstly of a metamorphosed series, composed of granitic and syenitic rocks in the form of gneiss, mica slate, and hornblende slate, and secondly of a stratified series, composed of quartz rock or sandstones, conglomerate, shales and limestones, with interposed beds of greenstone. On a cluster of small islands granite was found breaking through the quartz rock. The colour of the rock was red. On one of the islands quartz beds on opposite sides of the granite were observed to dip in opposite directions, north on the north side and south on the south side, at an angle of 70^{o} or 80^{o}, and in another of the islands the quartz rock and granite were seen in juxtaposition, the former reclining on the latter."

This would seem to indicate that even at a fairly early date it was recognized that, in places, upper members of the Huronian rocks rested directly upon the lower, highly metamorphosed, basement rocks.

Murray described the quartzite rock as follows:

"The rocks of this group, where they come under our observation, like those examined the previous season further to the west, were found to be partly of aqueous and partly of igneous origin. The former consisted of sandstones, conglomerate slates, and limestones; the latter of beds of trap and trap dikes. The prevailing colour of the sandstones was white, sometimes with a tinge of pale green; often the colour was gray. The rock was always very siliceous, and most frequently fine grained, in some cases so close a texture as to assume the aspect of a compact crystalline quartzite; but sometimes it was sufficiently coarse to constitute a fine conglomerate, of which the component grains and pebbles were by far the greater part of quartz; but in the beds of coarser quality, pebbles of red or gray syenite occasionally occurred; some red jasper pebbles were observed in one or two places imbedded in white quartz rock, but they were by no means numerous, and they were confined to the upper portion of the formation."

This appears to be a description of the Lorrain quartzite, although it is possible that at that time Murray grouped the Mississagi and Lorrain together, or at least did not differentiate between them.

Murray's description of the slate layers of the Upper Slate conglomerate follows fairly closely with a description of the Cobalt argillite and conglomerate.

"The more purely argillaceous portions of the slate were generally black, or of a very dark brownish tinge, and, in these, a very symmetrical jointed structure, dividing the rock into rhombohedral forms of considerable regularity, was frequently recognized. The slates were very often observed to pass into a conglomerate holding pebbles of granite or syenite chiefly, varying in diameter from an eighth of an inch to a foot, and imbedded in a black argillaceous matrix. The limestones observed, though of minor importance as regards thickness, were of a marked character, and in most respects bore a strong resemblance to those associated with the quartz rock formations at the western end of the north shore of Lake Huron. They consisted of calcareous beds of a dark blue colour interstratified with layers in which lime appears to be altogether absent, the composition of these being almost purely siliceous or argillaceous. The outcropping edges presented alternations of thin, sharp ridges and grooves. No organic remains of any kind were found associated with any of these sedimentary rocks, but distinct ripple mark was frequently observed on the surfaces of the slates and sandstones."

By the time of publication of Logan's "Geology of Canada", Logan and Murray had worked out a rather complete section for the Huronian rocks of the district. This was presented in "The Geology of Canada" (1863), and Collins (1925) compared this section with the one that he obtained in the Bruce Mines area. Collins' comparison is illustrated in Table No. 1.

Table No. 1

Logan & Murray	Feet	Collins	Feet
(not mentioned)		Olivine Diabase	
(not mentioned)		Killarney Granite	
Greenstone		Diabase Intrusives	
		Thessalon Greenstone (Keweenawan Series)	
		(Irruptive Contact)	
White Quartzite	400	(Not Fully Investigated) Logan and Murray's statement accepted as substantially correct.	
Yellow Chert & Limestone	200		
White Quartzite	1500		
Yellow Chert & Limestone	400	Banded Cherty Quartzite	700
White Quartzite	2970	Lorrain Quartzite	5500-6500
Red Jasper Conglomerate	2150		
Red Quartzite	2300		
Upper Slate Conglomerate	3000		
(Not Mentioned)		Unconformity	
(Not Mentioned)		Serpent Quartzite	1100
(Not Mentioned)		Espanola Limestone	0-75
(Not Mentioned)		Espanola Greywacke	250 - 400
Limestone	300	Bruce Limestone	150 - 250
Lower Slate Conglomerate	1280	Bruce Conglomerate	20 - 500

Table No. 1 Continued

	Feet		Feet
White Quartzite ----	1000	Mississagi Quartzite -	1000 - 12000
Chloritic Slates# ---	2000		
Grey Quartzite ----	500		
Unconformity		Major Unconformity	
		Pre-Huronian Granite Gneiss	
Laurentian -----		Pre-Huronian Sediments	
		Pre-Huronian Schist-Complex	

Equivalent to the Thessalon greenstone in the second column.

The work of Logan and Murray established many of the basic ideas which are common in the geological interpretation of the north shore area today. Features which Logan and Murray made clear include: (1) The existence of two slate conglomerates with their associated strata, (2) The existence of an unconformity between these two slate conglomerates, (3) The dark or black colour of the upper slates and slate conglomerate, and the greenish or bluish colour of the lower series, (4) The gradation, in many cases, of the lower series downward into gneissic rocks, and (5) The resemblance of the upper slate series to the strata observed in the Lake Timiskaming area.

Between the time that Murray and Logan visited the area and the time that Collins began his major mapping program, geological surveying along the north shore of Lake Huron was of a sporadic nature with no concentrated mapping program. Many famous geologists, including McFarlane (1866), Irving (1884), A. Winchell (1887-91), Pumpelly (1892), Van Hise (1892), Barlow (1893), Ingall (1903-4), and Leith (1935), visited the north shore area and made various proposals as to the sequence of rocks. The resulting great confusion in nomenclature gave rise to the formation by the Geological Society of America of the Special Committee on Precambrian Nomenclature. Members of the committee visited several important localities and attempted to determine the correct relations. No committee report was actually issued but Hays (1905) presented his views on many of the localities visited.

The discovery of the new Sudbury area (1885) and the Cobalt area (1903) increased interest in the north shore district. The Ontario Department of Mines and the Geological Survey of Canada sent several parties into these areas to investigate the new discoveries. These workers included such men as Barlow (1904) and Coleman (1892-1924). Coleman claimed that he had found three major unconformities in the Huronian rocks in the Sudbury area. The relatively unmetamorphosed rocks between the upper two unconformities he correlated with the Huronian of Logan and Murray, and the more highly metamorphosed sediments at the base he termed the Sudbury Series, and considered the series equivalent to Logan's Timiskaming Series. Coleman believed the Gowganda conglomerate to be of glacial origin and studied the formation in some detail in an attempt to prove his considerations.

In the period 1914-1925 work, under the direction of W.H. Collins, T.T. Quirke, and Eskola, was carried out in key sections of the Echo Lake, Bruce Mines, Thessalon, Blind River, Whiskey Lake, and Round Lake areas. Collins (1925) summarized the geology of the Huronian area in a memoir of the Geological Survey of Canada. In Table No. 2 the stratigraphic sequence of Collins is compared with other sequences which have been proposed before and after his mapping.

The Mississagi quartzite of the Bruce Mines area was placed by Collins as equivalent to the Wanapetei quartzite of Coleman's Sudbury Series. The intermittent basal conglomerate in the Bruce Mines area he placed as equivalent to the Ramsay Lake conglomerate, which in the Sudbury area Coleman had mapped as separating the Bruce Series and the Sudbury Series. Thus the lower part of Collins' Bruce Series is equivalent to the upper part of Coleman's Sudbury Series but the formations

TABLE NO. 2

LOGAN	COLEMAN MURRAY	COLLINS	McCONNELL	ROBERTSON	FRAREY	HAY
	KEWEENAWAN DIABASE & SEDIMENTS	OLIVINE DIABASE	YOUNGER GRANITE	OLIVINE DIABASE		BASIC & ACID LAVA OLIVINE DIABASE
		KILLARNEY GRANITE	BASIC & ACID LAVA	KILLARNEY GRANITE		
		DIABASE	OLIVINE DIABASE QUARTZ DIABASE	KEWEENAWAN DIABASE		KEWEENAWAN DIABASE
	UNCONFORMITY	UNCONFORMITY	UNCONFORMITY	UNCONFORMITY	UNCONFORMITY	UNCONFORMITY
	AMNIKIE	WHITE WATER SERIES		OLIVINE DIABASE GRANITE? SUDBURY DIABASE		DIABASE ?
	UNCONFORMITY	UNCONFORMITY	UNCONFORMITY	COBALT SERIES	COBALT GROUP	COBALT GROUP
UPPER COPPER BEARING SERIES	UPPER HURONIAN	COBALT SERIES	COBALT SERIES			
UNCONFORMITY	UNCONFORMITY	UNCONFORMITY	UNCONFORMITY	UNCONFORMITY	UNCONFORMITY	UNCONFORMITY
LOWER COPPER BEARING SERIES	LOWER HURONIAN	BRUCE SERIES WANAPETEI Q.	BRUCE SERIES	BRUCE SERIES	BRUCE GROUP	BRUCE GROUP
UNCONFORMITY	UNCONFORMITY	UNCONFORMITY	UNCONFORMITY	UNCONFORMITY	UNCONFORMITY	UNCONFORMITY
LAURENTIAN	LAURENTIAN GRANITE SUDBURY SERIES TIMISKAMING	GRANITE SUDBURY SERIES TIMISKAMING	SOO SERIES	DIABASE ALGOMAN GRANITE SUDBURY SERIES DIABASE	DIABASE	DIABASE GRANITE
	UNCONFORMITY	UNCONFORMITY	UNCONFORMITY	UNCONFORMITY		
	GRANITE	GRANITE	GRANITE	GRANITE OLDER DIABASE	GRANITE	GRANITE
	KEEWATIN = GRENVILLE	KEEWATIN	BASEMENT SERIES	KEEWATIN GRANITE	BASEMENT SCHISTS	BASEMENT SCHISTS

are in a reversed order. Collins noted that the Huronian sequence increases from north to south, and from west to east. Collins and Quirke (1930) suggested that the Huronian was deposited in an elongate basin whose northern shore lay slightly to the north of the present shore of Lake Huron. In the eastern section of the Huronian belt, where the relatively unmetamorphosed sediments come in contact with highly gneissic rocks, Collins and Quirke have mapped the contact in some detail. The granitic rocks exposed at Killarney, they believe, have formed through granitization of the eastern part of the basin. The Grenville, then, would represent a deeper, more highly metamorphosed phase of the Huronian.

Brunton (1921), of the Geological Survey of Canada, did the first detailed mapping in the Sault Ste. Marie map-area. He investigated parts of Deroche, Hodgins, Gaudette, and Shields Townships in the northeast corner of the map-area. Prospecting in the area had revealed a few small deposits of iron formation, and it was Brunton's purpose to seek out and investigate these in conjunction with his mapping. Bain (1923), a member of Brunton's party, investigated the deposits of the Breitung Mine as the subject of a Master of Science Thesis. Bain later mapped the Webbwood area near Sudbury.

The Ontario Department of Mines conducted surveys in the Western Algoma area in the mid 1920's. As a result of this work, three reports were published: The Batchawana Map-Area (Moore, 1926), The Sault Ste. Marie Map-Area (McConnell, 1926), and The Ranger-Garden Lake Area (Hurst, 1928).

McConnell identified two ages of granite, one post-Huronian and the other an earlier granite which he classified as Algoman. He tentatively identified the younger granite as Killarney, although he states that its position relative to the Huronian was not precisely determined. Below the Bruce Series sediments McConnell found a series of conglomerates, quartzites, and andesitic lavas which he believed, possibly, to be equivalent to the Sudbury Series, but because of the great distance between the two areas, he preferred to use the new term "Soo Series". McConnell's stratigraphic column is shown in Table No. 2A.

In the Batchawana area, north of Sault Ste. Marie, Moore found no Huronian sediments, but he did find a much earlier series of iron-formation, arkose, slate, and lava which he termed the Batchawana Series. In the Ranger Lake area, Hurst found two ages of granite, but because of the lack of Huronian rocks in the area, he was unable to state an age relationship with respect to the Huronian.

Table 2A

McConnell's Table of Formations (1926)

QUATERNARY

Pleistocene - Lake clays, sands and gravels, boulder clays.

PALAEOZOIC

Cambrian - Lake Superior sandstone, shales, and conglomerates.

PRECAMBRIAN

Keweenawan - Olivine diabase dykes
younger granite
quartz diabase
basic and acid lavas.

Unconformity and Intrusive contact

Hüronian - Cobalt Series - Upper Cobalt quartzites
Lower Cobalt greywackes, quartzites, and conglomerates.

Bruce Series - Bruce Limestone
Mississagi Quartzite

Soo Series - Aweres quartzites, conglomerates, and greywackes.
Duncan Greenstone
Driving Creek Quartzites, and conglomerates.

Great Unconformity

Pre-Huronian - Algoman (?) - Granite and granite gneiss batholiths.

Basement Series - Hornblende and chlorite schists.
Lavas, conglomerates, greywackes, and quartzites - cut by pre-Huronian diabase and granite.

Between 1930 and 1950 most of the work in the north shore area centred around the deposits at Sudbury. In 1950-51 Dr. Thomson, of the Ontario Department of Mines, mapped a township in detail in an attempt to reveal important structures and relationships which had been missed in reconnaissance surveys. This work showed that different conglomerates having similar lithological characteristics had been correlated incorrectly by Collins. Thomson found no apparent break between the Bruce Series and the Sudbury Series.

The discovery, in 1953, of uranium deposits in the Blind River area led to a spectacular staking rush, and increased geological interest in the north shore area. E.M. Abraham (1953-55), of the Ontario Department of Mines, began mapping in the Iron Bridge area, and M.J. Frarey, of the Geological Survey of Canada, began revising the mapping of the Bruce Mines-Garden River area (1953-1963).

The recent history of the Blind River has been outlined by Robertson (1960). It includes mapping by McDowell (1957), Roscoe (1956,1957,1958), Pienaar (1958), and Robertson (1960). The ores of the Blind River Area have been studied by Arnold (1954), Milne (1959), Patchett (1959), Pienaar (1958), Trail (1954), Ramdohr (1958), Joubin (1956), and Davidson (1957).

CHAPTER 11

PHYSIOGRAPHY

TOPOGRAPHY

The Sault Ste. Marie area lies at the east end of the Lake Superior basin and includes parts of two major physiographic provinces of North America. North of the St. Mary's River rise the highlands of the Ontario-Quebec section of the Laurentian Upland Province of Canada. A prominent escarpment separates the shield area from the Central Lowland Province which is represented by the flat plain along the St. Mary's River, and consists, in part, of a maturely dissected coastal plain.

The Precambrian rocks of the Canadian Shield stand in rugged hills with cliffs 300 to 400 feet in height occurring frequently. The elevation rises from 580 feet at the St. Mary's River to 1875 feet in the north-east corner of the area. Local relief in the Precambrian area is from 250 to 400 feet. The contact with the lowland plains is marked by a southward facing escarpment 200 to 300 feet in heighth. From the top of the escarpment, in the Echo Bay area, the land rises toward the north with a slope of 45 to 55 feet per mile. Northwest of Sault Ste. Marie the Precambrian stands as a series of irregular low hills, most of which are less than 100 feet in heighth. Many low valleys in the Pre-cambrian area show thick lacustrine deposits. The wide Goulais River valley and the Garden River valley show lacustrine deposits several miles into the uplands area.

Southeast of the Garden River the hills show a generally northwest direction which marks the attitude of the underlying rocks and of the accompanying thrust faults. Fault zones have been eroded, generally, to form elongate valleys. Here, many of the northern slopes of the hills are drift covered, but steep cliffs with large talus slopes (Plate 11) mark the south side of the hills. The northwest direction of the hills is cut off by the northeast direction of the Garden River valley.

North of the Garden River, topography is more subdued with local relief of 150 to 200 feet. The hills here are elongate in a north-south direction, and they mark the direction of schistosity in the Basement Series rocks. Straight valleys striking northeast and northwest result from major shear zones in the underlying granite gneisses and hornblende schists. The Trout Lake-Crooked Lake fault forms one of the northeast valleys.

The Goulais River valley in the northeast corner of the map-area is bordered by hills having relief of up to 800 feet. The Bellevue Ridge is the most prominent of these hills (Plate 111).

Glacial polishing and roches moutonnées are characteristic of much of the Precambrian area. Roches moutonnées are especially noticeable in areas of lower local relief.

Plate 11: Talus slope of Gowganda argillite southwest of Echo Lake.

Plate 111: View looking south from Bellevue Ridge towards Algoma Central Railway.

In the Sault Ste. Marie area the lowland plain is covered by a thick section of Pleistocene lacustrine deposit. It shows very low relief, although escarpments marking old lake terraces may locally be as high as 75 feet.

DRAINAGE

Four major rivers, three of which flow into the St. Mary's River and the fourth into Lake Superior, drain the upland part of the Sault Ste. Marie map-area. All except the Echo River are marked by numerous, shallow, gravel rapids, especially during periods of low water. The Goulais, Root, and Garden Rivers show a great fluctuation in volume from spring to summer. Flooding in low-lying areas along the Goulais River is quite common during the spring run-off. The Echo River keeps a more constant flow. Where these rivers flow through areas of lacustrine deposits they generally have low gradients, but in the upland regions they are marked by numerous rapids and waterfalls.

The St. Mary's River system provides the main drainage system for the region. The waters of Lake Superior fall over a resistant ridge at Sault Ste. Marie and follow the St. Mary's River system to Lake Huron. Almost the entire drop from Lake Superior to Lake Huron occurs at the St. Mary's Falls. The falls at Sault Ste. Marie has been harnessed by the Great Lakes Power Company for the supplying of electric power to the city of Sault Ste. Marie, Ontario.

The Precambrian area shows numerous small lakes which are drained by small high-gradient creeks. Some of the largest of the lakes are Driving Lake, Crooked Lake, Reserve Lake, Northland Lake, Weashkog Lake, and Trout Lake.

GLACIATION

Introduction

The east end of Lake Superior, and the St. Mary's River areas include a stretch of land in which many glacial features of the waning Wisconsin stage of the Pleistocene Ice Age are present. Evidence of the four previous stages of the Ice Age have all but been obliterated by the action of the Wisconsin stage. Recessional moraines of the Valders Substage appear across the north peninsula of Michigan (Leverett, 1915). Beaches from large glacial and post-glacial lakes are frequent in the area. In the Sault Ste. Marie area alone, five major beaches of post-Valders lakes can be found, and many minor intermediate beaches also occur. These beaches have all been raised since the retreat of the ice so that they now stand as much as 500 feet above the present level of Lake Superior.

The Lake Superior basin forms one of the major physiographic features of the area. According to Schwartz (1944), the Lake Superior basin was occupied originally by a large river valley, and it guided the earlier glacial erosion. The immediate cause of the present topographic basin, then, was the deepening of the river valley by successive lakes of glacial ice.

Evidence of Ice Action

(a) Striations

The presence of numerous resistant quartzites in the Sault Ste. Marie map-area afforded excellent opportunity for the production of glacial striae. In the Echo Lake region, 150 measurements of striations were made. A general direction of N5°E was found, but locally where a prominent trend in the underlying rock approached this direction, striations were deflected as much as 30°. Certain localities indicate two directions of striations, the northerly set, and an older, northeast set. In most outcrops the northeast set was not observed, and wherever it was observed it was cut by the more northerly striking striations.

Coleman (1899), also, reports two sets of glacial striae in the Sault Ste. Marie area. He recorded glacial striae S12°W to S25°W, and in the Echo Bay area he reports two sets, S2°E and S30°E. These were also recorded by Murray in his early mapping of the area.

(b) Moraines

Leverett (1929) has mapped the Pleistocene geology of most of Northern Michigan. He has recorded numerous moraines south of Sault Ste. Marie. The Kinross Moraine reaches from Kinross Station on the Soo Line, through Stalwart and Gatesville, to Lake Huron, about six miles southwest of Gatesville, Michigan. It has an average width of 1-2 miles, but a few miles southwest of Kinross it expands to a boulder-strewn tableland about four miles wide. In places the moraine stands as much as 100 feet above the bouldery plains.

Southwest of Sault Ste. Marie, Michigan, a series of small ridges stand above the level of the clay plain. They appear to be ridges that have been partly buried by clay. A gravel ridge southwest of Sault Ste. Marie, Michigan, known as Lacke Hill, is about three miles long, one-quarter of a mile wide, and 15-50 feet high. It runs south from a point near the southwest city limit. These ridges show gravel with beds dipping sharply westward on the east slope as well as on the west slope.

This is thought to have been a low glacial ridge on the top of which a gravelly ridge has been built. Leverett (1915) feels that the ridge is the result of aqueo-glacial action, although residents commonly regard it as an old lake beach.

Sugar Island, in the St. Mary's River, has two ridges of morainic aspect across its northern part. One, on the west side of the island, is about one mile in width and six miles in length. Its crest is at an altitude of from 780-840 feet above sea level and about 200-260 feet above the St. Mary's River. It rises 50-60 feet above the clay plain to the east of it. The surface of this ridge is thickly strewn with boulders and smaller stones, some of which may have been stranded on it during the lake occupancy. A second ridge, about three miles long and one to two miles wide, lies across the northeastern part of Sugar Island. Its west border is about one and one-half miles from the east end of the ridge just described. Leverett (1915) has recorded numerous lake beaches on its crest and slope.

In the area north of Sault Ste. Marie, Ontario, moraines are difficult to recognize because of the high relief in the Precambrian rocks in the area. Ground moraine consist of a loose, brown, non-calcareous, sandy till formed from eroded Precambrian formations. Fragments of the Huronian formations and of the earlier Precambrian formations are abundant, many of them being soled and showing striations. Ground moraine is widespread throughout the Precambrian area, and locally where it has partially filled valleys may attain a considerable thickness.

(c) Lake Features

As the glacial ice retreated, numerous small glacial lakes began to form in the lake basins and these gradually merged until the Nipissing phase when one large lake essentially filled the Superior, Huron, and Michigan basins. The beaches from these lakes have been tilted and raised since they were formed.

In the Sault Ste. Marie area, the Pleistocene beaches have been investigated by Taylor (1897), Lawson (1893), and, later, by Coleman (1899). Taylor has stated that those beaches in the order of 400 feet above Lake Superior are of the Lake Algonquin stage, and that the lower series represents the Nipissing level. According to Hough (1958), ice filled the Superior basin until after the Lake Algonquin stage, and as a result, none of the lakes older than the Algonquin, that is, Lake Keweenaw and the Lake Duluth Series, in the Superior basin, had any effect on the east end of the basin.

Hough's reasons for stating that glacial ice occupied the eastern Superior basin at this time are as follows. North of Sault Ste. Marie there are sand and gravel deltas at the level of the Algonquin beach (1015). These are located at the south ends of valleys which traverse the crystalline rock upland separating Whitefish Bay and Goulais Bay of Lake Superior from the Sault Ste. Marie area. The valley bottoms, floored with sand and gravel, are graded to the level of the Algonquin beach, and their profiles rise gently from the Algonquin beach in a north or northwest direction toward Lake Superior, then drop more abruptly into the Superior basin in youthful-appearing sections. Also, a mass of till located in the Goulais River valley near Bellevue Station, fourteen miles north of Sault Ste. Marie, has an outwash plain on its eastern valley-side, and a thick deposit of varved clay extends from there, eastward up the Goulais valley for several miles. A line drawn from the mass of till, southwestward across the upland valleys, through the point in them which marks the upper limit of their gradation to the Algonquin beach, apparently marks the position of the front of a glacier. If this line is continued southwestward across the entrance of the St. Mary's River to Nadoway Point, Michigan, it joins a moraine which has been mapped by Leverett (1929).

Lawson (1893) has measured 32 beaches north of Sault Ste. Marie. Coleman, in his surveys throughout the area from Thessalon to the Goulais River, recorded 21 points, and found that few of them matched the elevations shown by Lawson. Coleman found that in many cases , especially where wave ridges were measured, there was a succession of ridges, each a few feet lower than the previous one, often with 50 feet or more between the highest and lowest ridge. These are especially noticeable in the delta area of the Goulais River. Coleman suggests that such a succession of ridges must indicate a fairly gradual ascent of the land.

According to Hough, the Algonquin plain is at an elevation of 1015 feet six miles north of Sault Ste. Marie, and it descends to an elevation of 934 feet on St. Joseph Island, approximately 25 miles to the south. He notes that at Rexford, Michigan, 35 miles west of St. Joseph Island, a glacial outwash plain at an elevation of 930 feet is cited as a record of the Algonquin stage. An isobase drawn from Rexford to St. Joseph Island bears about 15° south of east which is the bearing of the Algonquin isobases in the Huron basin. Beaches recorded by Taylor, Leverett, Coleman, and Hay are shown in Table No. 3.

Leverett & Taylor		Coleman	#	Hay	
Root River	Sugar Island	Garden River	Goulais River	Goulais River	Sault Ste. Marie
	613	22	39		619?
	652	45		647	650
	680	77	57	652	
	704		102-113		695
	730	149-158	136		753
	780	171	190	780	775
	810	213			
	820				
	822			910	825-900
881	838		280		950
887	845		304	1020-1025	1025-1050
965	858		327-379	1100	1100
981	862		432-475		1125-1150
1000			502-596		
1005					
1018					

Table No. 3: Beach ridges observed in the Sault Ste. Marie area.

Elevation above Lake Superior (Elevation 603?)

On Mackinaw Island four major beaches lower than the Algonquin stage have been recorded as follows:

Beach	Original Altitude	Present Altitude
Wyebridge	740	785
Penetang	510	748
Cedar Pt.	493	724
Payette	465	686

Hough feels that it is possible to correlate the terraces north of Sault Ste. Marie with these beaches. The terrace at 780-790 feet he takes as the Payette beach (218 feet below the Algonquin). Leverett and Taylor (1915) recorded fifteen more or less distinct terraces between the Payette beach and the Algonquin beach in the Sault Ste. Marie area. The terraces at 860 feet, 880 feet, and 935 feet have been correlated with the Cedar Point, Penetang, and Wyebridge beaches respectively. Below the Payette beach, Hough recognized two lower beaches, the Shequiandah (758 feet) and the Korah. The Korah beach crosses at north Sault road, 2.7 miles north of the southern boundary of Korah Township and two miles west of the eastern boundary of Korah Township. The village of Korah has been built on this beach terrace.

Lake Nipissing was the last of the large post-glacial lakes. It occupied the Superior, Michigan, and Huron basins. According to Hough, the greater part of the post-Algonquin uplift had occurred before the Nipissing beach was formed. The Nipissing beach lies from 25 to 70 feet above the present level of Lake Huron.

According to Leverett (1929), the ridges at the rapids in the St. Mary's River have risen above the level of the water of the Huron basin in comparatively recent time, perhaps since the beginning of the Christian Era. Before this occurred, a strait connected Lake Superior with Lake Huron along the course of the St. Mary's River.

The prime purpose of the present mapping was not to investigate Pleistocene features, but wherever features of interest were found they were recorded. Figure 3 has been drawn to show Pleistocene glacial lake features in the Echo Bay-Garden River area. Many of the features, such as spits, bars, etc., were identified on the ground by the presence of gravel pits. In the Echo Bay-Garden River area the most prominent beach appears at an elevation of about 760 feet. This terrace probably correlates with the Payette beach as described by Hough. At this time, Echo Lake was joined to the main Nipissing Lake by a wide estuary through which the Echo River now flows as a misfit stream. The Garden River valley was flooded to form a large bay off the main lake. Varved, lacustrine, clay deposits can be traced up the Garden River valley to the eastern edge of the map-area, and northward along Driving Creek for about three miles. The Garden River now meanders across these old lake sediments and in places has cut some excellent sections. The "High Dump" on the south side of the Garden River, about five miles from its mouth, appears to have formed as a broad, shallow, sand beach in the lake bed. The crest of the High Dump is at an elevation of about 775 feet. From Echo Bay to the Garden River, the major south-facing escarpment formed the shore at this time.

Upper beaches of the Algonquin stage are indicated by the presence of gravel beach deposits at an elevation of about 1100 feet. On the Jardun Mines Road, just east of Maud Lake, a gravel pit occurs at the crest of the hill at an elevation of about 1025 feet, and just to the west occurs a terrace of a higher beach at an elevation of 1100 feet.

Near the city of Sault Ste. Marie, the lower Nipissing beach is well displayed. It can be traced from the Leigh Bay airfield, northeastward to Korah, and then eastward to highway 17. Here, the beach lies in a southeast direction, and passes through the city. East of Sault Ste. Marie it turns north and intersects with the major escarpment near Crystal Falls. The beach has an elevation of from 650-700 feet. McConnell reports the elevation at 625 feet,or 49 feet above the present level of Lake Superior. The upper beach terraces are visible several miles to the north of the main Nipissing beach. The highest beach observed appears at an elevation of about 1050 feet. Lawson has recorded two higher beaches at elevations of 1105 feet and 1199 feet. The small gravel deposits found on the banks of the West Root River, east of McIntyre Lake, and at an elevation of about 1100-1150 feet, probably represent these higher lake levels. Similar gravel deposits were seen north of Driving Lake at an elevation of 1050-1100 feet. West of Sault Ste. Marie, sand bars form a succession of wave ridges, with a drop of about five feet from ridge crest to ridge crest. These are especially noticeable east of Bennet Creek, and northwest of the village of Korah. Wave ridges also occur in Korah Township, just north of the Algoma Steel Corporation slag heap.

Glacial lake features are well preserved in the Goulais River valley, along the north boundary of the map-area. In the delta area of the river, low beach ridges are very prominent. From Goulais Bay eastward to the new Trans-Canada Highway, 33 of these ridges can be identified with a total elevation difference of about 75 feet. The more prominent ridges rise up to five feet above the succeeding lower ridges, but, in general, the difference in elevation from crest to crest is only about one foot. South of Kirby's Corner, the first main beach above the present beach occurs at an elevation of about 650 feet. The next beach ridge appears as a series of gravel pits around the Goulais River valley. At Bellevue Station, beach deposits are found at an elevation of from 1020-1025 feet. Along the Algoma Central railway, from Glendale to Northland Station, sections of varved clays were identified at elevations up to 900 feet. In the valley of Silver Creek, about one mile south of the Algoma Central railway, a beach was found at an elevation of about 1100 feet. Northeast of Searchmont, a large, flat, sand plain has formed on the upper Algonquin beach. It appears as a sand plain, about one mile to two miles in width, and probably formed a broad, shallow beach.

McAllister (1950) has measured varves from 41 locations in the Goulais River valley. Near Searchmont he was able to correlate a total of 441 varves from four sections. Three other sections in the area which did not correlate with these others showed 1287 varves. McAllister estimates that between these two groups of sections at least two thousand varves are covered by overburden. Further downstream he measured a lower section which showed 1444 varves, none of which overlapped with the above-mentioned varves. Thus he visualized varves representing about 4000-6000 years.

In Lots 10 and 11, Concession 2, Deroche Township, a flat, sand plain at about 1075 feet shows a pitted surface. McConnell suggests that these are kettle lakes.

McConnell reports that a drill hole put down to a depth of 443 feet near the Carp River failed to reach bedrock. The sediments penetrated were as follows: 160 feet of clay, 15 feet of sand, 66 feet of clay, 1 foot of sand, and 201 feet of silty clays.

The varved clays in the Garden River valley show disturbed zones which are both overlain and underlain by horizontal varved beds. McAllister (1950) has identified similar zones along the Goulais River, and has studied them in some detail. They appear as strongly-folded zones, bounded above and below by undisturbed varves, with no evidence between them of erosional hiatus (Plate lV). In the Garden River valley, the zones could be traced for several hundred feet. In the Goulais River valley, McAllister found these disturbed zones to have a great horizontal extent.

McAllister (1950) notes that some of the disturbed zones are strongly contorted, and are of variable thickness horizontally; in some places, truncating other varves; and at other places, truncating themselves, or showing evidence of injection, laterally, from another direction. He found no evidence of ice gouge or erosional truncation of the upper parts of the folds. It has been postulated that they are due to grounding of an iceberg, but if this is the case there should be some evidence of ice push, and one would also expect to find ice-rafted material.

In the Garden River valley (Plate V) where these zones were found, the lower layer, along which sliding occurred, was invariably a sand layer about 1/4-1/2 inch thick, and in places it had been almost completely disrupted by the flowing. It was found that the disturbed zones generally contain more sandy material than the undisturbed zones. Thus it is assumed that the disturbed zones must be, in some way, related to the presence of these thin, sand layers.

Varved clays, along the Goulais River and the Garden River, contain numerous concretions; some are as large as one square foot in area. Along the Goulais River, south of Maple Lake, the varves consist of

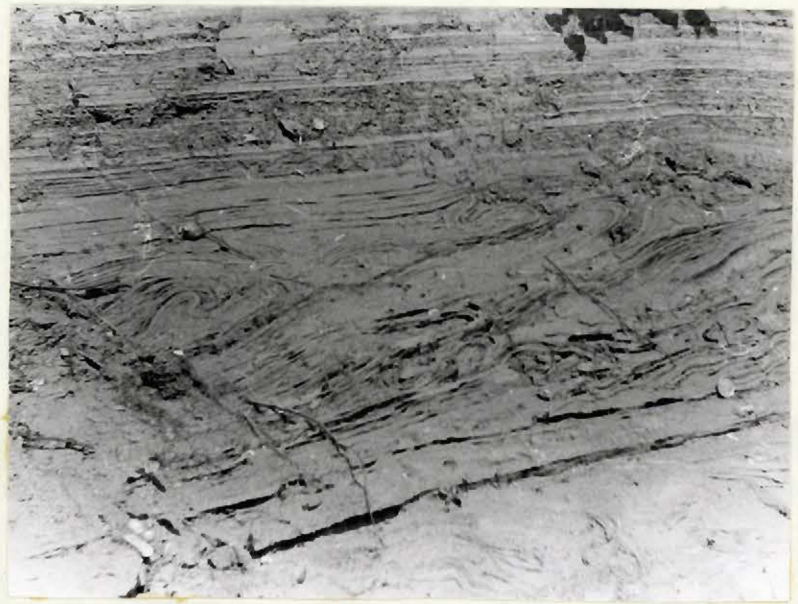


Plate lV: Disturbed zone in varved clay along Goulais River showing horizontal varves above and below.

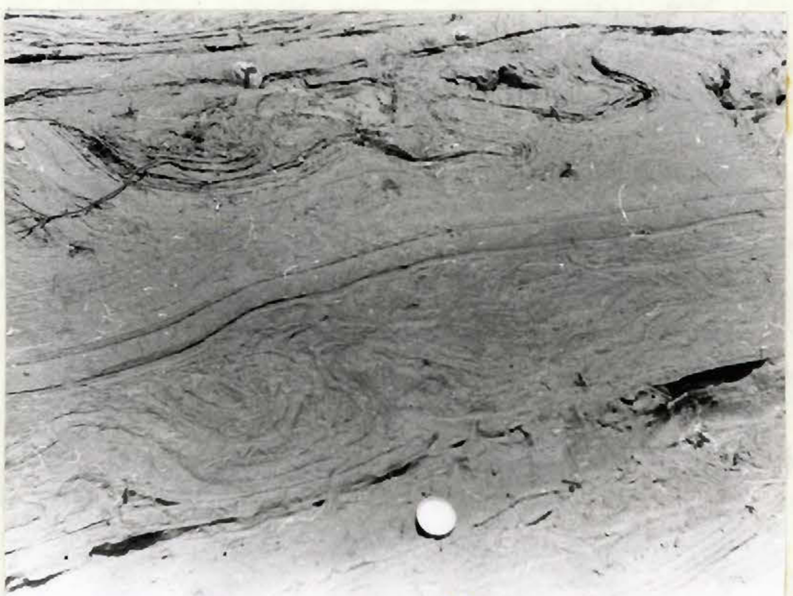


Plate V: Disturbed zone in varved clay along Garden River. Sliding has occurred along thin sand layers.

interbedded grey and red clays; the number of grey varves is five times the number of red varves. Concretions were found, generally, within the red clay varves, or at the contact between a grey varve and a red varve.

CHAPTER 111

GENERAL GEOLOGY PETROGRAPHY

GENERAL GEOLOGY

The rock formations of the Sault Ste. Marie area can be divided into three major groups: (1) highly metamorphosed and steeply tilted meta-volcanics, meta-sediments and igneous rocks of the basement 'series', (2) relatively unmetamorphosed and slightly tilted, Huronian sedimentary rocks, and volcanic rocks, and (3) flat-lying, unmetamorphosed,early Palaeozoic sandstones.

The rocks of Huronian age and older have been intruded by Keweenawan dykes and small stocks; most of the dykes are of a diabasic composition, and the stocks are of a gabbroic composition. Granitic batholiths and gabbro dykes, of an earlier period, intrude the basement schists and sediments. In the Gros Cap area, about eleven miles west of the city of Sault Ste. Marie, basic and acidic lavas of Keweenawan age overlie, with angular unconformity, the granite gneiss of the basement.

These three major groups can readily be subdivided into more definable rock units. Table No. 4 illustrates the stratigraphic succession revealed by the current mapping.

The basement rocks can be further divided into:

Table No. 4

TABLE OF FORMATIONS

CENOZOIC Pleistocene and Recent.-

Swamp and stream deposits, glacial till, lacustrine varved clays, sands and gravels.

---------- UNCONFORMITY ----------

PALAEOZOIC Cambrian (?)

Red and grey, mottled sandstone.

---------- UNCONFORMITY ----------

PRECAMBRIAN PROTEROZOIC

Basic and acidic lavas.

Gabbro, diabase, and basalt.

Huronian

Cobalt Group

Lorrain Formation.- Quartzite, siltstone, greywacke, and pebble conglomerate.

Gowganda Formation.- Greywacke, argillite, conglomerate, and quartzite.

--------- SLIGHT UNCONFORMITY ---------

Bruce Group

WEST	**EAST**
Aweres Formation.- Polymictic conglomerate, quartzite, and greywacke.	Serpent Formation.- Mainly fine-grained quartzite, minor conglomerate, arkose, argillite and grit.

Table No. 4 (cont'd)

Bruce Group

WEST	EAST
Duncan greenstone.- basic volcanic rocks, commonly amygdaloidal, minor pillow lava and interbedded sedimentary rocks.	Polymictic conglomerate.- (basal Serpent (?)) - polymictic greywacke conglomerate and greywacke.
Espanola Formation.- Bruce limestone.- very minor laminated siliceous limestone.	Espanola Formation.- Bruce limestone.- grey laminated siliceous limestone.
Bruce conglomerate.- not definitely identified.	Bruce conglomerate.- polymictic greywacke conglomerate and greywacke.
--- SLIGHT UNCONFORMITY ---	--- SLIGHT UNCONFORMITY ---
Mississagi Formation.- arkosic quartzite, quartz-pebble conglomerate, polymictic conglomerate, minor argillite.	Mississagi Formation.- arkosic quartzite, quartz-pebble conglomerate, polymictic conglomerate, minor argillite.

----- MAJOR UNCONFORMITY -----

ARCHAEAN

Granite.- Massive equigranular.

Granite.- Granitic gneisses with basic inclusions.

----- INTRUSIVE CONTACT -----

Chlorite schist, amphibolite, tuff, minor iron-formation and quartzite.

(1) a chloritic and hornblende schist complex, probably of volcanic origin, (2) a group of pyroclastic rocks, now highly altered, and having the appearance of a quartz porphyry, (3) meta-sedimentary rocks, most of which are of an iron-formation composition, and appear to be interbedded with the chloritic schists, and (4) a granite and syenite complex, now generally altered to granite gneiss

The chloritic schists, pyroclastics, and meta-sedimentary rocks are confined, almost entirely, to a steeply-dipping, northerly-striking belt of isoclinally-folded rocks. This belt can be traced south from the Northland-Glendale area to the Garden River, where it has been displaced by a major fault zone. North of Driving Lake, the presence of pillowed and amygdaloidal structures indicates a volcanic origin for the chlorite schist. The west contact between the schist and the granite gneiss is, on a regional scale, parallel to the foliation in the schists, although, in detail, the contact is quite irregular, with numerous small granite and pegmatite dykes which can be traced into the schists. Silicification of the schists is intense near the granite gneiss contact. Xenoliths of chloritic schist occur throughout the granite, but they are especially numerous near the contact.

Granite and granite gneiss are the most common rock types in the Sault Ste. Marie area. They are confined to three major areas: (1) from highway 17 west to Lake Superior, (2) in the central part of the map-area, from the Bellevue Ridge south to Driving Creek, and (3) east of the chlorite schist belt and north of the Garden River.

Granites of two ages have been identified; an older granite which has been transformed, generally, to granite gneiss, and a younger granite of a more massive nature. This younger granite was identified by McConnell (1926) as a Killarney-age granite, but current mapping shows it to be related, in age, to the basement rocks. Intrusion of the younger granite occurs in all three areas, but it is most prevalent in the central area.

These highly folded and metamorphosed basement rocks are generally considered to represent an early orogenic period. The large, granitic batholiths were intruded into the volcanics and sediments during this mountain building. The schists have been classified as Keewatin, but there is no basis for this correlation other than their predominantly volcanic nature. Deep erosion of the mountain range has exposed the granitic core over a large area, and the meta-sediments and meta-volcanics remain only as minor infolds, and xenoliths. The Huronian sediments were deposited in shallow seas which encroached upon the eroded remnants of this mountain range.

The Huronian rocks have been divided into two Groups; an older, Bruce Group, and a younger, Cobalt Group. The Cobalt Group extends beyond the Bruce Group where it overlies the basement directly, and overlies the Bruce Group with slight angular unconformity. In the Sault Ste. Marie area, the Bruce Group can be divided into a western section and an eastern section. The eastern section outcrops southeast of the Garden River, and the western section outcrops in a northerly-striking belt which extends from the Garden River to the Bellevue Ridge. The western section is differentiated by the presence of volcanic strata and of coarse, clastic material, and by the absence of carbonate rocks.

The Mississagi quartzite is the basal formation in both the eastern and western sections. It includes quartzite, arkose, greywacke, and polymictic conglomerate, all of varying thicknesses. In the western section, the formations, especially in the lower part, appear as thick, polymictic conglomerates; the eastern area is of a more quartzitic nature, with only minor conglomerate zones. The conglomerate zones are slightly radioactive. The thickness of the Mississagi formation is quite variable; an average thickness of 2000 feet is quite normal. This variable thickness probably represents the filling of depressions in the old, weathered surface of the basement rocks.

In the east, the Mississagi formation is overlain by an impure, siliceous conglomerate known as the Bruce conglomerate. In the west, the Mississagi is overlain by an amygdaloidal, greenstone rock, 200-300 feet thick, which McConnell named the Duncan greenstone. Locally, the Bruce Formation occurs between the Duncan and the Mississagi, and northwest of the Garden River, the Duncan has been eroded away so that the Aweres Formation overlies the Mississagi. The Bruce Formation appears to have been deposited in depressions in the eroded upper surface of the Mississagi, and, therefore, is of a local nature. It may have been, at one time, more widespread, and, then, been removed by erosion prior to the deposition of the Serpent Formation. The upper part of the Bruce Formation is a fine-grained, grey, laminated, siliceous limestone known as the Bruce limestone.

In the Echo Lake area, the Bruce limestone is overlain by a siliceous, polymictic conglomerate that contains angular fragments of the Bruce limestone and lower Huronian formations. The erosion surface on the Bruce limestone shows a relief of about twenty-five feet. This polymictic conglomerate is taken as representative of the first deposition in Serpent time. The polymictic conglomerate is followed by a thick succession of feldspathic quartzite of the Serpent Formation.

The Duncan greenstone is overlain by a coarse conglomerate which, apparently, represents a facies change of the Serpent, but because of the coarse nature, the name Aweres Formation, which was first given to it by McConnell, is still used. South of the Bellevue Ridge, the upper, volcanic rocks of the Duncan are interbedded with the lower, Aweres conglomerates. Further south, the Aweres conglomerate overlies the eroded, upper surface of the Duncan. The lower Aweres conglomerate contains numerous pebbles of Duncan greenstone, even in the north where the volcanics are interbedded with the conglomerates. Northwest of the Garden River, the Duncan greenstone has been completely eroded so that the Aweres lies directly upon the Mississagi quartzite.

The Serpent-Aweres Formation is the upper unit of the Bruce Group, and it is overlain, with slight angular unconformity, by the Gowganda Formation, the lowest unit of the Cobalt Group. West of Echo Lake, the lower Gowganda conglomerate rests upon an eroded, Serpent surface which, at one time, had a relief of possibly as much as 500 feet. Generally, the Gowganda was found to overlie the Serpent disconformably, but locally, a discordance of up to ten degrees was measured.

The Gowganda Formation consists of a thick sequence of slates, slate conglomerates, conglomerates, minor greywacke, and "argillite". It is generally considered to be of glacial origin. The typical boulder "tillite" of the Gowganda occurs in only a few, scattered localities in the Sault Ste. Marie area. Most of the formation consists of a "varved", slate sequence with numerous ice-rafted pebbles. The slates, when analysed, were found to contain feldspars, quartz, chlorite, etc., but did not contain any clay minerals.

The upper Gowganda appears as a thin-bedded, pinkish quartzite, and this is followed, conformably, by the impure quartzite of the lower Lorrain Formation. The thick, upper part of the Lorrain consists mainly of pure, white quartzite, with occasional quartz, pebble layers. The central part of the formation contains a jasper, pebble conglomerate which is a characteristic feature of the Lorrain; it has been used as an ornamental stone.

The Lorrain quartzite forms the resistant backbone of the Bellevue Ridge, across the north, central part of the area. Here, a synclinal structure in the Cobalt Group has been thrust over the older rocks to the south. In the southeast, the Lorrain and Gowganda homoclinally face toward the south, at low dips.

Acidic and basic lavas of Keweenawan age overlie granitic rocks in the Gros Cap area, west of Sault Ste. Marie. DuBois has correlated these volcanics with Keweenawan volcanics in the area around Lake Superior by means of palaeo-magnetic methods. Acidic and basic dykes, apparently associated with these lavas, intrude the Huronian and earlier rocks in the Sault Ste. Marie area. Collins notes that these quartz, diabase intrusives are characteristic of the Huronian area, and can be traced from Sault Ste. Marie to the Cobalt area.

The lowlands along the St. Mary's River are underlain by a mottled, red and white, early Palaeozoic sandstone. McConnell (1926) and others suggest that this sandstone is equivalent to the Potsdam sandstone of Eastern Ontario. DuBois has shown that, actually, it may be of upper Keweenawan age. The sandstones overlie the Huronian and earlier rocks with angular unconformity, and the contact is marked, in places, by boulder conglomerate which contains boulders of the Huronian.

The large, south-facing escarpment in the Sault Ste. Marie area appears to have formed prior to deposition of the sandstones, for the sandstone dips away from the escarpment. This escarpment may have formed the shore during the deposition of the sandstone. McConnell (1926) reports drill holes 510 feet deep in the sandstone which did not reach the base.

Thick, unconsolidated, Pleistocene gravels, tills, and varved clays overlie much of the area. Glacial rounding and polishing of outcrop surfaces, scouring of the softer beds, and joint planes, and the development of striae are common.

PRE-HURONIAN BASEMENT ROCKS

In the Sault Ste. Marie area, the term "basement series" has been used to refer to all rocks of pre-Huronian age, regardless of their origin. McConnell (1926) used the term to describe the volcanic and sedimentary rocks contained within the pre-Huronian complex. In the present report, the term "basement series" is not used. All rocks of pre-Huronian age are classified under the general term "basement rocks", and are described individually, according to their origin.

The basement includes two major groups of rocks; the chlorite and hornblende schists (meta-volcanics and meta-sediments), and the granite and granite gneisses (intrusives).

Meta-Volcanic and Meta-Sedimentary Rocks
(Chlorite and Hornblende Schists)

Highly altered, acidic and basic volcanics, tuff, quartz porphyry, iron-formation, and siliceous sedimentary rocks in the Sault Ste. Marie area have been described by McConnell (1926) as possibly being Keewatin age. These rocks have been highly altered to hornblende and chlorite schists. Structural relations indicate that these are the oldest rocks outcropping within the Sault Ste. Marie map-area. The term Keewatin is not used to identify these rocks because of the lack of correlation with any known Keewatin rocks.

These schists outcrop in two belts within the Sault Ste. Marie map-area; a northerly-striking belt which goes from the Garden River to Glendale, and an east-west striking belt north of the Bellevue Ridge. The former is disrupted, in the south, by an east-west striking branch of the Garden River fault zone which passes through Driving Lake. North of Driving Lake, the belt outcrops over a width of about five miles, from Section 4, Duncan Township to the western boundary of Kehoe Township. To the north, the schist complex narrows rapidly; near the northern boundary of Anderson Township it is only about one mile wide. Near Glendale, the schist occurs as thin bands within the granite gneiss, and in most places it would be properly identified as a hornblende gneiss.

The second belt of hornblende-chlorite schists lies north of the Bellevue Ridge between Northland and approximately the mid-point of Vankoughnet Township. In the south, it is cut off by a fault zone which runs parallel to the Bellevue Ridge and passes just to the south of Maple Lake. Southwest of Maple Lake, the fault splits, and a large horst of schists appears within the Gowganda conglomerate. In the east, the belt has been offset by a northerly-striking fault zone which passes through Northland Lake.

Inclusions of the schists are numerous throughout the granite and granite gneiss areas (Plate Vl). In Anderson Township, northwest of Anderson Lake, one inclusion showed a width of approximately 500 feet, and a length of one-half mile. Many of the inclusions have been completely recrystallized to amphibolite. The larger inclusions have a strike which approximates the strike of the main belt. The Jardun Mines office buildings, north of Sand Lake, have been constructed on another large schist inclusion.

On Figure 4, the contact between the schists and the gneisses, in Anderson and Hodgins Townships, has been

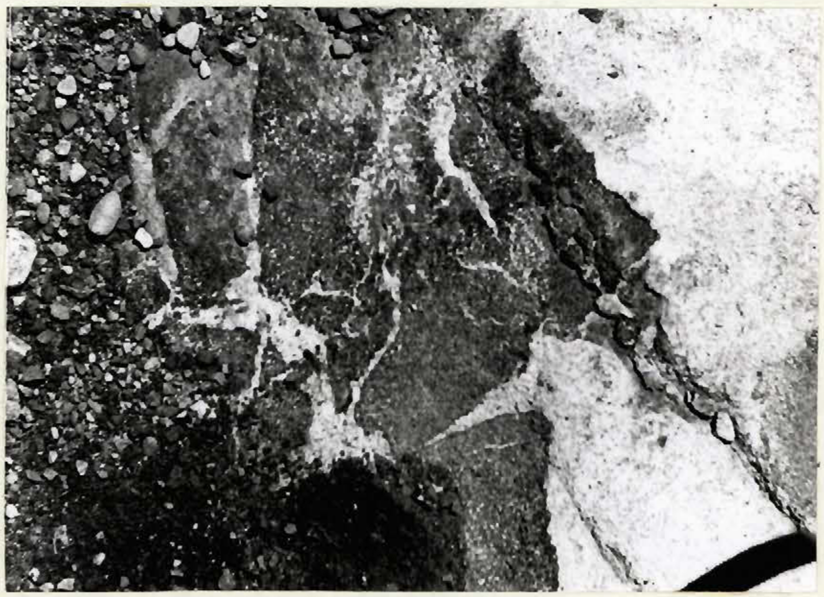


Plate Vl: Hornblende schist inclusions in granite-quartz monzonite in the Jarvis Batholith. 100 feet west of north shaft Jardun Mines.

drawn as a straight line. Actually, the contact is quite irregular in detail, with tongues of granite projecting many feet into the schist belt. The contact is actually a zone about one mile wide.

The rocks of the basement have been subdivided into: basic volcanics, acidic and intermediate volcanics, quartz porphyry, tuff, diorite, iron-formation, and conglomerate.

(a) Basic Volcanics

Basic volcanic rocks, now highly altered to hornblende-chlorite schists, outcrop in both of the schist belts. Southwest of Maple Lake, at the edge of the escarpment in Section 6, Van Koughnet Township, the basic volcanics appear less altered. Here, siliceous pillow boundaries are very abundant. Shearing has elongated the pillows so that they are now as much as four feet long, while they are only eight to ten inches wide. This pillowed zone extends eastward towards Northland where it has been intruded by the granite complex and then metamorphosed to a hornblende plagioclase gneiss.

Pillowed, basic volcanics appear in Sections 16 and 17, Duncan Township, along the contact with the massive granite. Here, metamorphism has almost completely destroyed the original structure, but, locally, fine-grained, siliceous, pillow borders, about one-half inch thick, can be identified. The outer rim of these pillows generally contains a few, small amygdules. To the north, this basic volcanic zone attains a more massive nature and, in places, shows an ophitic texture. West of Driving Lake, basic volcanics, some of which appear quite massive, are traceable over a width of about one mile.

In thin section, these rocks appear to be, more or less, completely altered. Plagioclase (An 42) is altered to sericite mica, and the ferromagnesian minerals are, in general, altered to chlorite. Unaltered hornblende is quite rare. Schistosity is visible through lineation of chlorite shreds. The more massive portions of the flows show an ophitic texture, with partially altered plagioclase (An 35-45) enclosed by pyroxene and hornblende. The pyroxene occurs only as relic structure. These rocks were originally of an andesitic-to-basaltic composition.

(b) Acidic Volcanics

Acid volcanics, of dacite composition, outcrop in Section 18, Duncan Township. Rhyolite is not common, although a few, thin flows, interbedded with the dacite, were identified. These dacites are, like the basic volcanics, highly altered to chlorite. On the weathered surface they appear a light green colour and thus are readily differentiated from the darker basic volcanics. Thin, siliceous layers appear as ridges on the weathered surface. They are fine grained and massive although, locally, they become slightly porphyritic. North of the east end of Driving Lake, porphyritic dacites were traced over an outcrop width of fifty feet. Both plagioclase (An 29) and potash feldspar phenocrysts were identified. Pillowed and amygdaloidal structures are lacking, although the thin, siliceous bands within the flows may indicate pillow boundaries.

In thin section, plagioclase (An 29) appears partially altered to sericite. Orthoclase, now altered to sericite, comprises about 10-15% of the rock. Quartz is a minor constituent, and where detected, it shows strong, undulose extinction and, occasionally, high fracturing. The ferromagnesian minerals are completely altered to chlorite which shows a pale green, pleochroic colour. Ophitic texture was not identified in any of the sections.

(c) Quartz-Feldspar Porphyry

Quartz-feldspar porphyry occurs at various stratigraphic levels within the basement volcanics of Duncan and Anderson Townships. On the weathered surface it appears as a grey-green colour, and, locally, it has a prominent, flaggy parting, with layers 1/4-1/2 inch thick. The feldspar phenocrysts are resistant projections on the weathered surface. The highly altered phenocrysts appear to be less resistant to erosive action and, in places, produce a pitted weathered surface.

Thin sections show plagioclase phenocrysts (An 35-40) in which crystal outlines are imperfect, and which, in places, are altered to sericite. Fracturing of phenocrysts is common, and, locally, a slight mortar structure is visible. The matrix is quite similar in composition and texture to the acid volcanics. The ferromagnesian minerals are, in general, altered to chlorite.

(d) Tuff

Pyroclastic material outcrops near the east border of Duncan Township. Here, it can be traced across a width of 1000 feet, but, to the north, near the south border of Anderson Township, it narrows to less than fifty feet. These rocks appear, in hand specimen, quite similar to the porphyry north of Driving Lake. On the weathered surface they are a pale grey-green colour and, locally, they may be somewhat flaggy.

These pyroclastics are comprised mainly of quartz grains in a matrix of sericitized feldspar, with varying amounts of chloritized ferromagnesian minerals. Rock fragments appear as zones or blotches of greater chlorite content. Many of these appear to have had, originally, a rhyolite content, although alteration is so intense as to make definite identification difficult. Fragments appear no larger than 1/4 inch in diameter and generally have highly angular outlines where fresh, but where chlorite alteration is intense, the outlines are masked.

White blotches, which are typical of the fresh surface, appear to be related to siliceous, rock fragments, rather than to single crystals. It is in this way that these tuffaceous rocks have been separated from the quartz-feldspar porphyries.

(e) Diorite-Gabbro

Diorite and gabbro masses occur throughout the schist belt, and in many places appear to be interbedded with the lavas. These masses may represent sills within the lavas, or may indicate flows of a more massive nature. On the weathered surface they appear as a rusty brown colour, and are well jointed. They vary from medium grained to coarse grained. Good exposures can be seen along the escarpment east of Dead Horse Lake.

In thin section, these more massive bodies are relatively unaltered. Ophitic texture, with laths of plagioclase surrounded by pyroxene and hornblende, is quite common. Plagioclase (An 30-40) shows both multiple albite twinning and broad carlsbad twinning. The plagioclase laths are somewhat stubby, with dimensions 2 mm. by 1 mm. as an average size. Many of the plagioclase crystals, especially some of the larger laths, show well-defined zoning. A typical, zoned grain has a core with a composition of An 37 Ab 63, and a slightly more acidic rim with a composition of An 33 Ab 67.

Brown augite is the main ferromagnesian mineral; hornblende and biotite occur in minor amounts. Local concentrations of magnetite are characteristic, although magnetite never comprises more than about one per cent of the rock. Both the augite and the hornblende show some alteration to chlorite.

East of Dead Horse Lake, calcite is a common accessory in the diorite, but it appears that it has been introduced after solidification of the diorote.

(f) Iron-Formation and Siliceous Sediments

Iron-formation occurs within the schist belt, near the granite gneiss contact, in Sections 21 and 22 of Duncan Township. From here, it extends northward into Anderson Township with a total outcrop length of about three-quarters of a mile. Thin, iron-formation bands were found interbedded with pillowed, volcanic rocks in Sections 25 and 26 of Van Koughnet Township.

South of Trout Lake in Section 34, Aweres Township, a prospect pit has been opened in iron-formation contained in a large xenolith within the granite gneiss.

The individual iron-formation units are 25 to 100 feet thick, and consist of interbanded chert, quartz, and magnetite, with the bands being about 1/4 inch thick. The iron-formation is black to grey in colour, depending upon the percentage of magnetite. The magnetite grains are generally of microscopic size, although a few bands have magnetite grains as large as one millimeter.

Thin section examination shows the iron-formation to be composed of alternating layers of chert and siliceous magnetite. The magnetite layers are composed of very fine-grained magnetite, with minor quartz and pyrite, and the cherty layers are composed of fine-grained or cryptocrystalline quartz, with fine, magnetite grains. The coarser, magnetite bands contain a fine-grained, dark, pleochroic mineral which appears to be a type of amphibole, although it is now mostly altered to chlorite. Rods of apatite occur in both the cherty and magnetite rich layers. Grain size within the layers is in the order of 0.01 mm., although, as stated above, a few layers are somewhat coarser. The cement in both the cherty and the magnetite bands is silica. Fine, quartz veinlets cut both types of bands.

In Lot 17, Duncan Township, a band of siliceous, sedimentary material, about fifty feet wide, was found to outcrop over a length of 400 feet. Unlike the iron-formation bands this zone appears to contain very little magnetite, although a thick, rusty gossan has developed on the surface. These sediments consist of alternating laminae of chert, each about 1/4 inch thick. These bands consist of fine-grained or cryptocrystalline quartz, with minor pyrite. Brecciation of the laminae is widespread, and quartz veinlets are numerous. Recrystallization has produced grains up to 0.25 mm. in diameter.

(g) Conglomerate

Thin bands of a highly siliceous conglomerate outcrop in Concession 111, Lot 8, Anderson Township. The outcrop is less than 25 feet wide. Pebbles consist of fine-grained, pink granite and a vein-type quartz. Cherty pebbles are less common. The matrix is essentially a greywacke, and consists of fine-grained quartz cemented by a material which is now highly altered to chlorite.

Intrusive Rocks of the Basement

Granitic rocks of the basement underlie at least one-half of the Sault Ste. Marie map-area. These rocks can be divided into two distinct groups: medium to coarse-grained, gneissic granodiorite, and massive, medium-grained granite and quartz monzonite. Both types contain many inclusions of the basement schists.

(a) Granite-Quartz Monzonite

Granite of a massive nature outcrops in an area of batholithic proportions (the Jarvis Batholith, McConnell, 1926) in the central part of the map-area. At the Bellevue Ridge this mass has an outcrop width of approximately six miles, but it tapers to the south, and pinches out in Section 5, Duncan Township. West of highway 17, in Pennefather, Korah, and Prince Townships, the area is underlain in general by granite gneiss, but, locally, has a more massive nature. The granite and granodiorite area near Gros Cap, west of Sault Ste. Marie, has been named the Gros Cap Batholith by previous workers (McConnell, 1926). Granite and granite gneiss outcrop in the northeast part of the Sault Ste. Marie map-area, in Anderson and Hodgins Townships. Along Silver Creek in Hodgins Township the outcrops are massive.

The granite varies in colour from a predominantly red, in the vicinity of Jardun Mines, Duncan Township, to white, in Pennefather Township. On the weathered surface, the red granite is pink to orange in colour, and the white granite is buff in colour.

In Jarvis and Duncan Townships, the granite contains many hornblende schist and granite gneiss inclusions, and is crosscut by aplite, pegmatite, and diabase dykes. Plate 1 shows granite, containing hornblende schist inclusions, cut by a small, pegmatite dyke, which, in turn, is cut by a thin, basic dyke. The inclusions vary in length from a few inches to several hundred feet. As the contact with the hornblende schist belt is approached, the number of these inclusions increases rapidly until, near the contact, they comprise as much as 50% of the total volume of the rock. The schist inclusions have been recrystallized, in general, to amphibolite. Granite gneiss inclusions are common throughout the Jarvis Batholith, and do not appear concentrated in any specific areas.

In the Jarvis Batholith, medium to coarse-grained granite and quartz monzonite form the principal rock types, and they grade into each other. Locally, the rocks attain a syenitic aspect. North of Jarvis Lake, and south of Crooked Lake, syenitic rocks are common. These syenites consist almost entirely of plagioclase, and perthitic microcline but, locally, they may contain as much as 30% hornblende.

Thin sections of the granite in the Weashkog Lake area show that it is composed of equigranular plagioclase, quartz, and perthitic microcline. Fine, albite, twin lamellae are characteristic of the plagioclase. The perthitic microcline contains numerous inclusions of randomly oriented plagioclase which, in some places, gives the rock a poikilitic texture. Quartz inclusions are less common in the microcline. Plagioclase is of the oligoclase variety (An 28). Quartz appears as anhedral grains showing moderate undulose extinction, and a small, optic angle. The plagioclase and microcline occur as subhedral grains. The granite, in this area, is generally deficient in ferromagnesian minerals. Hornblende, now almost completely altered to chlorite, occurs as a minor constituent. The modal analysis shown in column 1, Table No. 5, indicates that this rock is actually of a quartz monzonite composition.

West of Elizabeth Lake, near the contact with the Huronian rocks, the granite is highly sheared. In thin section, the quartz grains show marked undulatory extinction, and a measurable, optic angle. Universal Stage measurements give optic angles of up to 14°. In the area bordering the contact with the Huronian rocks, fracturing of the quartz grains, with the development of mortar structure, is characteristic. Perthitic microcline is abundant, and is similarly fractured. Plagioclase is of the oligoclase variety (An 26), but, unlike the quartz monzonite at Weashkog Lake, it is a minor constituent. The ferromagnesian constituents are hornblende and biotite. Both of these show alteration to chlorite. Recrystallization of quartz has resulted in the filling of many of the fractures within the rock. Modal analysis (column 2, Table No. 5) indicates that this rock is a granite.

South of Elizabeth Lake, sections of the rock show unaltered microcline with excellent grid twinning. Plagioclase (An 29) is abundant, but it is altered to sericite. Quartz occurs as anhedral grains interstitial between the subhedral microcline and plagioclase grains. Undulatory extinction is characteristic of all the quartz grains; Universal Stage measurements on these grains show optic angles of up to 8°. Bent albite twins are common. Inclusions of basement schist are extremely numerous in this area. Locally, the mafic content of the host granite is as high as 30%, and this is presumed because of the almost complete assimilation of some of the schist material. Hornblende is the principal, mafic mineral in these areas. In the rest of the granite, the mafic mineral is biotite.

Alteration of the biotite to chlorite is indicated by the green pleochroism of much of the biotite, and by the patchy areas of chlorite around the biotite flakes. Modal analysis (columns 3&4, Table No. 5) indicates that most of this rock is of a granite composition. Where inclusions have been completely assimilated, the plagioclase content may be as high as 40%, and the rock would therefore be a quartz diorite.

Northeast of Sand Lake in Lot 3, Concession 111, Jarvis Township, the rock varies from a granite porphyry to a very coarse-grained, pink granite which, in places, is sufficiently coarse to be called pegmatite. Phenocrysts of microcline occur as large as one inch in diameter. The matrix consists of an equigranular, holocrystalline mass of anhedral quartz, and subhedral microcline and plagioclase. Mafic minerals occur in accessory amounts. Both biotite and muscovite were recognized in these rocks. Modal analysis is shown in column 5 of Table No. 5.

In the Jarvis Batholith, the quartz monzonite, as described from the Weashkog Lake area, is the most typical rock. Quartz monzonite outcrops throughout most of the northern part of Jarvis Township and in Sections 16 and 25 of Duncan Township. The granite, quartz diorite, and syenite are of local occurrence.

In Pennefather and Prince Townships, intrusions, in the form of small stocks and batholiths, cut the large area of granite gneiss. In Section 27, Pennefather Township, outcrops are a white, medium to coarse-grained granite which weathers to a white or buff colour. Inclusions of the older granite gneiss and of basic material are abundant, and, in places, have been drawn into schlieren. Some inclusions have been partially melted and appear as ghosts within the granite.

In thin section, the rock was found to consist almost entirely of quartz and microcline. Plagioclase (An 29), which shows albite and carlsbad twinning, is of lesser importance. Both the microcline and plagioclase are quite fresh, although locally they have a clouded appearance. Straining effects were not seen in any of the sections of this granite. The quartz appears as anhedral grains about 0.5 mm. to 1 mm. across between the larger 1 mm. to 2 mm. subhedral microcline and plagioclase grains. Muscovite is the principal mafic mineral, but near the edges of the intrusive the mafic mineral is biotite. The biotite is altered to chlorite of the penninite variety. Alteration appears to follow layers (0.01 mm. thick) parallel to the cleavage of the biotite, and gives the biotite a striped appearance. A modal analysis is shown in column 6, Table No. 5.

In Sections 35 and 36, Pennefather Township, an area of granite of similar appearance cuts the granite gneiss. Here, the potash feldspar is perthitic microcline and shows moderate alteration to sericite. Inclusions of plagioclase and quartz are abundant in the microcline. Plagioclase (An 29) is less abundant than the microcline. Augite and biotite form the mafic part of the rock. Unstrained, anhedral, quartz grains occur between the subhedral microcline and plagioclase. Accessory minerals include apatite, titanite, muscovite, and iron oxides. In Section 26, Pennefather Township, a projection of this same granite has a similar composition except that here the mafic minerals include hornblende. Accessories such as titanite and apatite are more abundant. Modal analysis is shown in column 7, Table No. 5.

In the western part of Pennefather Township, in Sections 16, 20, and 21, outcrops are a light pink, fine to coarse-grained granite. Aplite zones are quite common. The potash feldspar consists of unaltered, subhedral grains of grid-twinned microcline. Plagioclase (An 25) is a minor constituent and is, in general, altered to sericite. In the aplite zones, all minerals, including microcline and plagioclase, appear as anhedral grains.Hornblende and biotite form the mafic component of this granite. Quartz shows no straining effects.

Most of Prince Township is underlain by medium to coarse-grained, red, intrusive mass consisting of syenite and diorite. This area has been named the Gros Cap Batholith by McConnell (1926). The weathered surface varies from an orange to a greenish colour, depending upon the hornblende content. The potash feldspar is usually orthoclase, but in the more syenitic parts some microcline was identified. Plagioclase (An 35) is the most abundant feldspar, and it occurs as subhedral grains up to 3 mm. across. Locally the feldspars appear clouded, but alteration is not widespread. Hornblende is partially altered to chlorite of the penninite variety. Magnetite comprises as much as five per cent of the rock, and forms the only major accessory. Hematite is a minor constituent and appears to be associated with the chlorite. Modal analysis is shown in column 8, Table No. 5.

In Hodgins Township, the granite, locally, attains a more massive nature. Along Silver Creek in Concession 11, Lots 7 and 8, outcrops consist of a fine to medium-grained, orange granite. This granite is almost completely free of mafic minerals, although some biotite was identified in thin section.

Table No. 5 **MODAL ANALYSIS BASEMENT ACIDIC INTRUSIVES**

Specimen No.	1	2	3	4	5	6	7	8	9
Quartz -----	31	36	27	10	33	29	27	2	29
Microcline ---	6	2	31	12	36	41	-	-	12
Orthoclase ---	-	-	-	-	-	-	-	26	-
Plagioclase --	24 An 23-28	10 21-27	29 28-32	41	22 19-23	21	22	30	31
Perthite ---	27	33	-	-	-	-	27	-	15
Biotite ----	3	7	2	7	4	2	1	7	4
Hornblende ---	5	6	10	21	-	x	x	33	5
Muscovite (sercite) ---	2	1	-	x	2	3	x	-	2
Zircon -----	x	x	-	-	x	x	-	-	x
Chlorite ------	1	2	x	5	x	x	-	x	x
Apatite -----	x	x	-	-	x	-	x	-	x
Iron oxides ---	x	x	-	x	x	-	x	x	x
Sphene -------	-	x	-	-	-	-	x	-	-
Calcite -----	-	x	-	-	-	-	-	-	-
Augite ------	-	-	-	x	-	-	2	x	-
Pyrite ------	-	-	-	x	-	-	-	-	-

Table No.5 (cont'd)

SPECIMEN LOCATIONS

1. Quartz monzonite.- Weashkog Lake, Jarvis Township.

2. Granite.- West of Elizabeth Lake, Duncan Township.

3. Quartz monzonite.- Southwest of Elizabeth Lake, Duncan Township.

4. Quartz diorite.- Southwest of Elizabeth Lake, Duncan Township.

5. Granite.- Northeast of Sand Lake, Jarvis Township.

6. Granite.- Section 27, Pennefather Township.

7. Granite.- Sections 35 &36, Pennefather Township.

8. Diorite-Syenite average.- Gros Cap, Prince Township.

9. Quartz monzonite.- Pebble from Lower Mississagi conglomerate, East of Maud Lake, Duncan Township.

(b) Granite Gneiss - Hornblende Gneiss

Granite gneiss outcrops in Prince, Dennis, Pennefather, Korah, Tarentorus, and Aweres Townships, north and west of Sault Ste. Marie, and in Anderson, Kehoe, and Hodgins Townships, east of Sault Ste. Marie. Locally, the granite gneiss has been disrupted by intrusion of massive granite; in other locations, the granite gneiss grades into massive granite with no indication of sharp contact. The degree of gneissosity changes rapidly. Along highway 17, near the Trout Lake Road, new rockcuts have revealed a hornblende-quartz feldspar rock with distinct gneissosity. Two miles further west, the only indication of gneissosity is a faint lineation of the biotite and hornblende grains in a rock of essentially a granite composition. In the Jarvis Batholith, in Jarvis and Duncan Townships, granite gneiss occurs as xenoliths in an otherwise massive granite (Plate V11). These xenoliths, in places, may comprise as much as 90% of the total volume. Northwest of Northland Lake, the Jarvis Batholith grades into granite gneiss. This is indicated by an increase in the number of xenoliths, and then nearer the granite gneiss, by stringers and dykes of the granite in the gneiss (Plate V111).

No attempt was made, in mapping, to separate areas of granite gneiss, hornblende gneiss, and granite, where each was of a local nature. In general, in the areas of granite and granite gneiss, the amount of outcrop is inadequate for this purpose. The granite and granite gneiss have been separated, in mapping, into areas of principally granite, and areas of principally granite gneiss.

In thin section, the gneisses seem to vary considerably. Along highway 17, near the Trout Lake Road, outcrops are a dark, well-banded hornblende gneiss of a quartz hornblende biotite feldspar composition. Gneissosity is indicated by alternating light and dark layers which are from 1 mm. to 1 cm. thick. Bands consist almost entirely of biotite and hornblende, or of quartz and feldspar. Hornblende, which is more abundant than biotite, has a pleochroic formula x-pale yellow-brown, y-green-brown, and z-green-brown. The biotite has a pleochroic formula x-pale brown, y-green-brown, and z-dark greenish brown. Grains of hornblende and biotite appear equigranular and from 1 mm. to 1.5 mm. in size.

Plagioclase (An 21) has multiple albite and pericline twins, and frequently shows broad carlsbad twins. The potash feldspar is orthoclase. The plagioclase appears as subhedral grains amongst anhedral orthoclase and quartz grains. The quartz is unstrained. Alteration is not intense, although locally the plagioclase is sericitized and the hornblende is slightly altered to chlorite. Accessories include titanite, zircon, apatite, and pyroxene of the augite variety (Z x C 38^{o}). An average composition calculated from ten thin sections is: orthoclase 20%, plagioclase 30%, hornblende 20%, biotite 8%, quartz 20%, and pyroxene 2%.

In the darker bands, the hornblende content is as high as 70%. In zones where the darker bands form the greater part of the rock, the interstitial plagioclase was found to be highly altered to sericite. Locally, the dark zones show a definite ophitic texture. Some of the dark zones, especially those with a thickness of one foot or more, appear to be metamorphosed diabase dykes.

Northeast and northwest of Northland, along the Algoma Central railway, and near the schist belts, many of the outcrops are a dark hornblende gneiss consisting of alternating bands of hornblende and red orthoclase. This gneiss appears to have been produced through injection of granitic material into the schists with resultant recrystallization of the minerals of the schists. The darker bands consist

Plate Vll: Contact between granite and granite gneiss xenolith. Jardun Mines area.

Plate Vlll: Stringer of granite in granite gneiss. North of Northland Lake near contact of Jarvis Batholith.

almost entirely of hornblende and sericitized plagioclase (An 29-35). The granitic layers are composed of subhedral grains of orthoclase with anhedral grains of quartz and biotite. Locally, the layers attain a syenitic composition. Northwest of Northland, the potash feldspar is microcline or perthitic microcline.

Most of the gneiss is a medium-grained, reddish coloured rock showing only slight gneissosity, and it varies in composition from granite to granodiorite. The outcrops just west of Surrette Lake are typical. The potash feldspar is generally orthoclase, but in places, such as Hodgins and Anderson Townships, it is microcline. Plagioclase is fairly albitic (An 19) as compared to the rest of the rocks in the Sault Ste. Marie area; occasionally it was found to have an anorthite content as high as An 30. The quartz generally shows undulatory extinction, especially near major fault zones. The plagioclase and orthoclase appear as subhedral grains with interstitial anhedral quartz. These gneisses have a low, mafic content. Biotite is the common mafic mineral, but locally the mafic mineral is chloritized hornblende. Gneissosity is evident through a lineation of the mafic minerals. Several modal analyses are shown in Table No. 6.

Table No. 6 **MODAL ANALYSIS BASEMENT GNEISSES**

Specimen No.	1	2	3	4	5	6	7
Quartz	25	18	2	26	31	21	19
Microcline	-	-	-	-	-	-	-
Orthoclase	30	17	8	46	49	57	52
Plagioclase	18	32	18	13	11	14	21
Biotite	9	7	-	11	3	7	4
Hornblende	15	23	68	1	3	x	x
Muscovite	x	x	2	-	x	x	x
Zircon	x	x	x	-	x	-	x
Chlorite	-	-	-	1	-	-	2
Apatite	x	x	-	x	-	x	-
Iron oxides	x	x	x	x	x	-	x
Titanite	-	x	-	-	-	x	-
Calcite	-	-	x	-	-	-	-
Pyrite	-	-	x	-	-	-	-
Augite	1	2	1	-	-	-	-

Table No. 6 (cont'd)

SPECIMEN LOCATIONS

1. Hornblende gneiss.- Section 29, Aweres Township.
2. Hornblende gneiss.- Section 29, Aweres Township.
3. Hornblende gneiss.- East of Glendale, Hodgins Township.
4. Granite gneiss.- Anderson Lake, Anderson Township.
5. Granite gneiss.- Section 2, Tarentorous Township.
6. Granite gneiss.- Section 32, Pennefather Township.
7. Granite gneiss.- Section 4, Aweres Township.

West of Trout Lake, a section of the gneiss shows a somewhat augen structure. This appears to have resulted from the metamorphism of a granite porphyry. The augens are about 1/2 inch in size.

HURONIAN ROCKS

In the Sault Ste. Marie map-area the Huronian rocks can be subdivided into two groups: a lower Bruce Group which rests with large angular unconformity upon the basement rocks, and an upper Cobalt Group which overlies the Bruce Group with slight angular unconformity. The Cobalt Group is more extensive than the Bruce Group, and in places, the Cobalt overlies the basement directly.

Bruce Group

In the Sault Ste. Marie map-area, the Bruce Group can be divided into a west section and an east section. This may possibly be the result of a facies change within the group. The formations within the Bruce Group are listed in the Table of Formations (Table No. 4).

(a) Mississagi Formation

In the Sault Ste. Marie map-area, the Mississagi quartzite is the basal formation of the Bruce Group. It rests with high angular unconformity upon the early Precambrian gneisses and schists. It consists mainly of thick quartzite and arkose beds, but thin pebble conglomerate and siltstone or greywacke layers occur, especially near the base of the formation.

The term was originally introduced by Alexander Winchell in 1888 to represent the basal formation of the Bruce Group. Collins used the term in 1914, but he changed the spelling from Mississagui to Mississagi (Collins, 1925).

The Mississagi quartzite outcrops over an area of several square miles in the south, central portion of the map-area. Much of that mapped originally as Mississagi by McConnell (1925) is now classified with the Serpent Formation, and thus the extent of the Mississagi Formation is not as great as previously mapped.

West of Echo Lake, the Mississagi is only of local occurrence. Outcrops, here, are associated with the Bruce limestone, and have been pushed up, by faulting, through the overlying sediments. In Duncan Township, the Mississagi outcrops along the contact of the Jarvis Batholith with the Huronian belt. Here, the outcrop width of the Mississagi varies considerably. Southwest of Maud Lake, the Mississagi outcrops over a width of about one and a half miles, but north of Reserve Lake, the outcrop width is 100 feet or less, and in places, is entirely absent. This belt of the Mississagi is cut off to the south by a branch of the Garden River fault zone. South of Driving Lake, the Mississagi quartzite, with the overlying Duncan greenstone formation, outcrops in an east-west belt which is actually a thrust slice of the Garden River fault zone. Excellent exposures of the Mississagi occur just south of Dead Horse Lake.

In the Sault Ste. Marie map-area, the Mississagi quartzite is, for the most part, a relatively fine-grained, feldspathic quartzite which weathers to a white to dull grey in colour or sometimes to cream in colour. The greywacke and conglomerate zones weather to a buff-green colour. Surface weathering has produced a kaolinized zone about 1/8 inch thick. Below this layer the feldspars appear to be quite fresh. Outcrops have been rounded and polished by glacial action and generally have glacial striae well preserved. The massive beds are generally well jointed; the thinner beds show fewer joints. Locally, the Mississagi stands as prominent escarpments along which frost wedging has produced large talus slopes.

The one hundred foot high escarpment one mile west of Elizabeth Lake is a good example. Along the west side of Maud Lake, steep cliffs of Mississagi rise above the water.

The fresh surface of the Mississagi generally has a bluish or slight greenish tint. Southeast of Driving Lake, the quartzite is purple to brown on the fresh surface. Regardless of colour, the fresh surface invariably has a very glassy appearance. A specimen, collected by D. Pine and reportedly taken from the Mississagi quartzite north of Garden River, showed a distinct green colour due to the presence of chromium mica. The existence of this green quartzite was not verified during mapping.

Cross-stratification, ripple marking, and graded beds are typical of much of the Mississagi. The cross-bedding of the Mississagi has been studied in detail by McDowell (1957), Pettijohn (1957), and Piennar (1958) in an attempt to determine the direction from which the sands came. Cross-stratification, ripple marking, and graded bedding are described in more detail in a later chapter.

On the basis of lithology, the Mississagi Formation can be subdivided into the Lower, Middle, and Upper Mississagi.

(i) Lower Mississagi

The Lower Mississagi includes arkosic quartzite, siltstone, greywacke, and conglomerate. Greywacke and conglomerate are the most characteristic and they form the greatest thickness. In the Sault Ste. Marie map-area, the only definite exposures of the Lower Mississagi occur about one mile southeast of Maud Lake. Here, near the granite contact, outcrops are a poorly stratified, polymictic conglomerate (Plate lX), with minor arkose and greywacke. About 300 feet south of the granite contact, the conglomerate occurs as thin lenses in a moderately well stratified section of greywacke and arkose. The conglomerate and greywacke zones show radioactive counts of two to three times background.

Stratification in the lower conglomerate section is indicated by alternating layers of various sized pebbles. The coarser layers have pebbles up to eight inches in diameter while the finer layers have pebbles three inches or less in diameter. The pebbles are generally a granitic composition and are white to grey in colour. Other pebbles identified, although of rare occurrence, include chert, jasper, iron-formation, hornblende schist, gabbro, diorite, and red granite. Abundance of pebbles varies from about

75% of the total volume of the rock, for the coarser layers, to about 20% of the total volume for the finer layers. The finer layers, that is those with a maximum pebble size of three inches, have a much higher proportion of fine matrix material than the coarser pebble layers. The pebbles are, in general, fairly well rounded, although a few show highly angular outlines, and some of the smaller pebbles are soled. The white granite pebbles are more resistant to weathering than the surrounding greywacke matrix.

Greywacke-Subgreywacke: The greywacke is a buff grey, medium to coarse-grained arenite consisting of highly angular fragments of quartz, feldspars, and rock fragments set in a pasty matrix of fine quartz and white mica. The clastic grains vary in size from rock fragments of about 4 mm. diameter to fine quartz less than 0.01 mm. in diameter (Plate X). Most grains, especially the larger fragments, are quite angular. Subangular and subrounded grains were identified but were rare.

Quartz grains exhibit undulatory extinction with optic angles as high as 5^{o}. Clastic grains are fractured and generally show serrated, grain boundaries.

Plate lX: Lower Mississagi polymictic conglomerate. Southeast of Maud Lake near Driving Creek. Pebbles are mostly white granite and red granite.

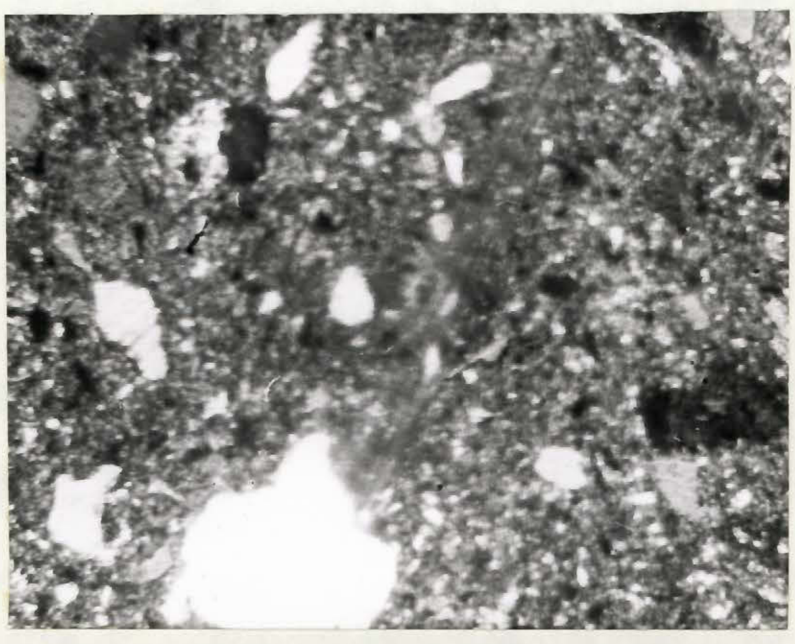


Plate X: Poorly sorted greywacke from Lower Mississagi showing sericite matrix and fine powdered quartz and feldspar. 16X

Fracture filling by sericite mica, and calcite has produced veinlets across the clastic grains.

Rock fragments are abundant, and consist primarily of granite, monzonite, diorite, greenschist, chert, and jasper. The granite fragments have either a quartz orthoclase or a quartz microcline composition, both with minor biotite. The monzonite fragments have approximately equal proportions of either orthoclase and plagioclase (An 32) or of microcline and plagioclase (An 32), with hornblende as the mafic component. Greenschist fragments consist of chloritized hornblende with sericitized plagioclase (An 39) in approximately equal proportions.

Feldspars include microcline, orthoclase, and various compositions of plagioclase (An 23-39). The plagioclase grains generally show moderate sericitization, although some grains appear to be quite fresh. Alteration of the orthoclase and microcline is negligible. Although the plagioclase varies over a fairly wide range of composition, most is in the order of An 30.

Accessory constituents include zircon, apatite, biotite, perthite, muscovite, augite, tourmaline, pyrite, and magnetite.

The matrix consists of a mat of fine sericite quartz, and altered feldspar. The quartz and feldspar fragments are silt size or smaller, and are quite angular. The sericite probably has been derived from the clay constituent of the matrix as well as from powdered feldspar. Chlorite is a minor constituent of the matrix.

The greywacke and subgreywacke are distinguished by the amount of feldspar. The greywacke is poorly sorted with a sorting index of 87; the subgreywacke is better sorted with an index of 73.

Modal analysis of these arenites is shown in Figure 5.

Arkose-Subarkose: The arkose and subarkose beds are grey, medium-grained arenites, composed of angular and subangular grains of plagioclase, orthoclase, microcline, and quartz in a felted mass of fine quartz (Plate Xl). Grains have low sphericity but are fairly well sorted as to size. The large clastic grains vary in diameter from 1.5 mm. to 2.0 mm.; the fragments of fine quartz are 0.02 mm. or less in diameter. Cross-bedding is often detectable in thin section as well as on a megascopic scale.

Quartz forms the larger part of the clastic component. Undulatory extinction is characteristic of

Plate Xl: Arkose from Lower Mississagi showing grains floating in sea of sericite. 20X most of the quartz. The feldspars are generally quite fresh, although a few grains have been almost completely altered to sericite. Plagioclase (An 25-37) exhibits good albite, pericline, and carlsbad twinning. Chess-board twinning was observed on one grain. Small rock fragments of chert, granite, hornblende schist, and diorite occur; these constitute less than two per cent of the total volume of the rock.

The sorting index was calculated at 40 for the arkose and at 35 for the subarkose. Modal analysis of these arenites is plotted on the composition diagram on Figure 5.

Conglomerate: The conglomerate beds are coarse, polymictic rudites which vary rapidly in composition over short distances. The larger pebbles are sub-angular to subrounded. The smaller pebbles, that is those less than one inch in diameter, are generally quite angular. The matrix varies from subarkose to subgreywacke to greywacke. The layers containing the finer pebbles have a subarkose matrix, but as the pebble size increases, the matrix changes to a sub-greywacke or greywacke composition.

The pebbles include most of the rock types of the basement, but fragments completely foreign to the area also occur.

The matrix is composed of quartz, microcline, orthoclase, plagioclase (An 21-33), hornblende, and fine sericite. The quartz shows undulatory extinction. The microcline and orthoclase are fresh; the plagioclase is slightly altered to sericite. The clastic fragments are cemented or are " floating " in a mass of sericite and powdered mineral fragments.

Modal analysis of the matrix of the conglomerate is plotted on Figure 5.

Pebbles From Lower Mississagi Conglomerate:

1. White Granite---White granite fragments, with low mafic content, form the majority of the cobbles and pebbles in the Lower Mississagi conglomerates. Megascopically, they closely resemble the granite and granite gneiss of the basement. Thin section examination shows them to be moderately to highly altered to sericite. The potash feldspar, in most pebbles, is microcline, but some pebbles have perthitic microcline in abundance. Quartz shows undulatory extinction and an optic angle of up to 6°. Plagioclase is of the oligoclase variety (An 28), and generally forms less than ten per cent of the total volume of the rock. Accessories include biotite, zircon,

hornblende, chlorite, apatite, and black iron oxides. Most of the biotite and hornblende has been altered to chlorite.

Several modal analyses of the granitic pebbles from the Mississagi Formation are shown in Table No. 9.

2. Red Granite-Monzonite---Red, medium to coarse-grained granite and monzonite pebbles are common, but are less abundant than the white granite pebbles. They resemble, in outward appearance, the red granites and quartz monzonites of the Jarvis Batholith. They have weathered to a buff colour due to kaolinization of the feldspars. Petrographic examination of the pebbles shows them to be composed of about equal amounts of plagioclase (An 21-29) and perthitic microcline. Microcline was observed in one section, but no orthoclase was identified. Quartz appears as anhedral grains between subhedral plagioclase and potash feldspar. The quartz shows cataclastic effects, that is, fracturing and strong undulatory extinction, typical of the rocks in the Sault Ste. Marie area. The mafics include biotite and hornblende, both of which are partially altered to chlorite. Zircon, apatite, and black iron oxides are the accessories.

A modal analysis of a red granite pebble is recorded in Table No. 5.

3. Hornblende Schist---Hornblende schist pebbles occur scattered throughout some of the conglomerate beds. They are usually smaller than three inches in diameter. On the weathered surface these pebbles are less resistant than the surrounding matrix and have eroded out to produce a pitted surface.

Thin section examination shows them to consist of chloritized hornblende and sericitized plagioclase. Schistosity has been produced by a distinct parallelism of the hornblende grains. Chlorite and sericite alteration have masked most of the textural features of the schist. Quartz is a minor constituent. Potash feldspar was not identified. The plagioclase feldspar is of the andesine variety (An 41).

(ii) Middle Mississagi

The Middle Mississagi is mostly siltstone and fine arkose or feldspathic quartzite. Conglomerate and greywacke occur as thin beds of limited extent. The Middle Mississagi is marked near the base by a granite and quartzite, pebble and boulder conglomerate. This conglomerate is quite similar in composition to the Lower Mississagi conglomerates except for a notable increase in the number of pebbles of sedimentary origin.

The Middle Mississagi outcrops south of Maud Lake. The area is generally till covered so exposure is poor. The fine quartzite and siltstone, southwest of Driving Lake and near the granite contact, is possibly of Middle Mississagi age.

On the weathered surface, these rocks are a buff to pale green colour. The fresh surface, especially on the siltstone beds, has a greenish tint. The weathered surface often is corrugated with ridges about 1/4-1/2 inch apart. This results from alternating laminae in the siltstone, some of which have a higher quartz content than others.

Near the base of the Middle Mississagi, disconformities are common, but they are of a local nature. Fine, clastic dykes are associated with these disconformities. Plate X11 shows a sandstone (quartzite) dyke filling a fracture in the siltstone. These dykes have proved effective in top determination.

Cross-bedding was identified in two places only in the Middle Mississagi (Plate X111). Graded bedding is common especially on a microscopic scale.

Siltstone: The siltstone is a greenish grey,

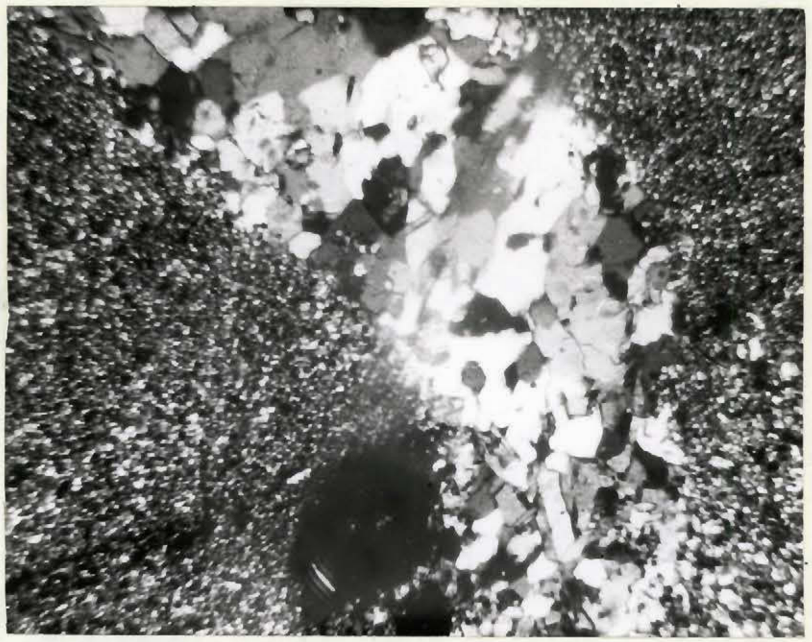


Plate XII: Sandstone dyke filling fracture in siltstone. Characteristic of disconformities near bottom of Middle Mississagi. 16X

Plate XIII: Cross-bedding in Middle Mississagi arkose. Scale 1" equals 3'. Northeast of Garden River Village.

equigranular rock composed of angular to subangular, silt-sized particles. Occasionally, sand-sized particles occur; the occurrence of fine pebbles is rare. On the fresh surface, fine, glassy, quartz grains appear as eyes in a dull background of chloritized and sericitized material. The siltstone generally shows very fine lamination, and graded bedding (Plate XlV). Lamination consists of alternating layers of clastic fragments of various sizes. Individual laminae vary from about 0.25mm. to 1 mm. in thickness. In the coarser-grained laminae, fragments are in the order of 0.1 mm. in diameter, while in the finer-grained laminae they are less than 0.05 mm. in diameter. The fine-grained laminae contain a much higher proportion of sericite and chlorite.

The principal constituents are quartz and feldspar; these are embedded in a matrix of fine chlorite and sericite. Powdered quartz and feldspar, that is, grains less than 0.01 mm. in diameter, comprise a large proportion of the matrix. Feldspar includes microcline, orthoclase, perthite, and plagioclase (An 15-27) in various stages of alteration to sericite. Quartz shows distinct undulatory extinction. Universal Stage measurements on the quartz grains show optic angles as high as 7°. Cryptocrystalline

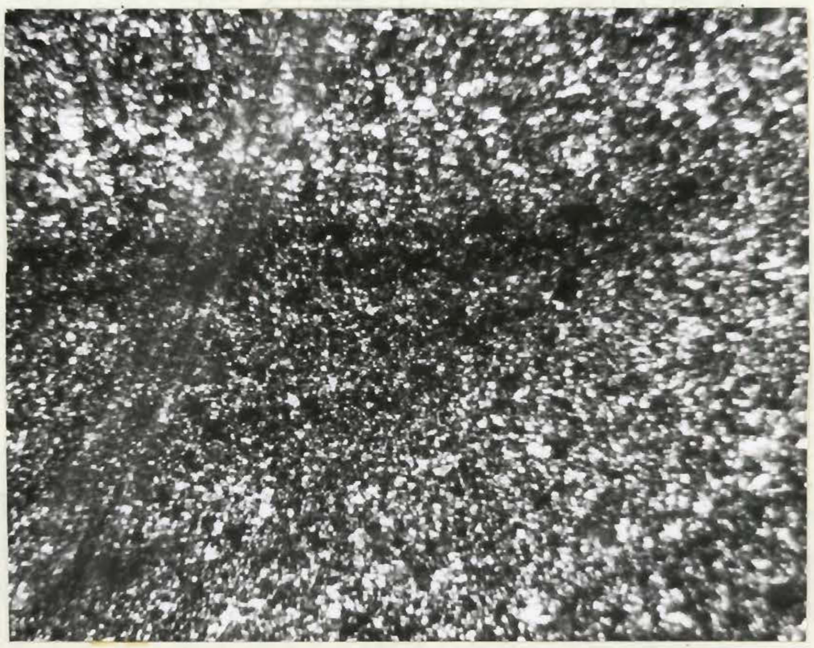


Plate XlV: Photomicrograph of cross-bedding and lamination in fine Middle Mississagi siltstone. 16X quartz, most of which is chert, occurs as angular to subrounded fragments. Other accessory detrital constituents are apatite, biotite, hornblende, rutile, titanite, tourmaline, and zircon.

A modal analysis of this siltstone shows it to be a quartz-rich rock equivalent in composition to a subgreywacke, and differing from a subgreywacke only in the size of the fragments.

Arkose-Subarkose: The arkose and subarkose beds are greenish to greenish-grey clastics of fine to medium-grained size. The clastic fragments are subangular to subrounded and are moderately well sorted as to size. Maximum grain size is about 1 mm.

Mineralogically, these arenites consist of quartz, plagioclase, orthoclase, microcline, and perthite. The quartz shows strong undulatory extinction. Plagioclase varies widely in composition (An 13-29), but most is in the order of An 24. Microcline is the major potash feldspar; orthoclase and perthite occur in minor amounts. The feldspar grains appear in various stages of alteration to sericite; the plagioclase is altered more than the potash feldspar. Accessory detrital minerals include zircon, apatite, magnetite, biotite, and hornblende.

The matrix consists predominantly of white mica, and fine, clastic material in a felted mass surrounding the larger clastic grains. Edges of the larger clastic grains are serrated due to the growth of sericite. Chlorite is a minor constituent and appears to be an alteration product of hornblende or pyroxene.

Modal analysis shows these rocks to have a composition between arkose and subarkose. The sorting index was calculated at 32.

Greywacke-Conglomerate: Greywacke and conglomerate appear as thin lenses within the siltstone and arkose. They are of greatest abundance near the base of the formation where they are associated with local disconformities. In composition and texture, they closely ressemble the greywacke and conglomerate of the Lower Mississagi except that they contain more material of sedimentary origin. Pebbles identified in the conglomerate include white granite, red granite, quartz monzonite, black chert, white chert, jasper, quartzite, hornblende schist, and iron-formation. These pebbles are angular to subangular; they range in size from 1/2 inch to 4 inches. The chert pebbles are subrounded and are no larger than one inch in diameter.

Mineralogically, the matrix of the conglomerate consists of plagioclase, orthoclase, microcline, and quartz. Sericite alteration is widespread. The greywacke closely resembles, in composition, the matrix of the conglomerate. Rock fragments are abundant in both the matrix of the conglomerate, and in the greywacke.

A modal analysis of the greywacke is plotted on Figure 5. The conglomerate and greywacke of the Middle Mississagi are better sorted than the conglomerate and greywacke of the Lower Mississagi. The sorting index was found to be 49.

(iii) Upper Mississagi

The Upper Mississagi consists of thick beds of well cross-stratified feldspathic quartzite and quartzite, with minor subgreywacke. Locally, thin arkose lenses interfinger, but they are of minor importance. In outward appearance, the quartzite of the Upper Mississagi resembles the siltstone of the Middle Mississagi except that the quartzite is coarser grained and is of a more consistent grain size. On the weathered surface, the quartzite is a buff colour which is caused by the kaolinization of the feldspars. These kaolinized feldspar grains appear as white specks in a glassy background of quartz. Thus the total feldspar content is readily obtained on a weathered surface. The fresh surface varies from a green to a bluish colour. The top beds of the Upper Mississagi consist of a coarse, glassy quartzite, with thin arkose or fine conglomerate layers.

The Upper Mississagi is well exposed around Maud Lake. On both the east and west shores, it rises in cliffs about fifty to sixty feet above the lake. From here, the Upper Mississagi is traceable in a northeast direction towards Reserve Lake. Northward from Reserve Lake, most of the outcrops of the Mississagi belong to the extreme upper part of the formation. Towards the north, the outcrops become more arkosic. South and east of Driving Lake and north of the Garden River, the Upper Mississagi is well exposed, especially near Dead Horse Lake. The scattered exposures of the Mississagi, west of Echo Lake, all belong to the upper part of the formation.

The Upper Mississagi is, for the most part, well cross-bedded (Plate XV). Cross-bedding is often marked on the planar erosion surface by a thin pebble layer.

Feldspathic Quartzite-Quartzite: The quartzite and feldspathic quartzite beds vary from grey to greenish

Plate XV: Cross-bedded, fine-grained feldspathic quartzite from Upper Mississagi.

or bluish in colour, and contain subangular to subrounded grains of quartz and feldspar. Grains in the feldspathic quartzite are more angular than the grains in the quartzite. Grain size varies from 0.03 mm. to 2 mm., but most grains are in the order of 1.5 - 2 mm. The finer clastic material occurs interstitially between the larger clastic grains. The feldspathic quartzite is usually slightly coarser than the quartzite. Quartz grains show moderate sphericity except where they have been flattened through cataclastic action.

Unlike the arenites of the Lower and Middle Mississagi, sericite is not abundant in the Upper Mississagi. The quartzite is composed almost entirely of quartz, with minor plagioclase, orthoclase, and microcline. Undulatory extinction and internal fracturing are characteristic of the quartz. The feldspars are only slightly altered to sericite. Plagioclase is of the oligoclase variety (An 23-27).

The grains are cemented by fine-grained silica. Sericite is a minor constituent, although in the feldspathic quartzite it is more important and may comprise as high as thirty per cent of the total volume.

Accessory detrital constituents form a very small part of the quartzite and amount to about one per cent of the feldspathic quartzite. Accessories identified include pyrite, zircon, black iron oxides, apatite, augite, titanite, and hornblende.

Modal analyses are plotted on Figure 5. The sorting index varies from 35 for the feldspathic quartzite to 30 for the quartzite.

Subgreywacke: The subgreywacke layers are distinguished from the feldspathic quartzite and quartzite by the presence of coarse fragments. The subgreywacke occurs in lenses within the feldspathic quartzite; these lenses are seldom thicker than about four inches. The clastic grains appear angular to subangular and vary from silt size to small pebbles.

Mineralogically, the subgreywacke consists of quartz, plagioclase (An 21-34), orthoclase, and microcline, floating in a mass of sericite and chlorite. Powdered quartz and feldspar form a large part of the matrix. The larger clastic grains show serrated edges because of the growth of sericite. Rock fragments amount to about 10% of the rock; they include quartzite, chert, granite, hornblende schist, and diorite. Chert is, by far, the most common. The accessory constituents include titanite, tourmaline, zircon, apatite, and pyrite.

Modal analyses are plotted on Figure 5.

(b) Bruce Conglomerate

The term Bruce Conglomerate was first used by Collins (1914) to denote the greywacke conglomerate above the Mississagi. It had been referred to by Logan and Murray as the Lower Slate Conglomerate. The term Bruce conglomerate has been in constant use since it was first used by Collins.

In the Sault Ste. Marie map-area, the Bruce conglomerate is of very limited distribution, and where it does occur, it lies disconformably upon the slightly eroded, Upper Mississagi surface. The Bruce conglomerate is a crudely-banded, medium to coarse, polymictic, pebble conglomerate containing highly angular fragments. This polymictic conglomerate grades into a coarse greywacke, or grit, near the top of the unit, but the total thickness of the greywacke is much less than the thickness of the conglomerate. The upper few feet of the Bruce conglomerate are quite calcareous.

The only good exposures of Bruce conglomerate, in the Sault Ste. Marie area, occur about a half mile northwest of the point on the west side of Echo Lake. Here, a large cliff is capped by the Bruce limestone which is underlain by the Bruce conglomerate. Southeast of Trotter Lake, scattered outcrops of the Bruce

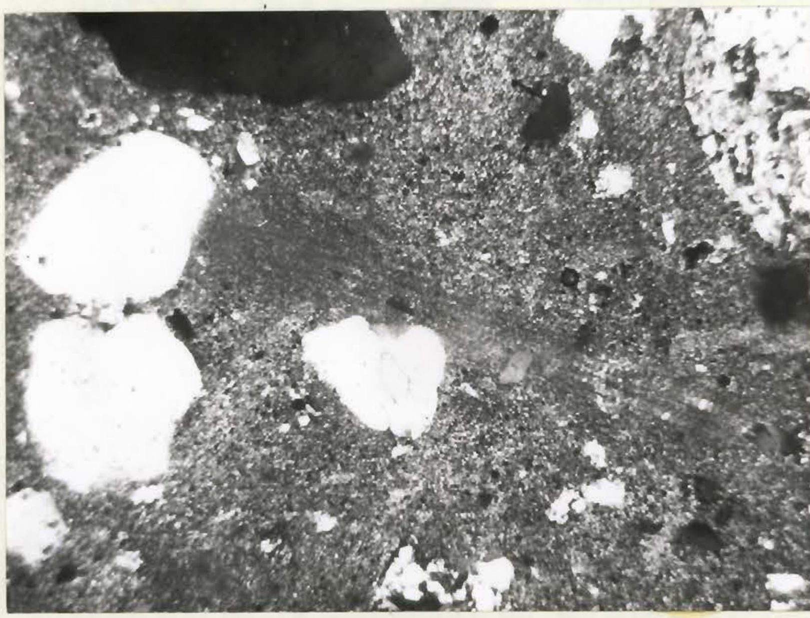


Plate XVl: Photomicrograph of greywacke from the Bruce conglomerate matrix consists almost entirely of sericite and powdered quartz. 20X conglomerate occur beneath the Bruce limestone. In the large knoll about one mile north of highway 17 and the village of Garden River, the Bruce limestone has been faulted up against the later Gowganda formation. Here, the Bruce conglomerate is, in general, faulted out, but small outcrops do occur near the fault plane, especially towards the east end of the knoll. A similar situation occurs just north of the junction of the Root River and Crystal Creek at the west border of the Garden River Indian Reserve.

On a weathered, lichen-stained surface, the conglomerate is dark brown or dark green in colour and shows a chatter marked or fractured surface. On such a surface the pebbles may go completely unnoticed even though they may be as large as six inches. On the fresh surface, the conglomerate is a dark green to almost black colour, with quartz eyes standing out prominently. The matrix appears to be quite siliceous.

Boulders up to three feet in diameter have been reported by Collins (1925), but in the Sault Ste. Marie area, the maximum size recorded was six inches. Most of the rudaceous material is in the order of 1/2 inch to 1 1/2 inches in diameter. Pebbles of granite, granite gneiss, and diorite or diabase are most common. The granite pebbles include both red and white varieties. Other pebbles include hornblende schist, chert, and quartzite. The quartzite pebbles are similar to the underlying, Upper Mississagi quartzite, but these pebbles occur very rarely. The quartzite pebbles tend to be flattened parallel to the bedding planes and thus have a somewhat egg-shaped appearance. On the weathered surface, the schist pebbles have a ribbed appearance because of the alternating hornblende and plagioclase rich layers.

Conglomerate: The conglomerate is an unsorted, polymictic rudite composed of a heterogeneous mixture of boulders, cobbles, and pebbles, embedded in a medium to coarse-grained greywacke matrix. Fragments are angular to subangular; occasionally they are subrounded. The coarser material is more rounded than the finer material. The matrix consists of clastic grains of quartz, feldspar, chert, and rock fragments cemented by a mass of sericite and chlorite. The sericite and chlorite amount to as much as fifty per cent of the matrix (Plate XVl).

The quartz fragments are highly angular and have a jagged appearance. The quartz shows strong undulatory extinction and an optic angle of up to 4^{o}. Black chert is quite common. The chert fragments are slightly better rounded than the quartz grains. Feldspar includes plagioclase, microcline, orthoclase, and perthite varieties. The orthoclase has a red colour due to a surface staining by iron oxides. Plagioclase varies in composition from An 25 - 35. All the feldspars are moderately to highly altered to sericite. The larger plagioclase grains (1mm or greater) show intense alteration to sericite, but the smaller plagioclase grains (0.2mm or less) show little or no alteration to sericite.

Minor constituents include biotite, pyrite, zircon, apatite, augite, titanite, and hornblende.

The matrix of the conglomerate consists of silt-sized fragments of quartz and feldspar, with fine sericite and quartz. Sections taken from near the base of the conglomerate show much less sericite in the matrix than sections taken from further up in the conglomerate.

Modal analyses for the Bruce conglomerate are plotted on Figure 5.

Greywacke: The greywacke is poorly bedded and consists of angular to subangular fragments cemented in an altered mass of sericite. On the fresh surface the greywacke is dull green in colour, and shows numerous, glassy, quartz eyes. Pebbles up to ½ inch in diameter may occur but are not common. These greywacke layers are essentially the same in composition and texture as the matrix of the conglomerate.

Pebbles: White granite, and granite gneiss pebbles are the most common. Their composition varies from quartz orthoclase to quartz microcline or quartz perthite. The mafic component is either biotite or hornblende, or both. The feldspars in the pebbles are much less altered than the feldspars in the matrix.

Robertson (1960) has chemically analysed two pebbles from the Bruce conglomerate, and has compared these analyses with analyses of granite pebbles derived from other Huronian rocks and the pre-Huronian granites. Chemically, he finds them to be intermediate in character between the two basement phases, but closer to the red type (granite and quartz monzonite).

(c) Espanola Formation

The term Espanola Formation has been used by Collins to denote the calcareous sedimentary rocks above the Bruce conglomerate. It consists of three units: the Bruce limestone, the Espanola greywacke, and the Espanola limestone. In the Sault Ste. Marie map-area, the Espanola greywacke and the Espanola limestone do not occur, although the coarse, polymictic conglomerate above the Bruce limestone probably represents a near-shore facies of the Espanola greywacke. This coarse, polymictic conglomerate is classified, in this report, as the basal unit of the Serpent Formation.

(i) Bruce limestone

The name Bruce limestone was first applied by N. H. Winchell (1891) in his resume of Huronian rocks. The term was not used much until it was reintroduced by Collins (1914) during his mapping of the Bruce Mines area.

The Bruce conglomerate grades, in a distance of about two feet, into a fine-grained, siliceous material of about siltstone composition and texture, and this grades rapidly into the finely-laminated, crystalline limestone typical of the lower part of the Bruce limestone. The upper part consists of thick beds of siliceous limestone.

The Bruce conglomerate is followed everywhere that it is exposed, in the Sault Ste. Marie map-area, by the Bruce limestone. The limestone also outcrops without the Bruce conglomerate. The best exposures of Bruce limestone occur along the west side of Echo Lake, on the point projecting into the lake. Here, the limestone is highly contorted, and shows the characteristic corrugation on the weathered surface due to the calcareous beds weathering faster than the alternating silty layers. The outcrops have been washed clean by the waters of Echo Lake, and are best exposed during low water periods. The Bruce limestone underlies a fairly large area west of the south end of Trotter Lake, but here the land is low and exposures are poor. South of Meniss Lake, the Bruce limestone has been thrust up through the Serpent quartzite, and is exposed in scattered outcrops. Limestone, not conclusively identified as Bruce limestone, was located along the west shore of Legge Lake in Jarvis Township. Here the limestone is a coarse crystalline rock, somewhat pinkish on the fresh surface, which contains a few, well-rounded pebbles of glassy quartz. This limestone is located in or near a fault zone, and may be a horst forced upward during fault movement. It contains chalcopyrite and pyrite, and a few volcanic fragments which appear to be part of a fault breccia.

On the weathered surface the limestone is a dark to light grey in colour. Locally, where the limestone contains pyrite, it has weathered to a rusty brown colour. The siliceous laminae are somewhat darker than the calcareous laminae. On the fresh surface, the limestone is grey to white in colour, and shows fine lamination.

Limestone: The Bruce limestone consists of finely crystalline, delicately laminated, grey to bluish grey, somewhat siliceous limestone. Laminae 1 to 2 mm. in thickness are readily detectable in thin section because of the variable amounts of silica. Some laminae contain sufficient silt-sized, quartz fragments to be classified as siltstone.

The quartz grains are highly angular and show frosted surfaces. They are no larger than 0.02 mm. and most are in the size range 0.005 to 0.01 mm. Sericite is a minor constituent of most laminae.

Towards the centre of the Bruce limestone, the beds are a fine, white, crystalline limestone composed of calcite grains with only scattered detrital grains of quartz. The coarser sections are slightly dolomitic. Knight (1915) noticed a considerable increase in dolomite content near the top of the Bruce, but present work and that of Collins (1925) does not indicate a major increase.

Table No. 7 lists analyses of various samples of limestone taken from west of Echo Lake where the most complete section of the Bruce limestone is available. For comparison, results obtained by Collins (1925) are also recorded.

Table No. 7

ANALYSES OF BRUCE LIMESTONE SAMPLES

	1	2	3	4	5	6	7	8	9	10	11	12
CaO	26.31	32.07	40.19	29.36	37.21	31.93	24.21	32.04	36.31	21.50	34.25	40.75
MgO	2.34	2.79	1.36	0.91	1.03	2.19	1.73	1.42	1.12	1.84	0.21	1.21
CO_2	-	-	-	-	-	-	-	-	-	18.82	27.05	33.03
FeO	0.94	1.31	0.71	0.41	1.04	1.13	0.47	0.39	0.67	1.61	0.96	0.32
Fe_2O_3	0.74	0.91	0.37	0.21	0.56	0.69	0.13	0.16	0.31	0.80	0.71	Tr
SiO_2	-	-	-	-	-	-	-	-	-	51.70	34.80	21.52
Al_2O_3	-	-	-	-	-	-	-	-	-	2.65	0.63	2.64
MnO	-	-	-	-	-	-	-	-	-	o.31	0.30	-
H_2O	--	-	-	-	-	-	-	-	-	0.73	1.50	0.65

Table No. 7 (cont'd)

SPECIMEN LOCATIONS

1. North of Crystal Creek, Garden River Indian Reserve.
2. North of village of Garden River, Garden River Indian Reserve.
3. From eroded surface, Echo Lake, Garden River Indian Reserve.
4. One mile south of Trotter Lake, Sample from 48 feet above Bruce conglomerate.
5. One mile south of Trotter Lake, Sample from 41 feet above Bruce conglomerate.
6. One mile south of Trotter Lake, Sample from 34 feet above Bruce conglomerate.
7. One mile south of Trotter Lake, Sample from 21 feet above Bruce conglomerate.
8. One mile south of Trotter Lake, Sample from 12 feet above Bruce conglomerate.
9. One mile south of Trotter Lake, Sample from 5 feet above Bruce Conglomerate.
10. Sample from eroded upper surface of Bruce limestone, Echo Lake, Ont., Ann. Rept., Ont. Bur. Mines vol XXlV, pt. 1, p.227.
11. Sample from 6 inches below eroded surface of Bruce limestone, Echo Lake, Ont., Ann. Rept., Ont. Bur. Mines, vol XXlV, pt. 1, p. 227.
12. Average sample from 50 feet of strata near top of Bruce limestone, Garden River, Ontario, Ann. Rept., Ont. Bur. Mines, vol XXlV, pt. 1, p. 227.

Siltstone: The siltstone layers within the Bruce limestone are grey to black in colour and consist of highly angular to well rounded fragments of quartz, cemented in a matrix of fine sericite and calcite. The clastic fragments comprise from 25 to 40 per cent of the rock. Quartz is the principal clastic material but others identified include plagioclase, microcline, jasper, and zircon. All the clastic grains have frosted surfaces. Penninite, pleochroic in light green, occurs as small flakes throughout the matrix. The silt layers contain pyrite crystals which have grown since recrystallization of the limestone and their growth has disrupted the fine lamination.

(d) Duncan Formation

The term Duncan greenstone was introduced by McConnell (1926) to represent the massive, sheared, and amygdaloidal volcanic rocks which outcrop in Duncan Township. The term has been retained in this report, but its stratigraphic position has been greatly revised.

In the central part of the map-area, the Duncan greenstone lies directly upon the Mississagi quartzite. The Bruce limestone is entirely absent in this area except for the small possible occurrence near Legge Lake.

In the Echo Lake region, the Mississagi quartzite is overlain by the Bruce conglomerate and the Bruce limestone, the Duncan greenstone being absent in this area.

Two and one half miles north of the village of Garden River, the Duncan greenstone outcrops in an escarpment 80 feet in height. Here, its exposure width is about two miles in a northeast direction. It continues northward in a belt towards the Bellevue Ridge, narrowing to a width of one mile west of Reserve Lake and widening to about two miles at Bellevue Station. The belt is terminated at the Bellevue Ridge by a prominent east-west fault. A second belt of Duncan greenstone lies between the east-west fault through Driving Lake and the Garden River fault zone. The greenstone is traceable from the Jardun Mines Road east to the boundary of Kehoe Township, where the two faults join.

Excellent exposures of Duncan greenstone occur about two miles west of Driving Lake and just east of the Jardun Mines Road. Here, the greenstone stands in an impressive topographic feature some 700 to 800 feet in height. Except for the escarpment north of Garden River, the above hill, and a few railway cuts west from Bellevue Station, outcrops of the Duncan greenstone are poor. In most of Duncan and Jarvis Townships, exposure consists of scattered outcrops in an otherwise flat muskeg and swamp highland.

The rocks consist of massive, amygdaloidal, and sheared lavas of from andesite to basalt composition. On the weathered surface they are a dark green colour, except where the feldspar content is high kaolinization has resulted in a buff to pale green weathered surface. Where amygdules have been eroded away, the surface is highly pitted (Plate XVll). East of Maud Lake, the lavas have large quartz amygdules which stand as resistant bumps on the weathered surface. Where these quartz amygdules are abundant, the rock resembles a conglomerate.

Thin quartz-pebble layers occur near the base of the Duncan Formation. These were identified in two localities, just east of Maud Lake, and about three quarters of a mile east of Driving Lake, McConnell (1926) described a conglomerate of similar nature which he located on the hill south of Driving Lake, but this conglomerate was not found during the current mapping. The conglomerate on Maud Lake is strongly radioactive.

Shearing is very prominent in the lavas and in places is so intense as to obliterate all evidence

Plate XVll: Pitted surface of Duncan greenstone because of the weathering out of chlorite amygdules. Pits are about 2 inches in diameter.

of stratification.

Amygdaloidal Lava: Amygdaloidal lava forms by far the greater part of the Duncan Greenstone Formation. On the fresh surface, it is a dark green, fine to medium-grained rock, and, locally, shows a slightly diabasic texture. The amygdules are of two main varieties: quartz-filled amygdules and chlorite-filled amygdules. The quartz amygdules occur up to one inch in diameter. The chlorite amygdules are about 1/4 inch in diameter and are more abundant. Where the chlorite amygdules have been sheared, they appear as dark spots within the rock and resemble fossil impressions.

Mineralogically, the groundmass of the rock is composed of plagioclase, amphibole, and pyroxene. The amphibole and pyroxene show alteration to chlorite and penninite. This alteration is so intense as to make determination of the variety of amphibole doubtful, but evidence indicates that it is hornblende (Plate XV111). Microlites of plagioclase are numerous. Average dimensions for these microlites are 0.15 mm. by 0.02 mm. Plagioclase also occurs as anhedral to subhedral grains between the amphibole grains. The plagioclase is of an intermediate variety (An 38) and is slightly altered to sericite. Where alteration is

Plate XVlll: Duncan greenstone showing highly altered groundmass and altered amygdule.

not intense the rock has a somewhat diabasic texture, with large laths (2 mm. in length) of plagioclase surrounded by anhedral and subhedral grains of hornblende and pyroxene. Accessories include biotite, quartz, black iron oxides, and pyrite.

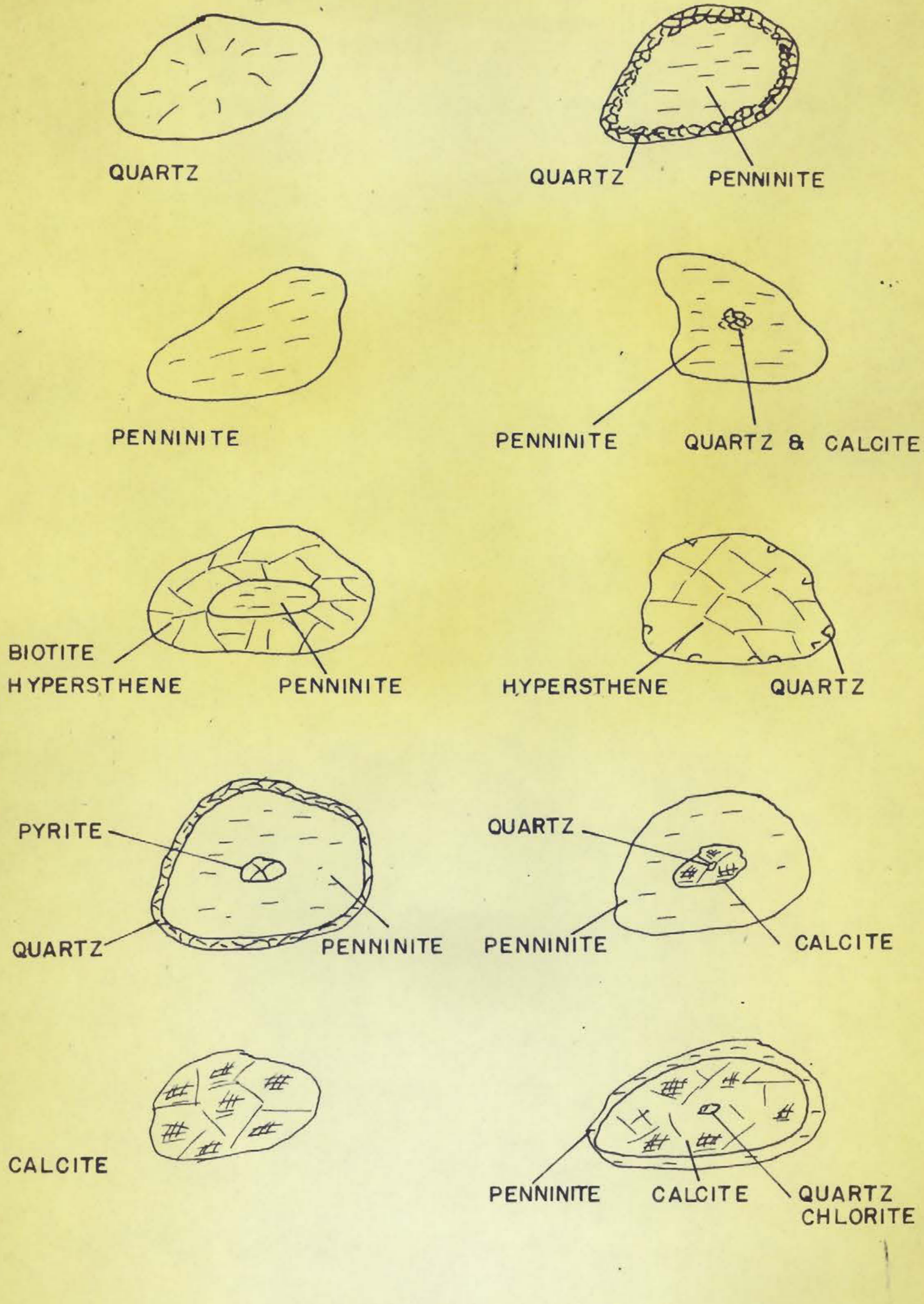
There are several varieties of amygdules and their differences can sometimes be used to correlate flows over short distances. In hand specimen there are two distinct varieties, the quartz-filled and the chlorite-filled (Plate XlX), but thin section examination allows a further subdivision into: (1) quartz-filled, (2) predominantly quartz-filled but lined with penninite, (3) penninite-filled, (4) penninite-filled and lined with quartz, (5) penninite-filled and lined with biotite, hypersthene, and minor quartz, and (6) calcite-filled. The general structure of these amygdules plus a few less common varieties is shown in Figure 6.

In one amygdule the pleochroic colour of the biotite carries into the penninite, although the brilliant blue birefringent colour of the penninite persists. Evidence indicates that the biotite and hypersthene have been produced by the reaction of the penninite with the surrounding rock. The pleochroic formula of the biotite is x - pale brown, y - dark

Plate XlX: Penninite filled amygdule with pyroxene grains as a lining 22X.

Figure 6

AMYGDULES FROM DUNCAN FORMATION



brown and z - dark brown.

The quartz-filled amygdules generally occur stratigraphically higher in the formation than the predominantly penninite-filled amygdules. The calcite-filled amygdules were identified in only one place, east of Driving Lake. Pyrite-filled amygdules were also found in this area.

Massive Andesite: The massive andesite is a fine to medium-grained, dark green coloured volcanic. Locally, it is slightly pillowed, and occasional amygdules can be identified. Diabasic texture is a common feature. Massive beds of andesite outcrop in the large hill just southeast of the junction of the Driving Lake Road and the Jardun Mines Road. On the south side of this hill, faint pillow boundaries were identified. South of Driving Lake, the Duncan greenstone is generally massive but does contain a few, thin, amygdaloidal flows.

Petrographically, these andesites are similar to the amygdaloidal andesites. Microlites of plagioclase are in the intermediate composition range (An 36). Where the texture is diabasic, the plagioclase is coarser, and is euhedral towards the hornblende and pyroxene. Plagioclase is slightly altered to sericite. The mafic minerals include highly altered hornblende and pyroxene. In places chlorite alteration has completely masked all igneous textures. Minor constituents include biotite and quartz. The massive andesites, unlike the amygdaloidal andesites contain no penninite (Plate XX).

Quartz-Pebble Conglomerate, Greywacke, and Arkose: Quartz-pebble conglomerates and greywacke occur interbedded with the volcanic rocks near the base of the Duncan Formation. These clastics are of very restricted occurrence and are confined to the bottom fifty feet of the formation. The quartz-pebble conglomerate consists of highly fractured, well rounded pebbles of quartz about one and a half inches in diameter cemented in a matrix of sericite and fine quartz. These conglomerate layers are interbedded with coarse arkose layers containing angular grains of feldspar. These feldspar grains are of a fairly uniform grain size (1/8 inch). All the beds are highly radioactive. The conglomerate layers have a high pyrite content which gives them a rusty weathered surface.

The best exposures occur in the cliff on the east side of Maud Lake (Figure 7). Here the Mississagi quartzite is followed by about fifteen feet of andesite and then by about fifteen feet of clastic

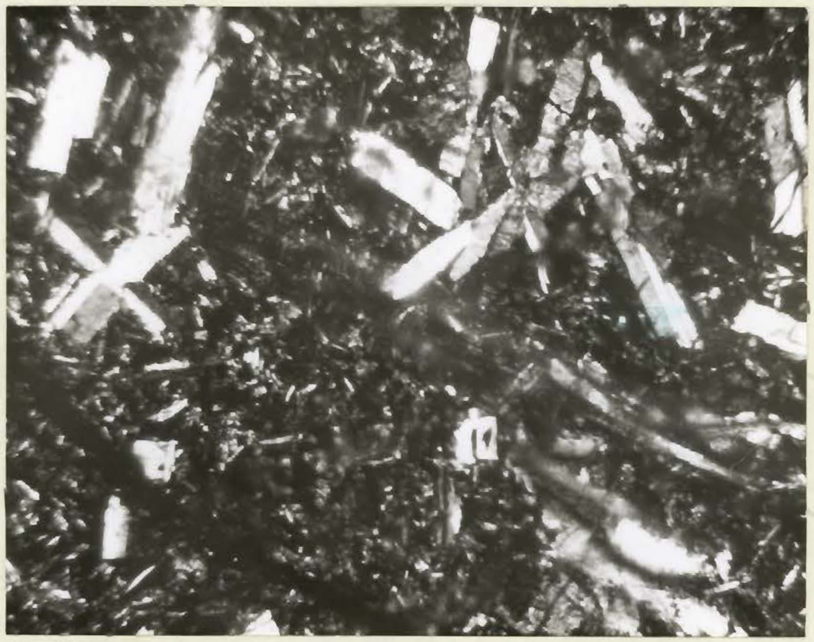
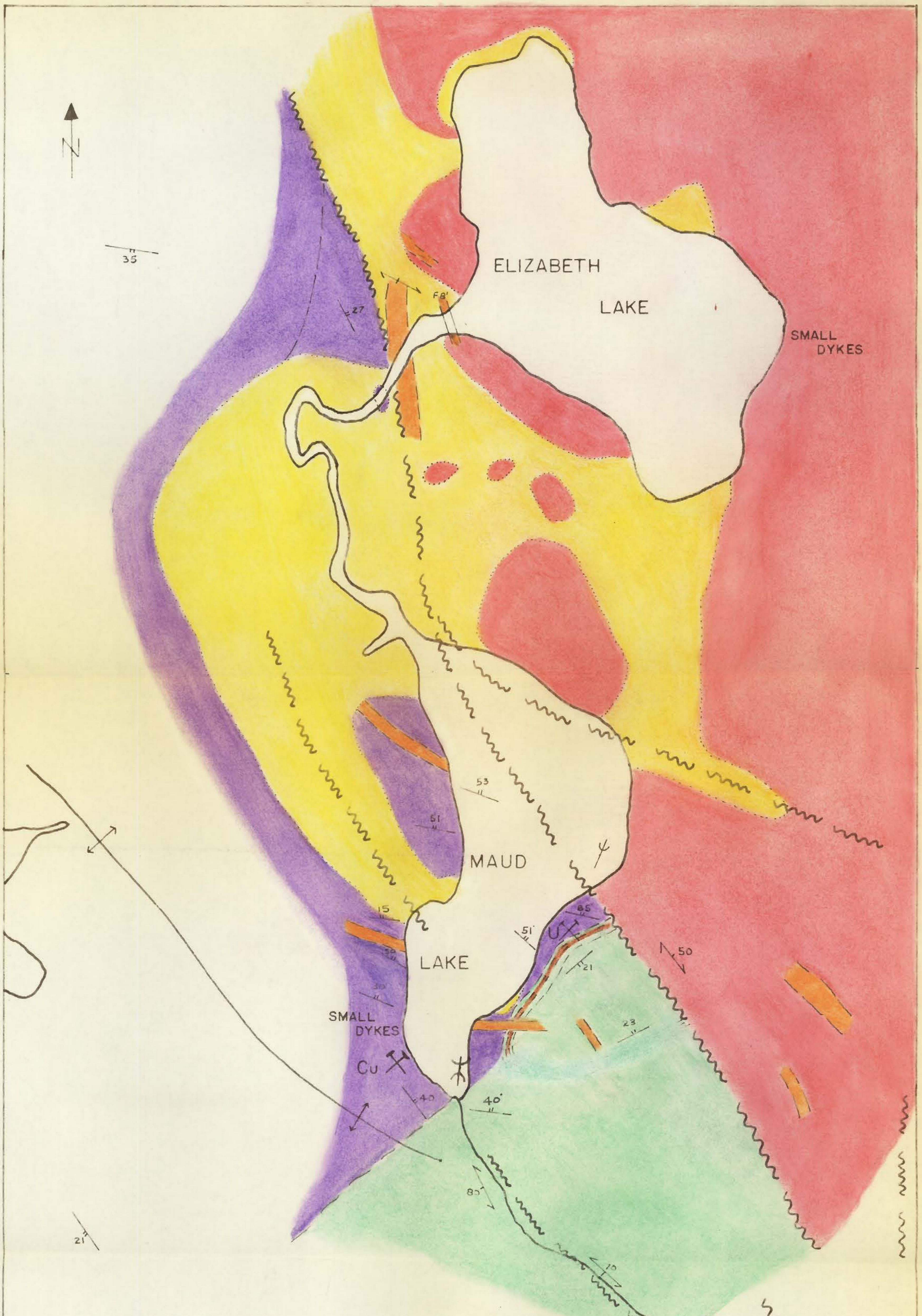


Plate XX: Slightly porphyritic Duncan greenstone showing laths of plagioclase in a groundmass of chlorite 64X.

Figure 7



ELIZABETH LAKE - MAUD LAKE AREA

SCALE 1" = 660'

LEGEND

SURFICIAL DEPOSITS

INTRUSIVES

DUNCAN FORMATION:

- AMYGDALOIDAL GREENSTONE
- MASSIVE GREENSTONE
- PEBBLE CONGLOMERATE & ARKOSE
- CHLORITIC SCHIST & AMYGDALOIDAL GREENSTONE

MISSISSAGI QUARTZITE

GRANITE

material. A similar relation is found above the Mississagi quartzite southeast of Driving Lake.

The pebbles in the conglomerate are fairly well rounded and show moderate sphericity. Most of the pebbles are of clear glassy quartz. Chert pebbles are rare. No rock fragments were identified. Some of the pyrite appears as "pebbles" or nodules up to one inch in diameter.

Petrographically, the quartz pebbles are fractured and show strong undulatory extinction. Orthoclase, microcline, and plagioclase were recognized in thin section but they are very minor constituents. The matrix is a mixture of sericite and fine quartz. Heavy detrital minerals are minor accessories within the matrix. They include titanite, zircon, apatite, tourmaline and black iron oxides plus several other dark unidentified minerals. These unidentified minerals may represent the radioactive content. The fine grained material in the conglomerate is considerably more angular than the coarser material. The volume ratio of pebbles to matrix is about 1:2.

The arkose layers are composed of coarse clastic grains of orthoclase, plagioclase, microcline, quartz, and chert (Plate XXl). The larger grains are subangular but the fine grains are highly angular.

Plate XXl: Arkose layer from near base of Duncan Formation. Angular fragments of quartz cemented by a sericite matrix 22X.

Feldspars comprise about sixty per cent of the clastic fragments. The matrix consists of fine, white sericite and powdered quartz. The clastic material-matrix ratio in the arkose is about 3:1.

Greywacke interfingers with the arkose. It is somewhat finer grained than the arkose and is separated from the arkose by the amount of matrix material. In the greywacke, the clastic-matrix ratio is about 1:1.

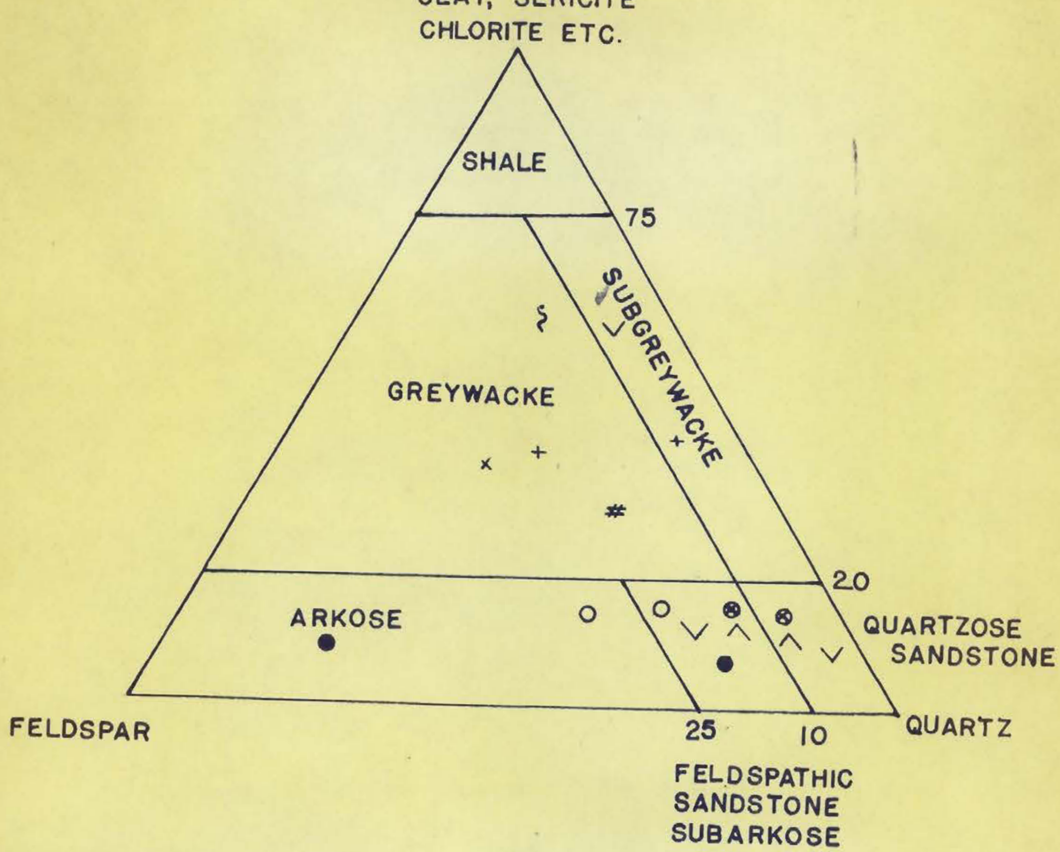
The sorting index for the conglomerate is 56 and for the arkose it is 45. Modal analyses for the conglomerate and arkose are plotted on Figure 5.

(e) Aweres Formation

The Aweres Formation was first described by McConnell (1926). It consists of coarse polymictic conglomerate, greywacke, arkose, and quartzite, and overlies the Duncan Formation. In the south, the contact with the Duncan greenstone is erosional, but in the north, the contact is gradational, with the conglomerate lenses occurring between flows of the upper part of the Duncan. The erosion surface in the south appears to have had a pre- Aweres relief of from 50 to 100 feet.

The Aweres is located geographically west of the Duncan greenstone. Where it first appears north of Little Lake George in the Garden River Indian

FIGURE 5



+ LOWER MISSISSAGI SUBGREYWACKE - GREYWACKE

o LOWER MISSISSAGI ARKOSE - SUBARKOSE

× LOWER MISSISSAGI CONGLOMERATE MATRIX

MIDDLE MISSISSAGI GREYWACKE

⊗ UPPER MISSISSAGI FELDSPATHIC QUARTZITE - QUARTZITE

§ BRUCE CONGLOMERATE MATRIX

● DUNCAN GREENSTONE CONGLOMERATE - ARKOSE

^ UPPER AWERES FELDSPATHIC QUARTZITE - QUARTZITE

√ SERPENT SUBGREYWACKE - FELDSPATHIC QUARTZITE - QUARTZITE

Reserve it has an outcrop width of less than one mile but this widens northwestward. At Trout Lake it has an outcrop width of five miles. North of Island Lake the outcrop width constricts rapidly. Where the Aweres Formation crosses the Algoma Central railway its outcrop width is less than one half mile.

Exposures of the Aweres are normally excellent especially where it is composed of thick beds of quartzite. In the Garden River Indian Reserve, where the formation has been intensely sheared, the rock has a chloritic nature and exposures are poor. Towards the Duncan greenstone contact, with an increase in greenstone pebbles and greywacke lenses the exposure becomes progressively poorer. Good exposures of quartzite occur north of Trout Lake and of conglomerate northwest of Maki Lake.

The weathered surface varies considerably in colour. In the southeast where the chlorite content is fairly high a rusty brown weathered surface is characteristic. North of Trout Lake where clean quartzite outcrops, exposures are grey to buff in colour and locally are almost white. In the northern section, with an increase in chlorite content, outcrops are again a rusty brown colour but where they have been polished by glaciation they are dark green to black in colour.

The Aweres Formation has been divided into two units: a basal unit of coarse polymictic conglomerate with subarkose, and an upper section of relatively clean quartzite. North of Island Lake this upper quartzite is completely absent.

(i) Lower Aweres

Conglomerate: The contact between the Aweres Formation and the Duncan Formation is marked by a basal conglomerate layer at least 200 feet thick. Towards the north, this conglomerate increases rapidly in thickness. The conglomerate is generally a coarse polymictic variety and contains fragments of most of the underlying rocks. As the contact with the Duncan greenstone Formation is approached the number of greenstone pebbles increases until near the contact these pebbles comprise about sixty per cent of the volume of the rock (Plates XXll & XXlll). Quartzite pebbles, showing cross-bedding, and resembling the upper Mississagi, occur throughout the conglomerate. In the Garden River Indian Reserve, where the Duncan greenstone has been completely eroded away so that the Aweres Formation overlies the Mississagi Formation directly, the basal conglomerate of the Aweres consists almost entirely of pebbles, cobbles, and boulders of

Plate XXll: Lower Aweres Conglomerate showing Duncan greenstone pebbles and the occasional pebble of Mississagi quartzite.

Plate XXlll: Conglomerate at base of Aweres showing elongated pebbles of the Duncan greenstone.

the Mississagi quartzite. Duncan greenstone pebbles are scarce in this area. It would appear that in this area the Duncan greenstone has either been completely removed by erosion prior to deposition of the Aweres or else the Duncan never did cover the area.

The pebbles in this conglomerate are generally egg shaped. This is undoubtedly related to stratification or schistosity in the parent rock, for most of the pebbles are elongate parallel to their stratification. The few granite pebbles which do occur are more spherical. The greenstone pebbles seldom exceed a length of about four inches and a thickness of 1 to 1 1/2 inches. The Mississagi quartzite pebbles are much larger; The largest pebble identified showed a length of 10 inches and a thickness of four inches. The greenstone pebbles are moderately schistose and contain many chloritic amygdules.

To the west the Aweres Formation extends beyond the Duncan Formation and the Mississagi Formation and overlies the basement gneisses. Here the basal conglomerate is of the coarse polymictic type and contains pebbles of granite and granite gneiss. The only greenstone and quartzite pebbles identified could not be confirmed as to their origin.

Southwest of Driving Lake and near the Garden River Fault zone a small outcrop of conglomerate rests upon the Mississagi quartzite. This conglomerate contains many greenstone and quartzite pebbles. This is the only outcrop of the Aweres conglomerate outside the main north-south belt in Aweres and Duncan Townships.

The matrix of the Aweres conglomerate could be classified as a greywacke. It consists of highly angular fragments of rocks and minerals in a groundmass of sericite and chlorite. Grain size varies from 0.01 mm. to 4 mm. Powdered quartz comprises about 25 per cent of the groundmass.

Rock fragments are of quartz-orthoclase, quartz-microcline, and orthoclase-plagioclase composition. Quartzite and chert fragments are not common. The main mineral fragments are quartz and feldspar. All the quartz shows strong undulatory extinction. The feldspars include orthoclase, microcline, perthite, and plagioclase An 18-34 and all are slightly altered to sericite. Many of the fractures within the conglomerate are filled with calcite. The accessory constituents include magnetite, zircon, apatite, pyroxene, and pyrite.

Pebbles from Basal Aweres Conglomerate:

1. Greenstone - In thin section, the greenstone pebbles appear as a highly altered mass of sericite and chlorite, with the occasional, partially altered feldspar grain. The chlorite shows pale green pleochroism and appears to be an alteration product of hornblende. Penninite, although common in some of the amygdules, does not occur in the groundmass of the rock. Biotite is not common and where it does occur it is partially altered to chlorite. The feldspar is predominantly plagioclase and it varies in composition from An 23 - 37 depending upon the pebble.

Most of the pebbles contain amygdules. These vary in size from 1/8 th inch to about 1/2 inch. Petrographic examination of the amygdules showed them to be of five major varieties: (1) penninite-filled and lined with quartz, (2) penninite-filled with a small core of quartz and calcite, (3) entirely filled with calcite, (4) penninite-filled and lined with a mixture of biotite and quartz, and (5) quartz-filled with a small core of penninite. Only the amygdules containing pyrite and those containing pyroxene, which were identified in the Duncan greenstone, were not found in the pebbles; a more complete study of the pebbles might possibly reveal these varieties.

Accessory constituents in the groundmass of the pebbles include pyrite, black iron oxides, titanite, and quartz.

2. Quartzite - Subarkose - The quartzite and subarkose pebbles are typically buff to grey in colour, and, if sufficiently large, may show cross-bedding. In hand specimen they resemble very closely the rocks of the Upper Mississagi.

In thin section, the grains appear subrounded and show moderate sphericity. They vary in size from 0.05 mm. to 2.0 mm. In the subarkose pebbles, the grains are slightly more angular and show a greater size range.

Mineralogically, the pebbles consist of quartz, which shows strong undulatory extinction, and feldspar of the perthite, microcline, plagioclase (An 23-33), and orthoclase varieties. Accessories include pyroxene, apatite, pyrite, zircon, black iron oxides, and tourmaline.

The cement is quite variable depending upon the pebble. Sericite may or may not be abundant. In some pebbles, the grains appear to be floating in a mass of sericite, and the grain boundaries are corroded as a result of the growth of the sericite. In others, especially those which are composed entirely of quartz grains, the matrix is almost entirely powdered quartz, with only minor sericite.

3. Granitic pebbles - The granitic pebbles are of several varieties. Red granite, white or grey granite and grey granite gneiss are the most common. In the east, near the contact with the Duncan greenstone, the granitic pebbles are of limited occurrence, but they are abundant in the west, especially northwest of Maki Lake. The maximum pebble size observed northwest of Maki Lake was 8 inches but most are about 2 to 3 inches in diameter.

Mineralogically these pebbles consist of either quartz - orthoclase - plagioclase, or quartz - microcline - plagioclase. The red granite pebbles contain a larger percentage of plagioclase An 27 - 32 and in some pebbles the plagioclase content is sufficiently high to classify the rock as a quartz monzonite. Perthite was identified but is not abundant in any of the pebbles studied.

The mafic constituent is either biotite or hornblende depending upon the pebble. The red granite or quartz monzonite pebbles generally have hornblende as the mafic constituent and the white granite pebbles have biotite. The hornblende and biotite generally show some alteration to chlorite.

Accessories identified include zircon, apatite, black iron oxides, and pyroxene.

Several modal analyses of some of these pebbles are shown in Table No. 8.

Feldspathic Quartzite: The top fifty feet of the basal Aweres conglomerate unit consists of interbedded feldspathic quartzite and conglomerate, with the occasional thin greywacke lens. Here, the conglomerate is of a small pebble variety (one inch or less), and the pebbles never comprise more than about twenty per cent of the volume of the rock.

Clastic grains are commonly subangular to subrounded and range from fine to coarse-grained, sand-sized particles. In some of the slightly coarser layers, small pebbles (less than 1/2 inch) of quartzite, chert, and greenstone are found.

Mineral fragments identified include quartz, microcline, orthoclase, and plagioclase, and these are all floating in a fine sericite matrix. Chlorite is a minor constituent of the matrix. The average potash feldspar-plagioclase feldspar ratio is 1:1. The plagioclase grains are partially altered to sericite, and tongue-like projections and embayments of sericite mark the edges of the

Table No. 8

MODAL ANALYSIS AWERES GRANITIC PEBBLES

Specimen No.	1	2	3	4	5	6	7
Quartz	30	22	34	17	19	24	23
Microcline	19	15	26	31	-	-	-
Orthoclase	-	-	-	-	37	41	52
Plagioclase	29	37	21	39	33	26	19
An	21-25	23-29	23-27	22-28	21-23	19-28	22-29
Perthite	10	9	3	-	-	-	-
Biotite	2	4	3	5	9	8	4
Hornblende	7	12	11	7	1	x	x
Muscovite (sericite)	x	x	x	x	x	x	x
Zircon	x	x	x	x	x	x	x
Chlorite	x	-	x	-	x	x	-
Apatite	x	x	x	-	x	x	x
Iron Oxides	-	-	x	-	-	-	-
Sphene	-	-	x	-	-	-	-
Augite	-	-	-	-	x	1	-
Pyrite	x	x	-	-	-	x	x

Table No. 8 cont'd

Specimen Locations

1. Quartz Monzonite - East of Surrette Lake, near Duncan greenstone contact, Duncan Township.

2. Quartz Monzonite - Alexander Lake, west shore area, Duncan Township.

3. Granite - Maki Lake, 200 feet north of west end of the lake, Aweres Township.

4. Quartz Monzonite - North of Island Lake near contact of Duncan Formation and Aweres Formation on the Algoma Central railway, Aweres Township.

5. Gneissis pebble - West of Trout Lake, Aweres Township.

6. Gneissic pebble - North shore of Mabel Lake, Duncan Township.

7. Gneissic pebble - Alexander Lake, Duncan Township.

quartz and microcline grains. The quartz grains show strain shadows and many show incipient recrystallization. Some of the quartz grains show intense fracturing.

Accessories include zircon, magnetite, titanite, and black iron oxides.

The sorting index is 71. The high sorting index, in combination with the high average matrix content of this feldspathic quartzite and the poor rounding of the clastic grains shows a textural immaturity for this arenite.

(ii) Upper Aweres

Quartzite: The upper part of the Aweres Formation consists of a considerable thickness of medium to fine-grained quartzite and feldspathic quartzite. Quartz pebble layers occur but they are normally less than one foot in thickness and are of local extent (Plate XXlV). Outcrops occur as large rounded hills (roche moutonée) which have weathered to a white or buff colour.

The clastic grains are equigranular and are subangular to subrounded. Mineralogically the quartzite consists of quartz, microcline, orthoclase, chert, and highly altered plagioclase. The feldspathic quartzite differs only in the total feldspar content.

Minor constituents include muscovite, apatite, pyrite, zircon, and black iron oxides.

The matrix varies from highly siliceous to highly micaceous. The feldspathic quartzite usually has a more micaceous matrix. Where the matrix is sericite, serrated grain boundaries caused by the growth of the mica are typical.

The sorting index for the feldspathic quartzite is 25, and for the quartzite, 20. Modal analyses of these rocks have been plotted on Figure 5.

(f) Serpent Formation

The Serpent quartzite Formation overlies the Bruce limestone with local disconformity. In the Sault Ste. Marie map-area, the contact is marked by a basal conglomerate, about two hundred feet thick, which contains numerous fragments of the Bruce limestone. According to Collins (1925), prior to 1914 no reference had been made to the Serpent quartzite. Collins (1914) in his description of the Huronian of the Timiskaming district identified the formation and gave it the name Serpent; the formation was first recognized at the headwaters of the Serpent River, near Quirke Lake, and therefore was given the name Serpent.

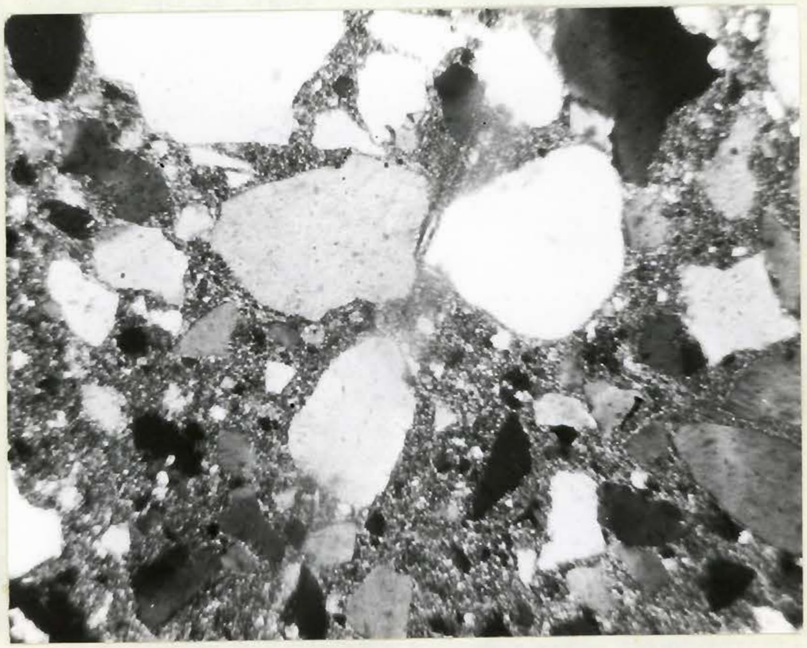


Plate XX1V: Section showing matrix of quartz pebble layer from Upper Aweres. Matrix is highly altered to sericite.

At Quirke Lake the Serpent overlies the Espanola, and, as Collins reports, (1925), the indurated silt at the top of the Espanola limestone merges into the Serpent quartzite in about fifteen feet. It grows lighter in colour, becomes slightly coarser grained, and is more quartzitic in appearance, but the fine lamination so characteristic of the silt persists.

The Serpent Formation appears to be much more extensive in the map-area than was formerly thought. McConnell (1926) recognized no Serpent quartzite in the area; he placed most of the quartzite, south of the Garden River, in the Mississagi Formation. This section south of the Garden River is now classified as Serpent.

For purposes of description, the Serpent has been divided into two units: a coarse, polymictic basal conglomerate, and a thick, upper sequence of quartzite and feldspathic quartzite. This upper section contains minor subgreywacke, argillite, and conglomerate.

(i) Basal Conglomerate

In the Sault Ste. Marie map-area the upper part of the Espanola Formation, the Espanola greywacke and the Espanola limestone, does not occur. Between the

Bruce limestone and the Serpent quartzite is a polymictic conglomerate which may be the facies equivalent of the upper part of the Espanola Formation. Frarey (1959) reports a similar conglomerate north of Bruce Mines at Ophir, Ontario.

This conglomerate is best exposed along the west shore of Echo Lake between the limestone on the point projecting into the lake and the Serpent quartzite further inland. Northwest of this point, the conglomerate has a patchy distribution above the Bruce limestone. West of Trotter Lake, highly sheared, polymictic conglomerate overlies the Bruce limestone, but, here, exposure is poor. North of Wigwas Lake a small anticline of Bruce limestone is surrounded by polymictic conglomerate. In many places this polymictic conglomerate is very difficult to separate from the Bruce conglomerate. The upper polymictic conglomerate contains Bruce limestone fragments and this is the best means of distinguishing between the two.

The weathered surface varies from a buff to green colour depending upon the chlorite content of the matrix. The pebbles, cobbles, and boulders of the conglomerate are subrounded to subangular, and are unsorted as to size. In general, it is somewhat coarser than the Bruce conglomerate, and the pebbles show considerably more rounding than those of the Bruce conglomerate. Most of the pebbles are either red granite or white granite. Quartzite, greenstone, and Bruce limestone pebbles are less common. On the weathered surface the conglomerate closely resembles the basal conglomerate of the Aweres Formation as seen northwest of Maki Lake.

In thin section, the matrix of the conglomerate shows angular mineral fragments floating in a sericite mass. The finer particles are considerably more angular than the coarser particles. Clastic grains include both mineral and rock fragments.

The rock fragments generally have a granite composition, and vary from quartz-orthoclase to quartz-microcline to quartz-orthoclase-plagioclase. Gabbroic fragments occur but are rare. Quartzite, limestone, and chert particles were also identified. Mineral fragments include quartz, orthoclase, microcline, and plagioclase (An 15-31).

The matrix consists essentially of sericite and chlorite, but, in some sections, powdered quartz comprises up to twenty five per cent of the matrix.

Subgreywacke: The subgreywacke of the Serpent

Formation is a fine to medium-grained arenite which varies from grey to green in colour. Along the east shore of Trotter Lake the subgreywacke is a yellow colour because of the high sericite content. Subgreywacke is found in the first one hundred to two hundred feet above the basal conglomerate, and it occurs interbedded with a cleaner, feldspathic quartzite.

Grains are angular to subangular,are not spherical, and show corrosion along their borders because of the growth of sericite. Some layers are closer to a greywacke in composition with the clastic material comprising only about forty per cent of the rock. Mineralogically, the subgreywacke consists of quartz, microcline, plagioclase (An 24-30), and chert. The quartz may or may not show undulatory extinction. Some of the feldspar grains are highly altered to sericite while others are quite fresh. The potash feldspar - plagioclase feldspar ratio is 11:1. Rock fragments are abundant. Accessory minerals include biotite, hornblende, apatite, and zircon.

The matrix is generally sericite, but chlorite occurs in patchy distribution, probably representing the alteration of ferromagnesian grains.

A modal analysis for this greywacke is plotted on Figure 5.

Feldspathic Quartzite: Most of the Serpent Formation above the basal conglomerate consists of a massive, white weathering, feldspathic quartzite. On the weathered surface it shows the characteristic porcelaneous structure or appearance as described by Collins (1925) and Piennar (1956).

The grains are subrounded and are moderately well sorted as to size. The average grain size is about 0.35 mm. with a range from 0.1 mm. to 0.4 mm.

Quartz generally shows strong undulatory extinction, and many of the grains show internal fracturing. The undulatory extinction appears in bands about 0.1 mm. wide and at 45° to the fractures within the grains. Some quartz grains show authigenic overgrowths. Perthite and microcline are the major potash feldspars. Plagioclase (An 18-36) is less common. The potash - plagioclase ratio is about 2:1. Minor constituents include zircon, apatite, hornblende, muscovite, biotite, magnetite, and pyrite.

The matrix is generally sericite, but unlike the subgreywacke it comprises only about ten to fifteen per cent of the total volume of the rock (Plate XXV).

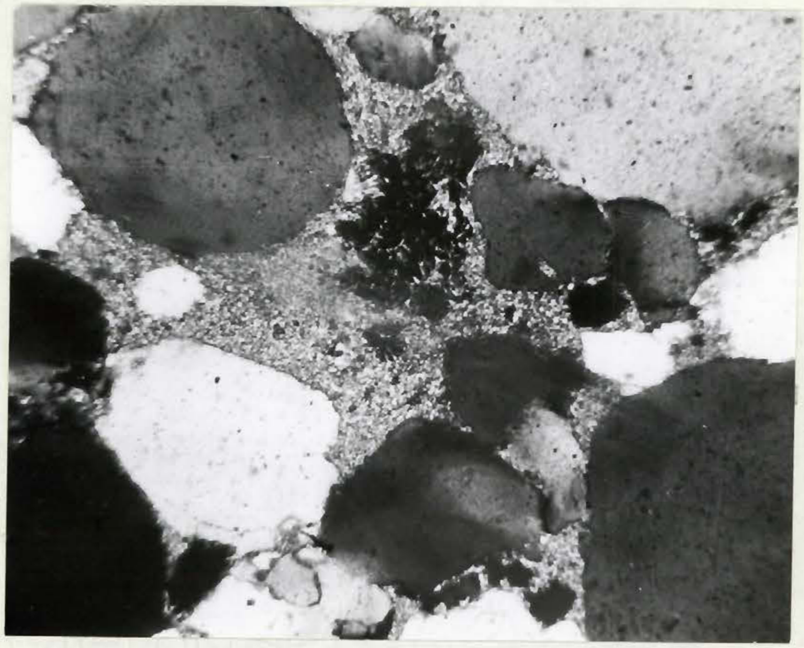


Plate XXV: Feldspathic quartzite from upper part of the Serpent Formation. Shows moderately well rounded grains and relatively low matrix content as compared to Lower Serpent quartzite.

Chlorite has a patchy distribution.

A modal analysis is plotted on Figure 5.

Quartzite: In the upper part of the Serpent Formation, the feldspathic quartzite is interbedded with a fine, white quartzite. The white weathered surface of this quartzite is characteristic. Where the quartzite contains feldspar the feldspar is kaolinized and it appears as dull white specks on the weathered surface. On the fresh surface the quartzite occasionally shows a bluish colour. Clean quartzite is not common in the lower part of the Serpent Formation.

Excellent exposures can be seen at low water level, along the west shore of Echo Lake.

Mineralogically these quartzites resemble the feldspathic quartzites except for a reduction in the overall percentage of feldspar. The pure quartzite is slightly finer grained, with an average grain size of 0.25 mm. and a range 0.03 mm. to 0.3 mm. The sorting index is 18.

Modal analyses are plotted on Figure 5.

Argillite: Argillite occurs as thin laminae, rarely more than two inches in thickness, interbedded with the feldspathic quartzite and the subgreywacke.

It generally shows excellent ripple marking of the wave type. The contact between the argillite and the quartzite is sharp. The upper contact generally shows sericite recrystallization and in hand specimen is almost a phyllite. On the fresh surface, the argillite is a dark green colour, and it weathers to a dark green or a rusty colour.

The argillite consists of fine, angular fragments of quartz and feldspar cemented in a matrix of sericite and chlorite, with the matrix comprising about sixty per cent of the total volume of the rock. Grains are poorly sorted and show a maximum size of 0.25 mm., but the average grain size is less than 0.05 mm.

Conglomerate: Conglomerate, other than the basal conglomerate previously described, is not abundant in the Serpent Formation. Thin interbeds of quartz pebble conglomerate occur in the upper part of the Serpent. East of Trotter Lake, a coarse, granite pebble conglomerate phase occurs, but this may actually be part of the basal conglomerate.

In the quartz pebble layers, the pebbles are subrounded and rarely are larger than one inch in diameter. The matrix consists of fine to medium-grained feldspathic quartzite. The clastic grains are subangular to subrounded. They include quartz, plagioclase (An 17-31), perthite, orthoclase, microcline, and fine rock fragments. Most of the feldspar is slightly altered to sericite.

Accessory minerals include hornblende, biotite, muscovite, zircon, apatite, and black iron oxides.

Cobalt Group

In the Sault Ste. Marie map-area the Cobalt Group can be divided into the Gowganda Formation and the Lorrain Formation. The Gowganda overlies the Serpent with slight angular unconformity. It appears to have been deposited upon a Serpent surface which had a relief of at least 500 feet.

(a) Gowganda Formation

The Gowganda Formation has formed a major controversy in Canadian geology since it was first described by Miller and Knight in 1905. At that time, Miller and Knight did not use the term Gowganda but classified it as Upper Huronian; Collins introduced the term Gowganda in 1917. Miller felt that desert conditions prevailed in the region at least some of the time of the formation of the middle Huronian.Coleman, from his work in the Ramsay Lake area, advocated a glacial origin.

The Gowganda Formation occurs in two distinctly different locations in the Sault Ste. Marie area. Gowganda argillite and conglomerate outcrop north of highway 17 from Garden River east to the Echo Bay area. Here, the Gowganda shows relatively shallow dips towards the south, and rests with slight angular unconformity upon the weathered surface of the Serpent quartzite. Inliers of Gowganda can be found in an area up to two miles north of the main Serpent Formation - Gowganda Formation contact. These inliers appear to be depression fillings in the weathered Serpent surface.

A second major area of Gowganda rocks is found along the Goulais River and just north of the Bellevue Ridge. At Northland Lake, at the east end of the Bellevue Ridge, the Gowganda is cut off by a northerly striking fault. This faulting has produced intense brecciation, and has provided a good host rock for the specularite hematite deposits of the Breitung Mine. From Northland Lake the Gowganda Formation can be traced westward to Van Koughnet and Fenwick Townships where it leaves the northern edge of the map-area. Scattered outcrops occur south of the Bellevue Ridge, and just to the west of the Algoma Central railway bridge.

The Gowganda Formation rocks generally stand as major topographic features in the Sault Ste. Marie map-area. North of highway 17 the Gowganda argillite forms a major escarpment 300 to 400 feet high. Just north of the Bellevue ridge the Gowganda stands as a ridge 250 feet high. Frost wedging from these cliffs has produced considerable talus (Plate 11).

As a formation the Gowganda shows the highest percentage outcrop of any formation in the Sault Ste. Marie map-area. The weathered surface appears a dark green to almost black in colour. Slaty parting or cleavage is quite characteristic of the weathered surface. The fresh surface is invariably some shade of green but the darker shades are by far the most common.

Most earlier descriptions of the Gowganda Formation describe it as a complex succession of boulder conglomerate, greywacke, and laminated greywacke. In the Sault Ste. Marie map-area, the Gowganda consists, in the main, of a fine, laminated argillite or greywacke. Boulder conglomerate is not characteristic although it does occur in Van Koughnet and Deroche Townships. North of highway 17, in the Garden River Indian Reserve, the Gowganda Formation generally consists of a "varved" argillite although fine-grained quartzite forms considerable thicknesses locally.

Conglomerate and Greywacke: The conglomerate and greywacke so typical of the lower part of the Gowganda Formation in the Cobalt area are of sparse occurrence in the Sault Ste. Marie map-area. West of Echo Lake, the depressions in the eroded Serpent surface have been filled with boulder conglomerate, and, here, thicknesses of three hundred feet were recorded. In the main Gowganda belt, north of highway 17, no boulder conglomerate was observed. North of the Bellevue Ridge, boulder conglomerate is more common. Excellent exposures occur in Van Koughnet Township, just south of the Goulais River. This boulder conglomerate may not form the basal Gowganda conglomerate, but rather may be from further up in the formation. From here, the boulder conglomerate can be traced eastward to Maple Lake. The highly sheared conglomerate south of Midge Lake, Deroche Township, may possibly be part of the lower Gowganda boulder conglomerate, but its altered nature makes correlation difficult.

In general, the lower conglomerate of the Gowganda Formation is a highly heterogeneous mass of boulders of various sizes, from three feet in diameter to one inch in diameter, cemented by a material of greywacke composition. The boulder composition comprises from about thirty per cent of the rock to next to zero per cent. Even where the boulder content is high, rarely do the boulders touch one another. The boulders are rounded to subangular, and occasionally show faceted surfaces.

The boulders include fragments of granite, granite gneiss, greenstone, quartzite, limestone, and chert. The limestone fragments are highly angular and resemble the Bruce limestone. Granite boulders, of quartz - microcline - biotite composition, are the most common. Quartz monzonite, syenite, and diorite pebbles are of lesser importance. The greenstone pebbles are highly chloritized, and are composed almost entirely of chlorite and plagioclase (An 36). The quartzite pebbles resemble the quartzite of the Lower Huronian Formations. Limestone pebbles are highly angular; nowhere are they very abundant.

Jasper pebbles are generally rare, although in the outcrops immediately south of the Bellevue Ridge jasper pebbles are frequent. Some of these jasper pebbles contain a considerable amount of hematite, and, in some cases, they would be better classified as iron-formation.

The matrix consists of highly angular fragments of mineral grains and rock fragments from 0.1 mm. to 4 mm. in size. The finer grains are considerably more angular. There appears to be very little cementing material. Chlorite forms the majority of the cementing material.

Fragments include quartz, most of which shows undulatory extinction, plagioclase (An 27-42), calcite, orthoclase, microcline, pyrite, and rock fragments. The feldspars show slight alteration to sericite. The calcite appears to have been introduced after deposition. Rock fragments identified include granite of a quartz - biotite - orthoclase composition and of a quartz - biotite - microcline composition, syenite of an orthoclase - hornblende composition, diabase in which the plagioclase and hornblende are quite fresh, and basic fragments which are now almost completely altered to chlorite and chert.

The Gowganda conglomerate in the Midge Lake area is considerably different than the Gowganda conglomerate in the Echo Lake area. In the Midge Lake area, quartz eyes are characterisitic of the weathered Gowganda surface. Granite and granite gneiss pebbles are numerous and comprise as much as seventy per cent of the rock. The matrix is highly chloritic. Fragments are subrounded to subangular, but show a tendency towards better rounding than the other Gowganda conglomerate areas. Unaltered plagioclase and orthoclase are common.

North of the Goulais River, the Gowganda conglomerate occurs as a massive boulder conglomerate interbedded with grit and arkose. This appears to be an upper conglomerate member. It resembles the Aweres conglomerate more closely than the Gowganda conglomerate. Boulders include granite, granite gneiss, greenstone, and chert, and vary in size up to eight inches.Most of the pebbles are about three inches in diameter. The pebble size varies rapidly from bed to bed. Beds vary in thickness up to about ten feet. The pebbles and boulders form about fifty per cent of the rock.

In thin section, the matrix shows subrounded fragments of quartz, orthoclase, microcline, plagioclase, and rock fragments. Quartz forms at least fifty per cent of the clastic material. The quartz grains all show prominent undulose extinction. Sericite and chlorite alteration are widespread. Corrosion of grain boundaries by sericite is marked, especially on the quartz grains.

Argillite and Argillite Conglomerate: The argillite and argillite conglomerate are characterized by thin laminae which show a thick, light-coloured, lower layer, and a thin, dark-coloured, upper layer. Towards the top of the Gowganda Formation, the argillite becomes lighter in colour, and is interbedded with thin quartzite laminae. The argillite laminae vary in thickness from about 1/10 inch to 1/2 inch.

On the weathered surface, the argillite is a light green colour, and it shows a characteristic slaty cleavage. Sheets up to two feet by three feet and one inch thick can be obtained quite readily (Plate XXVl).

Most of the "varved" argillite in the Sault Ste. Marie area shows a few scattered pebbles, some of which reach a size of eight inches. In general, they are less than 1/2 inch in diameter. Several of these pebbles were studied to show their relationship to the varves. All the pebbles examined showed cross-cutting relationships to the "varved" argillite.

One particular pebble , with its surrounding varves, was polished and studied in detail. The

Plate XXV1: Slaty cleavage developed on Gowganda argillite.

pebble itself, three inches in diameter, showed several faceted faces. The pebble had cut through six varves and had depressed eleven more varves. The varves that were cut were cut sharply against the pebble. There appears to have been about 1/2 inch of the pebble protruding from the mud after it had been dropped into the mud. The first varve deposited after the pebble showed a thickness of about 1/4 inch, but over the pebble it was only 1/10 inch thick. On one side of the pebble there was a slight accumulation of coarser material than was normally found in the varves. The pebble, at this point, apparently was acting as a dam to the movement of the particles. The pebble appears to have dropped about the time of deposition of the extreme top of the varve cycle.

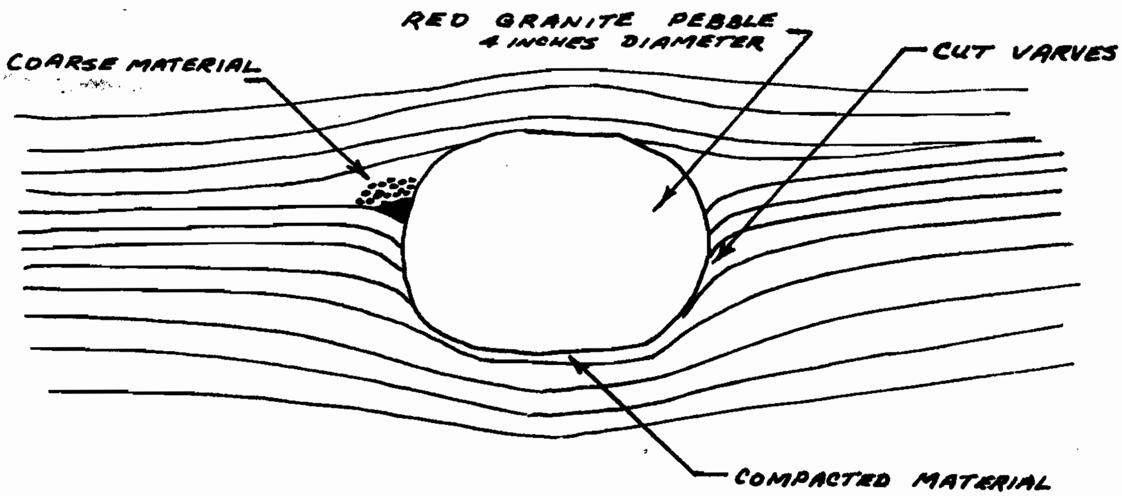


Figure 8. Granite pebble cutting varves in Gowganda argillite.

In thin section, the fragmental material is quite fresh. The feldspars show no alteration and are quite angular. Graded bedding, on a microscopic scale, is visible in most sections. The bottom part of the varve is considerably coarser than the upper part; there is a decided line of demarcation in grain size between the upper and lower part of the varve. The upper part of the varve shows considerably more matrix than the lower part. The lower part of the varve is cut off sharply from the varve below.

The varves vary slightly in thickness; the thicker varves show a greater tendency towards graded bedding. Grain size from top to bottom of several of the varves was measured (Figure 9).

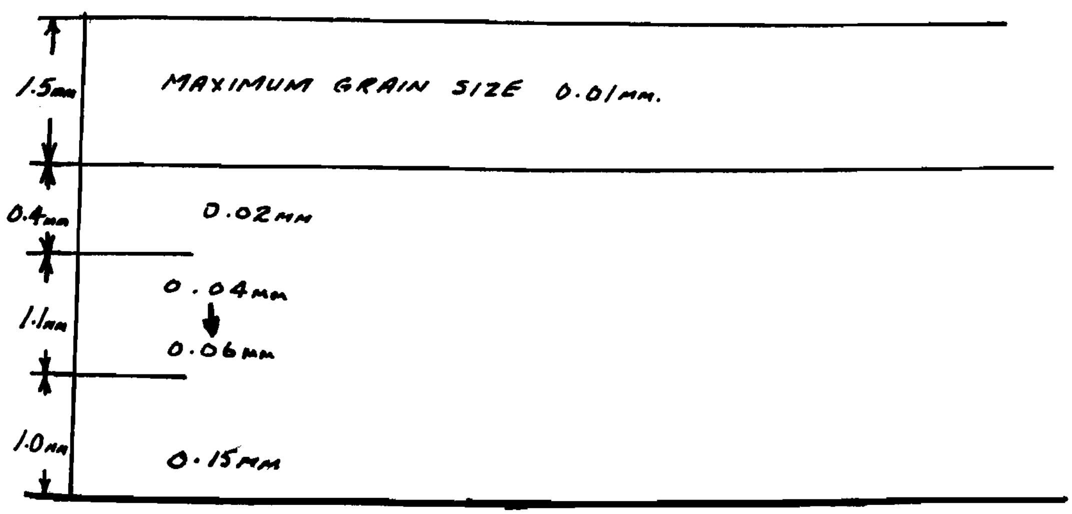


Figure 9. Grain size variation from top to bottom of typical varve in Gowganda argillite.

The matrix material of the varves was studied by x ray diffraction technique. First, the argillite was crushed to 80 mesh. This material was boiled in water for a period of twenty four hours. The solution was removed and dried, and the powder was fixed to a slide for x ray determination.

Results showed the residue to consist of quartz, feldspar, and chlorite, with minor biotite and muscovite.

Quartzite-Arkose: Quartzite and arkose occur interbedded with argillite near the top of the Gowganda Formation. The Gowganda quartzite varies from a fine-grained, dense, reddish quartzite to a medium-grained arkose. The arkosic bands consist of highly angular grains of quartz and feldspar. Alteration is not widespread, although a few of the feldspar grains are highly altered to sericite.

There is essentially no matrix material. What matrix there is appears to be very fine quartz and feldspar, with chlorite as a minor constituent.

The quartzite bands are fine grained, well sorted, and contain subrounded fragments. The quartz generally shows moderate to strong undulose extinction (2V angles up to 5^{o}).

Accessories in both the arkose and quartzite include chert, titanite, apatite, zircon, magnetite, and pyrite.

(b) Lorrain Formation

The term Lorrain was first used to describe the thick series of quartzite above the Gowganda Formation in the Timiskaming district.

In the Sault Ste. Marie map-area, the Lorrain Formation outcrops in two principal areas: west of the Echo River and southeast of Echo Lake, and in the north, along the Bellevue Ridge. Outcrops of the Lorrain Formation stand in high relief. South of Echo Lake, the Lorrain outcrops in a prominent hill, 400 feet above the average elevation. In the Bellevue Ridge, the Lorrain forms a cliff about 700 feet high.

Outcrops, generally, are white to reddish in colour, and show typical glacial rounding (roches moutonnee), glacial fluting, and glacial striations.

In the Sault Ste. Marie area, the Lorrain consists of a thin, lower, feldspathic or impure quartzite unit, and a thick, upper, clean quartzite and quartz pebble conglomerate unit. This lower feldspathic quartzite is considerably less resistant and stands as low hills, twenty to thirty feet above the local landscape. The lower, impure quartzite is generally reddish in colour while the upper quartzites are a decided white colour.

The Lorrain Formation can be divided into three principal rock types: impure feldspathic quartzite, quartzite or slightly feldspathic quartzite, and quartz pebble or jasper pebble conglomerate. In the Bellevue Ridge, thin bands of siltstone occur within the clean quartzite. (Plate XXV11)

Impure Feldspathic Quartzite: The Lower Lorrain consists of a reddish, impure, feldspathic quartzite which grades into arkose. In places, it resembles the reddish coloured portion of the Cambrian sandstone found along the Soo canals.

The grains are subrounded, and are moderately well sorted as to size. Cementation is generally poor and thus the rock has a very crumbly aspect. The matrix varies from calcite to sericite to silica; calcite is generally rare. Hematite is a minor constituent in the matrix, and appears as a coating on some of the grains. The average grain size is about 0.8 mm.

Quartz, some of which appears to be second cycle quartz, generally shows moderate undulatory extinction. It comprises about eighty per cent of the rock. Orthoclase is the principal feldspar; microcline and plagioclase occur in minor amounts. Minor constituents include chert, jasper, zircon, and apatite.

Plate XXV11: Thin siltstone and thick quartzite interbedded in upper part of Lorrain Formation of the Bellevue Ridge.

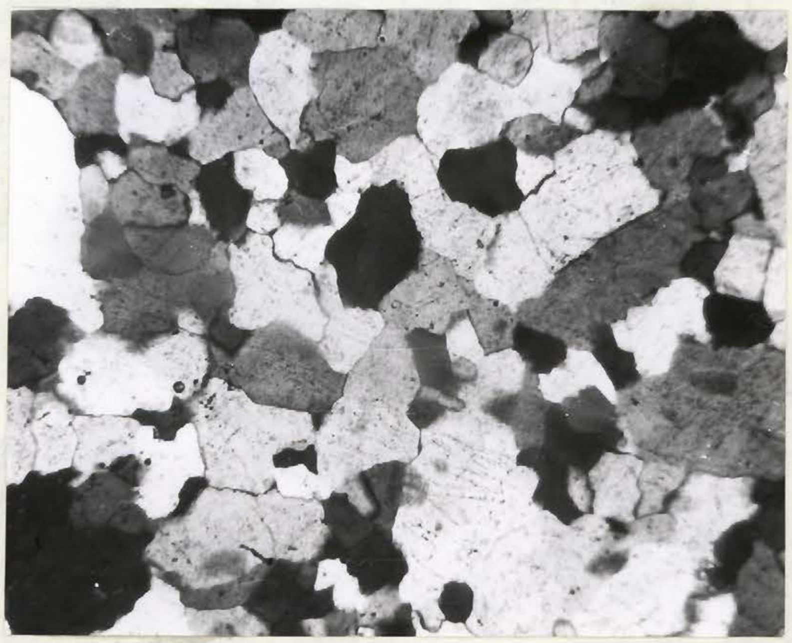


Plate XXV111: Photomicrograph of Lorrain Formation quartzite showing low matrix contnet. 45X

Quartzite: Most of the Lorrain Formation consists of a fine to medium-grained, white quartzite. In hand specimen, muscovite is generally visible as well as minor amounts of jasper. The grains are subrounded, and are fairly well sorted as to size. The average grain size is about 0.5 mm. The matrix generally comprises less than ten per cent of the rock (Plate XXV111). Sericite is the most common constituent in the matrix, but, locally, silica is the cementing material. Many of the quartz grains show strong undulatory extinction and prominent internal fracturing. Where the quartzite has been heavily fractured, hematite occurs along the fractures, especially in the quartzite of the Bellevue Ridge. Feldspar is a rare constituent and where it does occur it is generally quite fresh.

Conglomerate: The conglomerate of the Lorrain Formation varies from a quartz pebble conglomerate containing no jasper to a quartz pebble conglomerate with as high as twenty per cent jasper. Pebble size seldom exceeds about one inch. The jasper pebbles vary from well rounded to subrounded; the quartz pebbles are generally better rounded.

The matrix varies from sericite to quartz, but sericite is by far the most abundant. Accessories identified, in thin section, include microcline, plagioclase, orthoclase, apatite, zircon, and chert. Quartz and jasper comprise about ninety per cent of the total volume of the rock.

Post-Huronian Intrusives

Gabbroic intrusives of Post-Huronian age occur throughout the entire Sault Ste. Marie map-area. These occur as dykes, sills, and small stocks, and are most characteristic in the areas of the Cobalt Group rocks. The largest of these intrusives lies just south of Echo Lake, where it is bordered on the north by the Serpent quartzite and on the south by the Lorrain quartzite. This body may possibly be a large sill along the contact between the two formations. The Gowganda Formation is absent south-east of Echo Lake. East of the Searchmont highway, the central part of the Bellevue Ridge consists of a sill of gabbroic material about five hundred feet thick. Here, the intrusive is entirely within the Lorrain quartzite, but it is near the contact of the Lorrain and the Gowganda. Smaller stocks and sills are numerous, and are especially characteristic of the area south of the Garden River.

Thin, basic and acidic dykes occur throughout most of the Huronian area. These are too numerous to mention every locality, but the main types will be described. Several types of dykes, from the very acidic dykes to the olivine rich, peridotite dykes, were identified (Plate XX1X).

The dykes have been divided into: (1) amygdular diabase, (2) olivine gabbro, (3) highly acidic, fine-grained, porphyritic dykes, (4) fine-grained, porphyritic diabase dykes, and (5) porphyritic pyroxene gabbro and peridotite.

(a) Large Gabbro Intrusives

The large gabbroic intrusives generally appear as prominent ridges within the Huronian sediments. Collins (1925) points out that their occurrence is similar to the basic intrusives of the Cobalt area. The weathered surface is generally a rusty brown colour, and may show considerable jointing. The fresh surface is some shade of green, with dark green to almost black being the most prevalent. Granophyre sections are quite characteristic, especially in the large mass south of Echo Lake. Locally, magnetite appears in segregations of one to two pounds. Fine, sulphide specks are visible in most fresh specimens.

Twenty specimens, from different intrusives, were examined petrographically. They were found to vary from highly altered to quite fresh, and from quartz diorite to basic pyroxene gabbro. In the centre of the bodies, the texture varies from a well-defined ophitic one to a gabbroic one. The contacts are chilled.

North of Bar Creek, the intrusive contains sufficient quartz to be classified as a quartz diorite. Here, the quartz forms an intergrowth with plagioclase of an andesine composition. Zones of granophyre are very common here also. Collins (1925) found that in the coarser sections of these intrusives quartz is a minor constituent, and he assumes that the quartz was the last constituent to crystallize.

Most of the material of these intrusives shows hypidiomorphic granular texture. Gabbro, of hornblende - pyroxene - plagioclase composition, is the most common. Much of the plagioclase shows prominent zoning. Most of the plagioclase has a composition of An 53, but some of the zoned crystals have cores with an anorthite content as high as An 62. Carlsbad twins are quite common; albite and pericline twinning is less common. Biotite is of frequent occurrence, and, where found, it appears to be associated with magnetite. Pyroxene is, for the most part, well twinned, and, in places, shows a well-defined, herringbone structure. An extinction angle of Z x c 32° places the pyroxene in the diopside range. The amphibole is of the hornblende variety with an extinction angle of Z x c 16°. It shows strong pleochroism with a pleochroic formula of x - dark green, y - green, and z - pale green.

Most of the hornblende shows some alteration to chlorite. The feldspar is, in general, sericitized. In the zoned feldspar grains the core is considerably more sericitized than the more albitic rim.

The composition of these gabbros varies widely, but the larger intrusives generally have a composition as follows: hornblende 50%, plagioclase 35%, pyroxene 5%, and biotite 5%. Quartz, magnetite, chlorite, and sericite comprise less than two per cent of the total volume of the rock. The amphibole grains are generally slightly larger than the surrounding grains. Average measurements show the diameters to be as follows: amphibole 3.5 mm., plagioclase 2.0 mm., and pyroxene 0.5 mm.

(b) Olivine Diabase

Olivine diabase dykes are not common in the Sault Ste. Marie map-area. Only two dykes of notable size were identified. In the Duncan greenstone escarpment, west of the Jardun Mines Road, the greenstone is cut by an olivine diabase dyke which is about fifty feet wide. The second dyke outcrops beside the tote road, just southeast of Dead Horse Lake.

Here, the width was not accurately determined because of the lack of contacts, but the dyke is at least fifty feet wide.

The olivine diabase dyke east of Dead Horse Lake shows the characteristic ellipsoidal weathering described by Collins (1925) (Plate XXX). Here, the dyke has been weathered to a depth of at least three feet. Fragments of the weathered rock can be crumbled readily in the hand. Collins (1925) reports a dyke on Matindenenda Lake which has been broken down to a rubble of boulders and reddish sand several feet deep. Collins notes that alteration seems to play no important role in the process, because the residual bouldery masses are so fresh that samples taken only one inch beneath the surface show practically no sign of decomposition under the microscope. The reddish sand, he notes, likewise is composed of angular grains of feldspar and augite not greatly decayed.

The Dead Horse Lake dyke has weathered into ellipsoidal blocks generally about ten inches by four inches. The block boundaries appear to be related to jointing within the dyke. Collins found that the alterations showed a fixed spacial relationship to the joints, and he states that one naturally

Plate XXlX: Waterfall and rapids at south end of Elizabeth Lake. Rapids area is crossed by resistant basic dyke.

Plate XXX: Ellipsoidal weathering on olivine diabase dyke. Tote road south of Dead Horse Lake.

relates the joints to the process of alteration. The agent of erosion may have been one of the normal weathering agents that penetrates from the surface, but, as Collins suggests, it is more likely from the heated exhalations given off by the diabase itself.

Petrographic examination shows the diabase to consist largely of a calcic feldspar (An 65). Most of this feldspar is zoned, with an inner core of about An 75 and an outer rim of about An 60. Twinning is generally of the albite type with carlsbad and pericline being less common. The plagioclase occurs as large laths, with a maximum size of 4 mm., and these penetrate the smaller pyroxene and olivine grains. The olivine is highly fractured, and shows some alteration to serpentine. The pyroxene has an extinction angle of Z x c 47° and has been classified as augite, but, in places, it is somewhat diopsidic. The pyroxene is zoned; the inner core shows an extinction angle of Z x c 49°, and the outer rim shows an extinction angle of Z x c 42°.

Hornblende is a minor constituent, and it appears to be an alteration product of the pyroxene. Biotite, another minor constituent, likewise appears to be an alteration product. Accessory minerals include magnetite and apatite.

These diabases show typical ophitic texture, with slender laths of plagioclase wrapped by anhedral to subhedral pyroxene and olivine. They consist of 50% - 60% labradorite, 20% - 30% pyroxene, and about 20% olivine.

(c) Altered (Plagioclase?) Porphyry Dykes

Dykes showing a highly altered, reddish matrix cementing large phenocrysts of "plagioclase" are quite common, especially in the area west of Jardun Mines and in the area east of Dead Horse Lake. In the ridge about 1000 feet east of the south end of Dead Horse Lake, one of these dykes, about ten feet wide, stands almost vertically in the cliff. The characteristic red colour makes it stand out against the green background of diorite. This dyke shows chilled borders which are three to four inches thick, and the phenocrysts are found even in the chilled borders. The weathered surface is a rusty brown colour. The phenocrysts appear to be more resistant than the matrix and thus stand out on the weathered surface. The dyke is less resistant than the neighbouring diorite and has weathered down about one foot in relation to the diorite.

Thin section examination shows a highly altered rock with an indication of diabasic texture. Alteration is so intense as to make determination of the original mineral composition difficult. Phenocrysts show moderate birefringence, and although they appear to be feldspar in the fresh specimen, thin section examination shows the majority of them to be a highly altered pyroxene. In the matrix, plagioclase occurs as laths and shows a diabasic texture with reference to the highly altered pyroxene in the matrix. The pyroxene in the matrix shows good twinning with herringbone structure. The extinction angle is Z x c 46°. The pyroxene appears to be a variety of titaniferous augite.

The laths of plagioclase show multiple albite twins or simple carlsbad twins. Laths vary widely in size, but most are about 1/2 mm. long and 0.05 mm. wide. All the plagioclase shows some alteration to sericite. Some of the phenocrysts appear to be highly altered plagioclase. Indistinct twin boundaries, possibly along the albite law, are visible on some of the phenocrysts. Some of the altered plagioclase grains are surrounded by penninite which appears to be an alteration product of pyroxene.

Most of the matrix consists of a highly altered mass of chlorite and sericite.

A second dyke, almost the same as the one described above, occurs about five hundred feet west of the north shaft of Jardun Mines. Here, most of the phenocrysts are feldspar. On the weathered surface, these phenocrysts are a pale green-yellow colour. This dyke shows the same rusty brown weathered, knotty surface.

(d) Amygdaloidal Diabase Dykes

Several dykes, somewhat similar to the porphyry dykes described above, occur in the region between the Garden River and Echo Lake. Phenocrysts were not observed in these dykes, but most contain chlorite-lined calcite amygdules. In some dykes, these amygdules form as much as fifteen per cent of the total volume, but usually they are of minor importance.

On the weathered surface, the dykes are a rusty brown colour, and where the amygdules have weathered out, the surface is highly pitted. Ellipsoidal weathering, similar to that of the olivine diabase dykes, has progressed to a minor extent. On the fresh surface,,the rock is a red - brown colour, and most specimens show a distinct diabasic texture. (Plate XXl).

Plate XXXl: Photomicrograph of diabasic texture in amygdaloidal diabase dyke. Echo Lake area.

Thin section examination shows the rock to consist essentially of highly altered plagioclase, and penninite. The amygdules generally contain calcite and most are lined with penninite; a few of the amygdules are completely filled with penninite. Grains of black iron oxides are extremely abundant, probably comprising as much as fifteen per cent of the rock. These black iron oxide grains are generally smaller than 0.05 mm. in diameter (Plate XXXll).

In the Gowganda ridge about two miles west of the Echo River and just north of highway 17, one of these amygdaloidal dykes cuts the argillite. Blocks of the argillite have been broken off during intrusion of the dyke, and these blocks have been almost completely absorbed. The pebbles, which the blocks contained, have remained unaltered. As a result, the dyke shows well-rounded pebbles in an igneous matrix.

(e) Basalt Porphyry Dykes

West of Maud Lake, several, thin, basalt porphyry dykes cut the Mississagi quartzite (Plate XXXlll). These dykes are well jointed perpendicular to their walls. The weathered surface varies in colour from black to rusty brown. Fine laths of plagioclase are

Plate XXXll: Magnetite exsolved in pyroxene grains and producing a herringbone pattern. X45

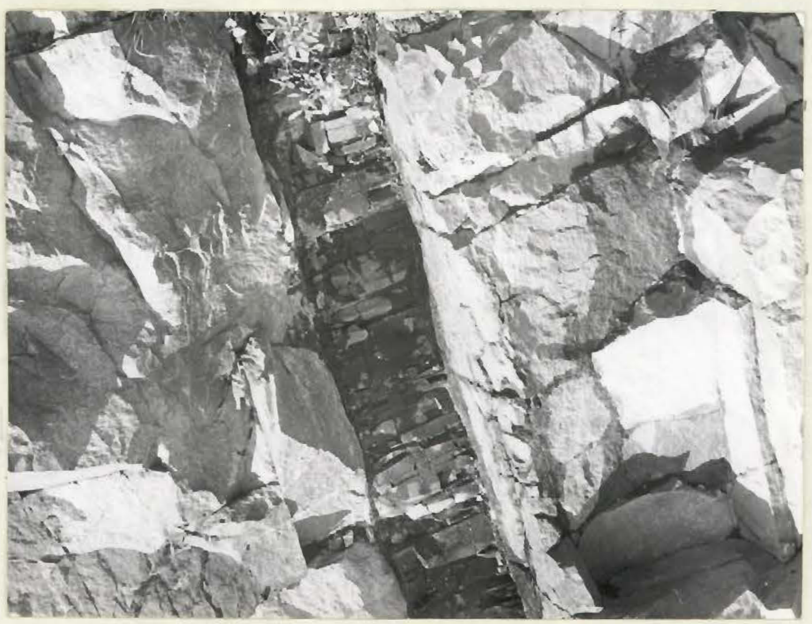


Plate XXXlll: Basalt porphyry dyke cutting Mississagi quartzite. West shore Maud Lake.

visible in hand specimen. Chilled borders are well illustrated.

Under thin section examination, the rock shows fine laths of plagioclase (phenocrysts) in a dense matrix containing numerous plagioclase microlites. The matrix is pleochroic in pale green, and appears to be predominantly chlorite.

A somewhat similar dyke, but of a coarser nature, cuts the granite along Driving Creek, just east of the Jardun Mines Road. Here, the phenocrysts are as large as 1/2 inch in diameter; most of them are biotite.

In thin section, this dyke shows abundant biotite and pyroxene in a fine-grained groundmass of highly altered material. The pyroxene grains are highly altered; in places, only the cores remain. Black iron oxides form about five per cent of the rock

(f) Felsite Porphyry Dykes

Acid dykes are of rather rare occurrence in the Sault Ste. Marie map-area. In the creek flowing south from Maud Lake, about one half mile downstream just at the base of a small waterfall, a rhyolite porphyry dyke, about four feet wide, cuts the surrounding sediments. This dyke can be traced along strike for 900 feet, and apparently is related to shearing. On the fresh surface, the rock is a light pinkish colour, and shows glassy phenocrysts of quartz and altered phenocrysts of feldspar.

Thin section examination shows phenocrysts of euhedral quartz in a matrix of highly altered material. Plagioclase (An 27) forms some of the amygdules but it is generally highly altered. Some of the supposed phenocrysts actually appear to be amygdules. These are lined with fine-grained quartz, and are filled with chlorite. The matrix consists of a highly altered mass of unidentifiable minerals. Sericite is widespread.

(g) Keweenawan Lavas

McConnell (1926) reported a succession of lavas at the tip of Gros Cap, about eight miles west of Sault Ste. Marie, and he classified these lavas as Keweenawan. Moore (1927) reported similar lavas at Mamainse Point, north of Sault Ste. Marie.

McConnell (1926) describes these lavas as follows:

" Acid and basic lavas occur at Gros Cap and northward along the coast for a few hundred yards. The basic lavas include both vesicular and massive types and are probably younger than the red acid lavas as they enclose fragments of a similar rock. The bands are tilted to the southwest at angles of up to 65 degrees. The massive variety is a holocrystalline rock consisting of fairly fresh augite and basic feldspars, some hornblende and dark iron ores. Quartz occurs in occasional grains and rarely in intergrowths with feldspars. A tendency to an ophitic structure is often noticeable. A green variety of lava proved to be similar to the black, lithilogically, except that the alteration was more advanced and uralized augite and chlorite more abundant. The contact line with the granite was peculiar, at places inclined towards the granite at an angle of about 75°. The granite also holds inclusions of basic rock but the granite is coarse grained at the contact."

In the field, the lava in the Sault Ste. Marie area (Ile Parisienne map-sheet) occurs as a highly fractured, red-stained, fine-grained rock. Fracturing has occurred to such an extent, that with accompanying weathering, fresh samples are very difficult to obtain. At Gros Cap, the lavas stand in vertical cliffs about one hundred feet above Lake Superior.

In the fresh specimen, phenocrysts of quartz and orthoclase are quite evident. The fresh surface closely resembles the felsite porphyry dykes in the Huronian rocks. Chlorite-filled amygdules are of scattered occurrence.

Thin section examination shows the red porphyritic lava to consist of euhedral quartz phenocrysts in a groundmass of a feathery material showing numerous microlites of feldspars. Many of the microlites occur in radiating patterns. Red-stained orthoclase grains are very prominent. Much of the needle-like, feathery material appears to be quartz. The orthoclase, in general, occurs as small, rounded grains completely surrounded by quartz. Black iron oxides comprise about five per cent of the rock.

The more basic amygdaloidal and porphyritic volcanic rocks outcrop on the islands about one mile north of Gros Cap. Thin section examination shows them to be highly chloritic. Plagioclase (An 42) is the predominant feldspar, and it occurs both as phenocrysts and as microlites. The green matrix consists essentially of altered augite and hornblende. Most of the feldspar grains show red iron staining.

Most of the pebbles on the shore north of Gros Cap have a basic volcanic composition; one pebble was found which contained about fifty per cent native copper.

Palaeozoic

(a) Lake Superior Sandstone

The Lake Superior sandstone was first identified by Hougton. The term Sault Ste. Marie sandstone is a much later term and is used less often. The sandstone also has been correlated with the Potsdam sandstone of Eastern Canada and the United States.

This sandstone occurs in the Sault Ste. Marie map-area as a red mottled sandstone or as a grey to white coloured sandstone. It outcrops in only a few small areas, but it is generally thought that much of the plain in the vicinity of the city of Sault Ste. Marie is underlain by this sandstone. Exposures of the sandstone occur northeast of Sault Ste. Marie, near the contact with the basement complex. About one and one-half miles west of the Algoma Steel Corporation slag heap, the sandstone is exposed in a few small outcrops. Along the Soo canals, large blocks of the sandstone occur, but these may possibly have been transported. Small outcrops of grey sandstone occur along the Root River where it crosses highway 17 north. During the summer of 1960, excavation for a forced main sewer in Sault Ste. Marie allowed examination of the sandstone beneath Bay Street. In the Ile Parisienne map-area, the sandstone occurs along the south shore of Goulais Bay.

The sandstone consists of a lower reddish portion and grades upwards to a white to buff coloured sandstone. Much of the reddish coloured sandstone shows leaching effects which give it a mottled appearance.

In thin section, the grey sandstone shows subrounded grains with moderately high sphericity. Grains are fairly well sorted as to size with most being about 0.4 mm. in diameter. A few grains are highly angular. Most of the grains are quartz; some of these show fairly prominent undulose extinction. Microcline, orthoclase, and plagioclase occur in about equal amounts and comprise about ten per cent of the rock. Chert grains comprise about five per cent of the sandstone. The cement is a minor constituent as the grains are packed tightly together. What cement there is, is a mixture of hematite and silica. Stratification is not noticeable in thin section.

The red sandstone is quite similar to the grey sandstone except for an increase in the amount of hematite. Grains are slightly more angular in the red sandstone, but they can still be classified as subangular. Many of the quartz grains show strong undulose extinction. Hematite surrounds the grains, and it appears to be the main cementing material. Many grains are fractured, and these fractures have been filled with hematite. No stratification is noticeable in thin section.

In the mottled red and grey sandstone, the grey portions show sericite alteration in the cement. The sericite continues for 2 mm. past where the hematite first appears. Indications are that the hematite is being leached out.

In both the red sandstone and the grey sandstone, frosted grains are numerous.

McConnell (1926) reports a basal conglomerate, five to six feet thick, in Horseshoe Bay, north of Sault Ste. Marie. Thomson (1953) reports a similar conglomerate at mile 66.4, highway 17. The conglomerate, five feet thick, is reported to contain large, angular boulders of the underlying granite. These are imbedded in a shaly matrix.

CHAPTER lV

STRATIGRAPHY / CONTACT RELATIONSHIPS

STRATIGRAPHY AND CORRELATION

Correlation of rocks, in the area from Lake Timiskaming to Sault Ste. Marie, has been disputed since the time Logan first visited the area and divided the rocks into a Lower Copper Bearing Series, an Upper Copper Bearing Series, and the Potsdam sandstone. Collins (1925), after many years of work on the rocks along the north shore of Lake Huron, completely revised the data of Logan, and published a stratigraphic column which has lasted essentially in its original form (Table No. 1). This stratigraphic sequence is similar to that used by McConnell (1926) in his first mapping of the Sault Ste. Marie area, although, in the Sault Ste. Marie area, McConnell reported a series stratigraphically below the Bruce Series (Table No. 2A). This older series he termed the Soo Series, and suggested that it might possibly be equivalent to the Sudbury Series, but because of the great distance between the two areas, he preferred to use the new term. Modifications, in recent years, to Collins' stratigraphic column have resulted mainly from extensive work at Blind River, where numerous diamond drill holes have given a much clearer picture of the stratigraphic sequence. This new data has been compiled by Roscoe (1957) of the Geological Survey of Canada. He has completely revised the stratigraphic sequence and terminology, mainly by dividing the formations into smaller units (Figure 10). This sequence has been used by Pienaar (1958) in his study of the Blind River area, but it has not seen general usage because of the difficulties in subdividing the formations to such an extent where only limited surface outcrop is available.

In this report, a stratigraphic sequence which is actually a combination of that used by Collins (1925) and McConnell (1926) will be followed. Revisions have been made where mapping by McConnell and by the writer do not agree. The sequence of Roscoe has not been used mainly because lack of information in the Sault Ste. Marie area makes it impossible to divide the sequence into smaller units and there has not been sufficient mapping between the two areas. Frarey (1959), in his mapping in the Echo Lake area east of Sault Ste. Marie, has followed essentially the same sequence as the writer.

In this present chapter, the stratigraphic sequence in the Sault Ste. Marie map-area, and the reasons for correlation with the rocks of the Blind River area and other areas, will be discussed. Certain formations, such as the Gowganda, are fairly definite as to correlation since they have been traced in outcrops along the length of the north shore of Lake Huron. Other formations, such as the Aweres and Duncan, afford considerable problems because nowhere have they been detected in other Huronian areas. The stratigraphic sequence used by the writer is illustrated in Table No. 4 and in the legend for Figures 4 and 4A.

The mapping of the Sault Ste. Marie map-area was undertaken in an attempt to solve some of the problems that have evolved through mapping of the Huronian rocks along the north shore of Lake Huron. In particular, the Soo Series as classified by McConnell (1926), needed clarification.

The main stratigraphic and correlation problems in the area are:

(1) The ages of the granite bodies in the area. (Earlier mapping has shown two ages of granite: a pre-Huronian granite which is now partially transformed to gneiss and forms part of the basement complex, and a younger post-Huronian granite which has at different times been classified as being of

Killarney age.

(2) The age of the Soo Series, including the Driving Creek Formation, the Duncan Greenstone Formation, and the Aweres Formation.

(3) The age of much of the quartzite south of the Garden River. This quartzite had previously been mapped as Mississagi.

(4) The relationship of the Gowganda Formation to the underlying Serpent Formation.

(5) The relationship of the Aweres Formation to the Duncan Greenstone Formation.

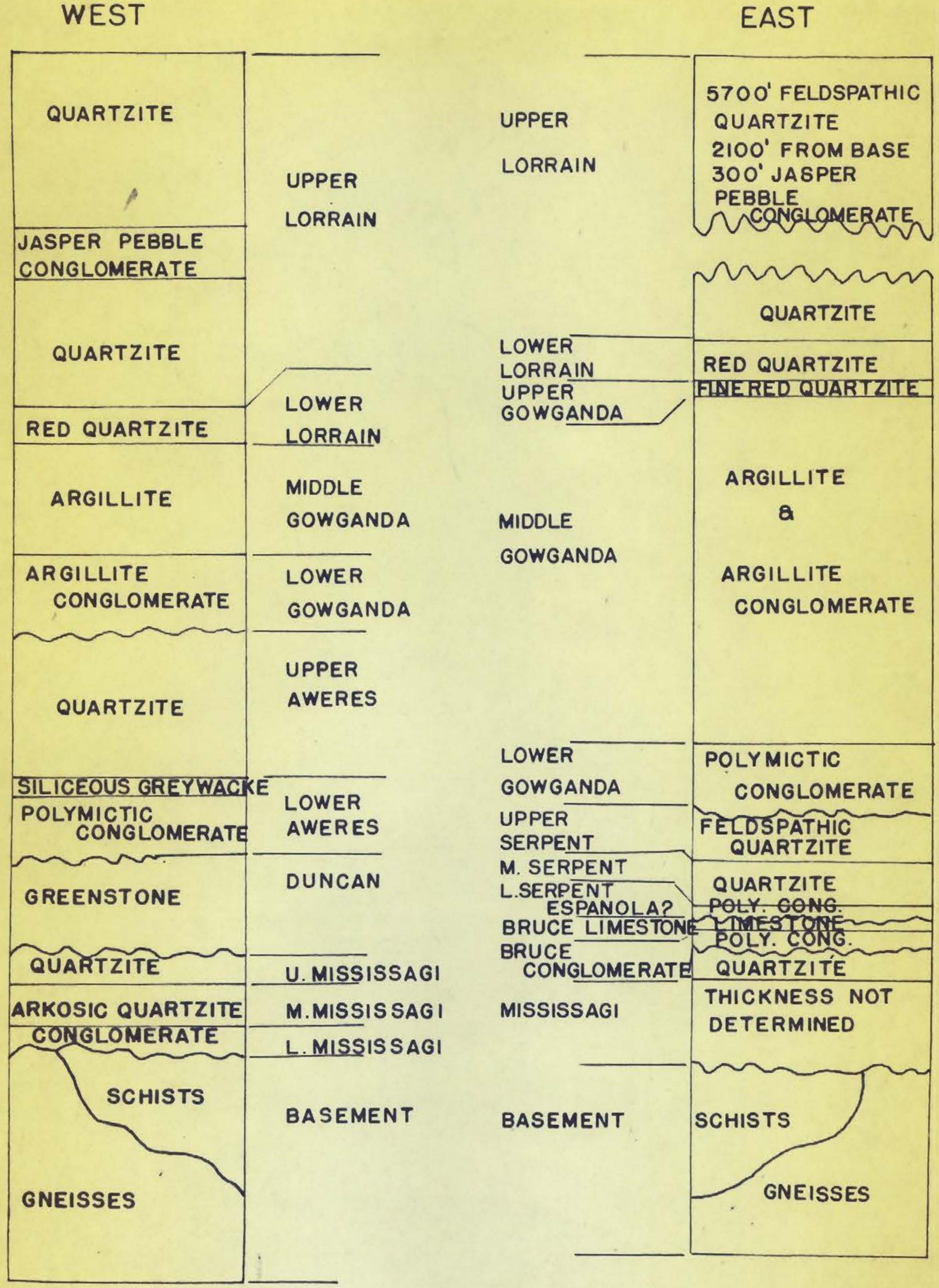
Figure 11 shows a composite drawing of the stratigraphic sequence that has been employed in the mapping of the Huronian rocks.

BASEMENT SCHISTS

The basement schists of the north shore area have previously been classified as Keewatin, as they show a general similarity to Lawson's original Keewatin of the Rainy Lake area. Lawson (1929), in discussing some of the problems of the Huronian, placed the Keewatin below the Sudbury Series and the Timiskaming Series, and he feels that granite intrusions into the Keewatin did not occur until after deposition of the Timiskaming Series and the Sudbury Series. Collins (1925) does not use the term Keewatin. He prefers to call the schists simply Pre-Huronian schists. McConnell (1926), likewise, refers to these schists as Pre-Huronian, although he does mention that they are similar to what has been called Keewatin. Coleman, in various reports on the north shore, refers to the schists as Keewatin, and feels that they may be equivalent to the Grenville rocks. Bain (1924) refers to the well-exposed tuffs and lavas around the Breitung Mine, Northland Lake, as Keewatin. Robertson (1956) refers to the iron-formation within the basement schists and notes that these are the marker beds typical of the Keewatin, and although he does not specifically state it, one would infer that this is his reason for classifying the schists as Keewatin. He infers, also, that some of the granite may be actually of pre-schist age. Nuffield (1955), in studying the geology of the Montreal River area, about eighty miles north of Sault Ste. Marie, refers to the paragneiss and the schists as pre-Algoman. Abraham (1953), in surveying in Sothman Township, north of Sudbury, found a lower, acidic to intermediate volcanic group overlain by more basic volcanics;.both sequences are now highly altered. He classified this complete lava assemblage as Keewatin.

FIGURE II

VERTICAL SCALE 50FT. = 1 IN.



STRATIGRAPHIC SECTIONS SAULT STE. MARIE AREA

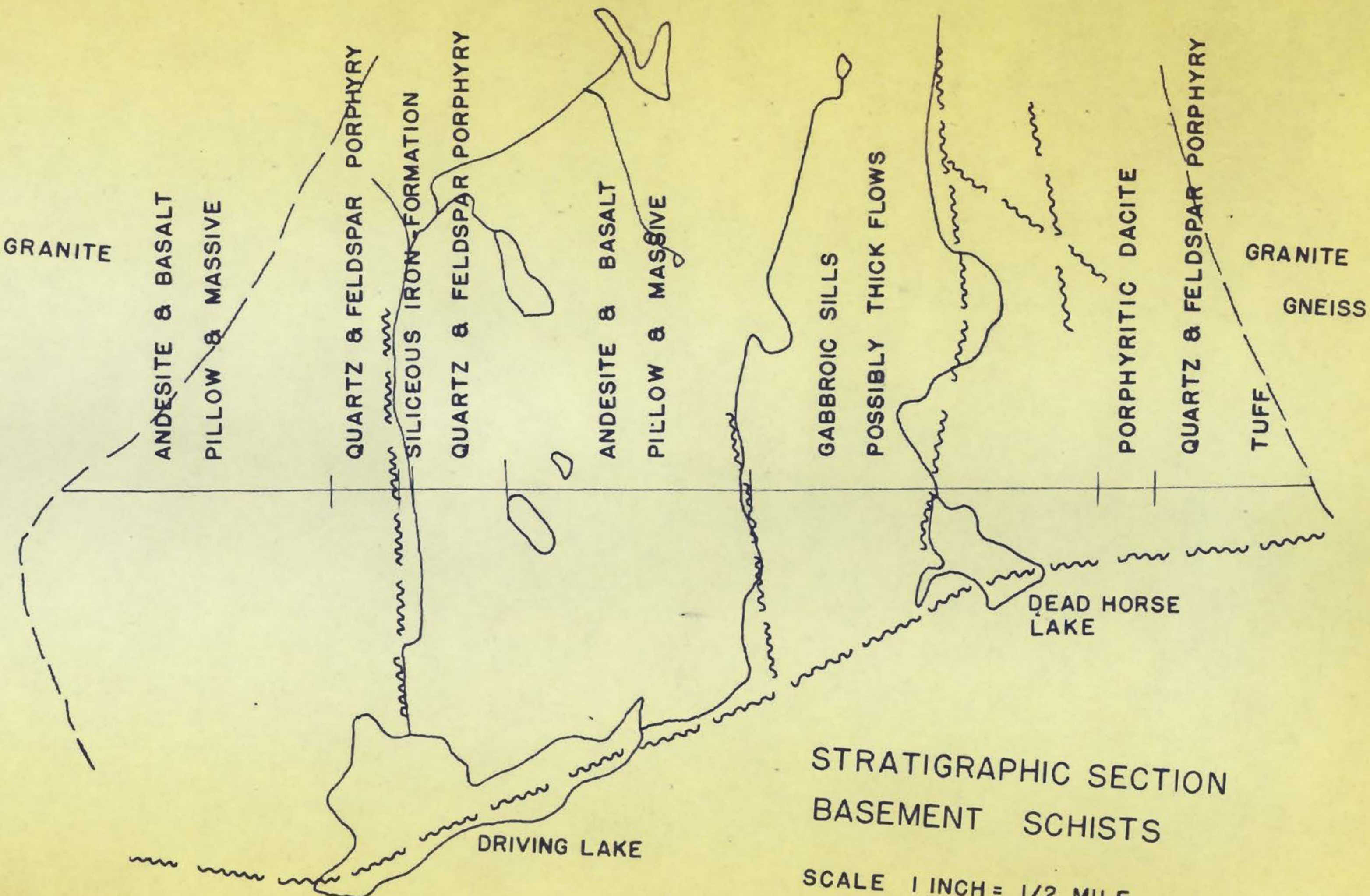
In the Goulais River Iron Range area, about fifty miles northeast of Sault Ste. Marie, Moore and Armstrong (1946) classified the schists as Keewatin. Here, the lower section of the series is mainly volcanic rock, varying from rhyolite to basalt, and showing tuffaceous areas and agglomerate zones. Above this, they noticed a sequence of clastic sediments, quartzite, arkose, and greywacke, with some stratified tuff. The upper section they noted to be mostly iron-formation. Moore (1925) grouped all these rocks together in the Batchawana Series, and tentatively correlated them with the Timiskaming, because lavas that ordinarily would have been placed in the Keewatin were found interbedded with conglomerate and other sediments of the Timiskaming type.

In the Sault Ste. Marie map-area, the basement schist series consists of a section of basic volcanic rocks with minor sedimentary and pyroclastic rocks. McConnell (1926) reports the presence of conglomerate and greywacke irregularly distributed through the greenstone. He notes that this conglomerate closely resembles the conglomerate of the Lower Cobalt, and that it possibly may be infolds of the Lower Cobalt. During the current mapping of the area, the area of supposed basement conglomerate south of

Maple Lake, Deroche Township, was investigated. It was found that these sediments are actually Lower Cobalt, and that the apparent alternating with the Basement schists is the result of faulting parallel to the Goulais River valley. This faulting has placed large horsts of Basement schists in juxtaposition to the Lower Cobalt. No large areas of clastic sedimentary material were identified in the basement series during the current mapping. Thin bands of cherty iron-formation, and possible altered conglomerate occur north of Driving Lake, and near the eastern boundary of the schist belt.

McConnell (1926) sectioned the basement schist belt at two points north of Driving Lake. In the south, progressing from west to east he found, in ascending order, according to dip - west of Driving Lake - chlorite and hornblende schist, along the north shore of Driving Lake - alternating bands of quartz porphyry, feldspar porphyry, and chlorite schist, east of Driving Lake - chlorite and hornblende schists with gabbroic intrusions, and at the granite contact he found a thin band of tuff.

In the current mapping, a section was measured from the granite contact northwest of Driving Lake, eastward through the north end of Dead Horse Lake, to the contact with the granite in the east (Figure 12). In the extreme west end, the schists are highly intruded and disrupted by granite and pegmatite. They consist of andesite and basalt pillow lava which now is highly altered to chlorite and sericite. The pillow beds are 10 to 200 feet thick, and are interbedded with massive andesite and basalt. Top determinations on the pillows indicate that the younger rocks are towards the east. A section of about 2000 feet of pillowed and massive lavas was measured. These lavas are followed to the east by a highly sheared greenstone which resembles an altered quartz porphyry or feldspar porphyry. This sheared material is about 400 feet thick, and may possibly be an altered pyroclastic. The eastern contact of this band is marked by a fault zone along the eastern side of which there is a thin band of siliceous iron-formation. In places, this siliceous material resembles a sheared conglomerate. East of the fault zone, the section again consists of a considerable thickness of massive and pillowed lavas. Most of these lavas have an andesitic composition. North of the eastern end of Driving Lake, the section contains about 400 feet of flaggy quartz porphyry -



STRATIGRAPHIC SECTION
BASEMENT SCHISTS

SCALE 1 INCH = 1/2 MILE

FIGURE 12

feldspar porphyry; this porphyry may also be a highly altered pyroclastic. This is followed to the east by a thick section of amygdaloidal and pillowed lavas with intermittent massive layers. Towards the east, the massive layers become more prominent. These lavas are all highly altered to chlorite schist. The total thickness of the lava unit is about 2000 feet. In the vicinity of Dead Horse Lake, the basement is represented by a thick series (2500 feet) of gabbroic sills. These may possibly represent a series of thick lava flows. The gabbroic sills are cut by many gabbroic and diabase dykes. The gabbroic sills are bordered, on the east, by about 300 feet of porphyritic dacite. The last fourteen hundred feet to the granite contact consists of alternating bands of quartz porphyry, feldspar porphyry, and altered tuffaceous material. The quartz porphyry and feldspar porphyry may, in part, be altered pyroclastic material. The granite - schist contact is highly irregular. Granite dykes and tongues project several hundred feet into the schist belt. Large schist inclusions are common in the granite, and near the contact they are quite numerous.

In the Northland Lake area, Deroche Township, the greenstone belt has narrowed to less than one mile. In the Midge Lake area, the belt consists of a highly schistose material which is now completely recrystallized so that no original structures are visible. Where the belt crosses the Algoma Central railway, it has been metamorphosed to a hornblende gneiss with little or no indication of its former nature. Here, lit-par-lit injection with red granite is quite characteristic.

North of the west end of the Bellevue Ridge, the basement rocks consist mainly of well-pillowed andesite with strikes approximately east - west. Shearing has elongated the pillows so that top determination is difficult; the tops appear to be towards the north. Towards the north, the pillowed andesite grades into massive andesite and basalt. Cobalt conglomerate and argillite occur as fault blocks within the andesite. Towards the north, the andesite and basalt change to a hornblende schist which disappears under the thick, glacial sediment of the Goulais River valley.

GRANITE AND GRANITE GNEISS

The age of the granite and granite gneiss in the Sault Ste. Marie area and along the north shore of Lake Huron has been a continual source of argument.

Most writers recognize two distinct ages of granite: a pre-Huronian granite commonly known as the Algoman granite, and a younger granite which may or may not be post-Huronian known as the Killarney granite. Logan and Murray, in their original mapping of the district, found only one granite, and this they placed very early in the sequence. Coleman (1906-1913), in his early reports, describes a pre-Keewatin granite as being the only granite in the area, but in his later reports (1926) he also describes a Keweenawan granite in the Sudbury area. Collins (1925) was the first to use the term Killarney granite to refer to granite which he felt intruded the Huronian rocks near Killarney village, southwest of Sudbury. As a result of the mapping of Collins, there has been a tendency to call all fresh granitic material Killarney. Brunton (1921), Bain (1923), and McConnell (1926), in mapping the Sault Ste. Marie area, all classified the central granite mass around Jardun Mines as Killarney. Bain reports contact relations (which appear to indicate that the granite is younger than the Huronian) one-half mile south of mileage 20.5 on the Algoma Central railway and three-quarters of a mile southeast of Northland Station. Here, he found apophyses of granite projecting into the quartzite.

He found what appeared to be a partially assimilated xenolith of quartzite in the granite.

In recent mapping in the Blind River area, Robertson (1960) has done an exhaustive study of the granite types to try to determine some relations by which the two ages can be separated conclusively. Robertson found no evidence which would indicate post-Huronian granite north of the Murray Fault. Granite, near Aubrey Falls, on the Mississagi River, northwest of Quirke Lake, and near East Bull Lake near the Massey Tote Road, which previous workers suggested was post-Huronian, is similar to proven pre-Huronian rocks near Quirke Lake. Also, he found that the white pebbles and boulders of the Lower Huronian polymictic conglomerates are similar to the grey Algoman granite, and that the red boulders of the Gowganda Formation are similar to the red Algoman granite. Zircon concentrates showed the red phase Algoman to be characterized by simple malacon crystals, and the grey by complex hyacinth crystals. At Aubrey Falls, the red granite contains malacon similar to pre-Huronian rocks at Quirke Lake. Robertson concluded that, in the Blind River area, there are two granites of pre-Huronian age: a younger, massive, red, radioactive quartz-monzonite of uniform composition, and an older, gneissic, grey, non-radioactive granodiorite of variable composition with abundant basic inclusions.

During the current mapping, contact relations of the granite with the surrounding rocks were studied in some detail, and modal analyses of granite, granite gneiss, and pebbles in the Huronian rocks were done in an attempt to determine something about the age relationship of the granite and granite gneiss. The age of the granite gneiss in Anderson, Kehoe, and Hodgins Townships in the east , and in Prince, Korah, Dennis, Pennefather, Aweres, and Tarentorus Townships in the west can be classified, fairly conclusively, as post-basement schist, but its relationship to the Huronian is doubtful because of lack of contact relationships. McConnell (1926) states that it is pre- Bruce Series because the Huronian rocks southeast of the Garden River appear to overlie it unconformably. Actually, the contact has been shown to be a fault contact so his reason for classifying the granite as pre- Bruce Series is not valid. Along the east shore of Surrette Lake, in the Garden River Indian Reserve, Aweres conglomerate lies upon the granite gneiss. Here, the Aweres conglomerate rests with a high degree of unconformity upon the granite gneiss, and the boundary plane is approximately parallel to the bedding planes in the Aweres. Here, the change from granite gneiss to Aweres conglomerate constitutes a zone. About fifty feet from the contact, the granite gneiss is quite fresh, but this grades to a pale yellow-coloured rock in which ferromagnesian minerals are minimal. Near the contact, the granite gneiss is a highly sericitic mass with fragments of quartz and microcline. In the bottom four feet, the Aweres is represented by partially altered, granitic pebbles. Here, the contact of the sed- iments is hard to determine. Small sedimentary dykes of greywacke can be seen projecting into the granite gneiss; on a microscopic scale, these small dykes are very numerous. Above this conglomerate phase is a highly sericitic greywacke. In the north, in the granite gneiss and the sediments, the quartz shows strong undulose extinction. Here, the transition takes place over a depth of five feet. It appears that this contact zone between the granite gneiss and the overlying Huronian rocks is a regolith.

Robertson (1960) analysed, in the Quirke Lake area, a regolith of a similar nature. He found that, in the regolith, silica essentially remained constant, alumina increased, total iron, magnesium, and manganese decreased, and soda and lime are practically removed.

Similar contact relations were noted just north of Mabel Lake, but outcrops were poor here. From a point about one mile north of Mabel Lake, the contact between the Huronian and granite gneiss appears to follow closely along a fault. The fault may not be directly along the contact, but shearing is so intense as to obliterate the contact. In places, especially southwest of Crystal Lake, acidic dykes have been injected along the fault zone. About one mile west of Trout Lake, there is an indication that the fault leaves the area of the contact and enters the granite gneiss. From Maki Lake northward, the contact is masked by the waters of Heyden, Lower Island, and Upper Island Lakes. North of Upper Island Lake, the conglomerate is again found resting with a high degree of unconformity upon the granite gneiss. Here again, the actual contact is masked by overburden.

The contact with the basement schists is highly irregular. In Anderson Township, apophyses of granite can be traced up to one-half mile into the schist zone. Pegmatite and acid dykes into the basement schists are numerous near the contact, and, in places, can be traced to the granite gneiss body. Away from the contact, dykes are of minor importance. Large inclusions of greenschist are very common within the granite gneiss, and decrease rapidly away from the contact. Partially assimilated inclusions are very common; some inclusions have been completely recrystallized so that now they occur as hornblende gneiss. In Hodgins Township, the granite has almost completely recrystallized the schist so that now it occurs as hornblende gneiss.

Relations of overlying Huronian rocks with the red granite phase in Duncan and Aweres Townships is less distinct. The contact with the schist is similar to the contact of the granite gneiss with the schist; that is, a contact of definite intrusive relation with numerous small dykes near the contact and inclusions of the schist in the granite. Huronian rocks lie in contact with the granite from just southeast of Maud Lake, Duncan Township, to Bellevue Station on the Algoma Central railway. A line of swamps and lakes, including Maud, Reserve, and Legge Lakes, follows approximately along the contact so much of it is masked. Upper Huronian rocks lie in contact with the red granite along the south side of the Bellevue Ridge, from the Algoma Central railway to Northland Lake in the east.

Near Maud Lake, the contact was observed in three places. Southeast of the lake, along the contact of the granite and the Huronian, the Huronian rocks have been highly sheared parallel to the contact. About 300 feet from the shore and 50 feet to the north of this shear zone, the granite can be seen in contact with overlying greywacke and quartzite (Plate XXXIV).

Plate XXXlV: Contact between granite and base of Mississagi Formation showing regolith zone. East of Maud Lake.

Again, the contact appears to be a zone of transition from fresh, red, slightly gneissic granite, through a sericitic zone of light-coloured granite, to an indistinct zone of conglomerate, and highly weathered granite. Numerous, small, sedimentary dykes project into this weathered, granite surface. Above this is a medium to coarse-grained, grey-wacke and arkosic material interbedded. In thin section, there is no indication of alteration of the sedimentary material by the granite intrusion. On the contrary, the granite appears to show a weathering zone about four feet thick. The attitude, as indicated by slight gneissosity, in the underlying granite is markedly different from the attitude of the Huronian rocks.

In the creek valley between Elizabeth and Maud Lakes, the lower member of the Huronian is a highly sheared conglomerate containing numerous pebbles of granite, most of which are of the grey granite type with a few being of the red granite type. This conglomerate was found to be slightly radioactive. Closer to Elizabeth Lake, the contact is obscured by a basic dyke which appears to have been intruded along the contact. From here to Reserve Lake, the contact appears to follow a prominent shear zone along which basic dykes have been injected. About one mile northwest of the exit of Elizabeth Lake and in the creek valley from Reserve Lake, the contact was again observed. At this point, McConnell (1926) described a granitic mass, about 400 yards in length, intrusive into the quartzite of the "Driving Creek Formation". Current mapping shows this granite mass to be offset from the main mass by faulting. Also, what was described mainly as granite is actually a gabbroic dyke on or near the contact. In the creek valley, the quartzite is a very fine-grained, reddish rock resembling a rhyolite. This was found projecting into the granite in small dykes. In thin section examination, these small dykes were seen to be fillings of fractures, in the granite, by fine, clastic material. There is no evidence of intrusion of the granite. The upper, three inches of the granite shows fairly intense sericitization. One hundred feet further upstream, the contact is marked by a small, basic dyke which near its contacts has highly silicified the quartzite.

At the southeastern end of Legge Lake, the contact was detected. Here, a pebble conglomerate layer, about two feet thick, was found to overlie weathered granite. As before, at this point, the line of demarcation between the granite and the clastic sediments is sharper.

The contact between the granite and the Huronian rocks of the Bellevue Ridge was studied intensively.

Bain has shown that, here, the granite is intrusive into the Huronian. He described the rock here as an albitite. Near Northland Lake, granite and Gowganda argillite are in contact. For two hundred feet north from the contact, the Gowganda has been highly brecciated by fault action. Here, the breccia appears to be the result of the intersection of two faults: one parallel to the long direction of Northland Lake, and the other parallel to the Bellevue Ridge. South of the Breitung Mine, which is in the brecciated Gowganda, one passes into a highly sheared granite; in places, it is so highly sheared as to make the nature of the rocks indeterminable (Plate XXXV). In thin section, mortar structure, with elongation parallel to the direction of the Bellevue Ridge, was detected. Some samples have almost a mylonite appearance. About fifty feet south of the contact and parallel to it, the sheared granite has been intruded by a basic dyke which shows less shearing.

This prominent shear zone can be traced along the south side of the Bellevue Ridge to the Searchmont highway. The contact described by Bain (1923), about one-half mile south of mile 20.5 on the Algoma Central railway, was investigated. Here, also, the contact was found to be a shear zone parallel to the length of the Bellevue Ridge. A small, north - south fault

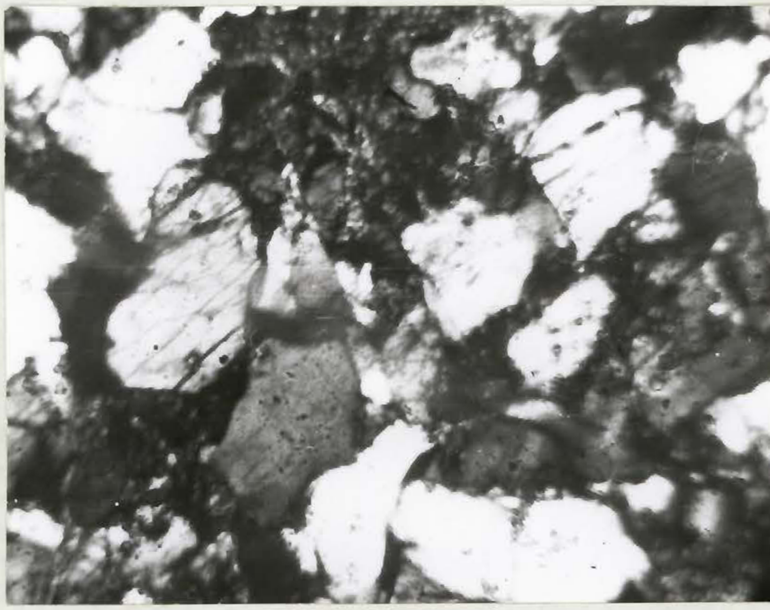


Plate XXXV: Fractured granite from granite batholith south of the Bellevue Ridge.

has offset the granite approximately one hundred feet so that now it projects into the quartzite ridge. The shear zone is about 100 feet wide with much of the material being a mylonite. Crushing of the quartzite near the contact is quite evident.

The writer believes that features which, to Bain, indicate granite intrusion into the Huronian, are actually due to intense hydrothermal activity related to the major fault zone. The iron ore deposits of the Breitung Mine would then be the result of hydrothermal solutions entering a brecciated zone at the junction of two faults. In this area, the nature of the quartzite has resulted in fracturing along which mineralizing solutions have deposited hematite. Such hematite fracture fillings are very common in the Algoma Central Railway quarry on the north side of Bellevue Ridge. This hydrothermal activity probably coincides with the intrusion of the gabbroic dykes.

Thirty eight modal analyses of red granite, grey granite, and of pebbles from the Mississagi and Gowganda conglomerates were done. These modal analyses indicate a similarity between the pebbles and the granite units. It was found that pebbles which show a distinct gneissosity contain orthoclase and represent more closely the granite gneiss. Modal analyses are shown in Table No. 9. For comparison with granite and granite gneiss modal analyses see Table No. 5 and Table No. 6.

BRUCE GROUP

In the early mapping by Logan and Murray, along the north shore of Lake Huron, they recognized a series of relatively unmetamorphosed rocks. At first, they classified these as possible Cambrian, but in " Geology of Canada " (1863) they termed them Huronian. Pumpelly and Van Hise (1892) recognized an unconformity at the base of the Upper Slate Conglomerate, and they divided Logan's Huronian into an Upper and Lower Series. In 1902, Seaman found an unconformity within the Lower Huronian of Michigan, and thus divided the Huronian into Lower, Middle, and Upper Huronian. Because of the difficulty in correlating into Michigan, Collins (1925) preferred to drop the terms Lower and Upper; he classified the Lower Series, along the north shore, as the Bruce Series, and the Upper Series as the Cobalt Series. The Cobalt Series had been named previously from the Cobalt district by Miller (1911).

In the Sault Ste. Marie map-area, McConnell (1926) recognized a series of clastics and volcanics which, he believed, lay unconformably below the Bruce Series.

Table No. 9

MODAL ANALYSIS GRANITIC PEBBLES - MISSISSAGI CONGLOMERATE - GOWGANDA CONGLOMERATE

Specimen No.	1	2	3	4	5	6	7	8	9
Quartz	21	17	33	27	24	19	37	29	22
Microcline	27	31	29	10	22	-	-	-	-
Orthoclase	-	-	-	-	-	37	42	28	32
Plagioclase	29	41	24	43	31	21	15	21	30
An	19-24	21-27	23-29	21-29	19-30	20-25	21-27	22-25	21-28
Perthite	17	3	-	-	-	-	-	-	-
Biotite	x	1	2	4	6	2	5	7	9
Hornblende	5	7	11	12	11	14	1	12	6
Muscovite (sericite)	x	x	x	2	x	4	x	1	x
Zircon	x	-	x	x	x	x	x	x	x
Chlorite	x	x	x	x	-	x	-	-	x
Apatite	-	-	x	x	-	x	-	-	x
Iron Oxides	-	x	-	-	-	-	x	-	x
Titanite	-	x	-	-	-	-	-	-	-
Augite	-	-	-	x	2	1	-	x	-
Pyrite	-	x	-	x	x	x	-	-	-

Table No. 9 cont'd

Specimen Locations

1. Gowganda Pebble - South of Boss Lake, Garden River Indian Reserve.

2. Gowganda Pebble - West of Echo Lake, Garden River Indian Reserve.

3. Mississagi Pebble - Southeast of Maud Lake, Duncan Township.

4. Mississagi Pebble - Southeast of Maud Lake, Duncan Township.

5. Mississagi Pebble - Southeast of Maud Lake, Duncan Township.

6. Gowganda Pebble - South of Maple Lake, Deroche Township.

7. Gowganda Pebble - South of Wigwas Lake, Garden River Indian Reserve.

8. Mississagi Pebble - Southeast of Maud Lake, Duncan Township.

9. Mississagi Pebble - Southeast of Maud Lake, Duncan Township.

This he divided into three formations: a lower quartzite - the Driving Creek Formation, a lava series - the Duncan greenstone, and an upper quartzite and conglomerate - the Aweres Formation. He termed the series the Soo Series. He indicated a possible correlation between the Soo Series and the Sudbury Series, a controversial series in the Sudbury area believed by many to be below the Bruce. The Sudbury Series was first described by Coleman (1913).

In Coleman's (1913), and in Burrows' and Rickaby's descriptions (1934) of the Huronian, they included the Mississagi quartzite in the upper part of the Sudbury Series, and placed it unconformably below the Ramsay Lake conglomerate which they noted as the oldest Bruce rock in the district. Coleman (1913), Lawson (1929), Collins (1936), and the International Nickel Geological Staff all found an unconformity between the Sudbury Series and the Bruce Series. Fairbairn (1941) found no evidence for the unconformity and included the Sudbury Series at the base of the Bruce Series.

In mapping the Sault Ste. Marie area, McConnell found that the attitude of his Soo Series rocks varied from north to northwest, and showed general dips towards the west. The Huronian sediments, southeast of the Garden River, he found to have a general attitude of northeast to east with a southeasterly dip. Thus he noted a considerable angular unconformity between the Huronian rocks southeast of the Garden River and those to the northwest. Also, he noted vast thicknesses of volcanics north of the Garden River. These had not been recognized previously in Huronian sediments of the Bruce and Cobalt. The great thicknesses could not apparently disappear within such a short distance.

Current mapping shows a major fault zone following the line of the Garden River. Near the Garden River Indian Reserve, this fault zone appears to separate into several branches. Thus the contact between McConnell's Soo Series and the Bruce Series is actually a fault contact. In mapping, in the southeast, the strikes, in fact, were found to be towards the northwest with general southwesterly dips. Thus McConnell's main evidence for assuming an angular unconformity, that is the difference in attitudes, is wanting. McConnell stated that the Duncan greenstone was of considerable thickness and infers that, in general, it is steeply dipping. Current mapping shows that, actually, the Duncan has a marked schistosity which is almost vertical, and parallel to the major faulting in the area. The bedding in the volcanics is variable but seldom dips greater than 48°. The true thickness is somewhat less than 500 feet (Figure 13).

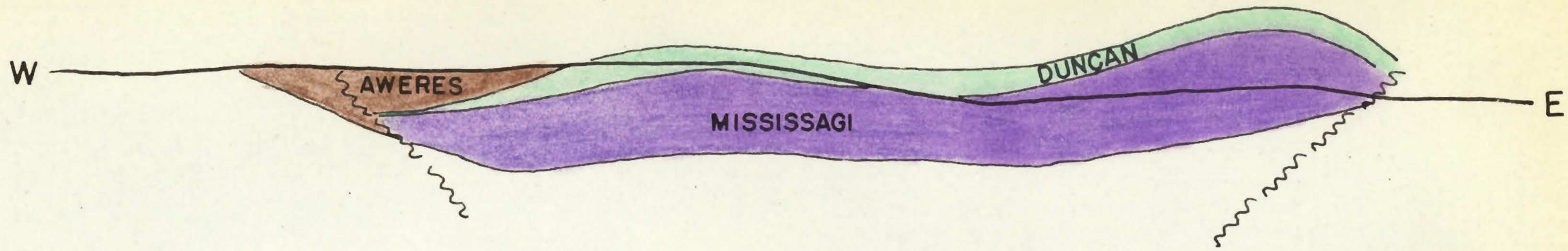


Figure 13

CROSS SECTION MABEL LAKE MAUD LAKE HOR. SCALE 1/2 MILE = 1 INCH

VERT. SCALE 1000 FEET = 1 INCH

A thickness of 500 feet seems to be quite reasonable for local volcanic activity. Frarey (1959) has mapped a similar basic volcanic unit in the Echo Lake area. He has placed this greenstone mass between the Mississagi Formation and the Bruce conglomerate. This had been described previously by Collins as the Thessalon Greenstone, and was assumed to be a late Precambrian basic intrusive. Collins noted only very minor amygdaloidal structures and very few other structures to indicate an extrusive origin. Collins found that the greenstone was crosscutting the Mississagi and did not actually form a horizon within it. These outcrops of supposed volcanic material within the Bruce Group are located about four miles east of Echo Bay, approximately ten to twelve miles from the outcrops of Duncan greenstone north of Garden River. Descriptions of the greenstone by Collins (1925) and by Frarey (1959) appear to match very closely a description of the Duncan greenstone. Frarey (1959) described a thin, radioactive, pebble conglomerate layer about ten to fifteen feet above the base of the greenstone layer. A similar, radioactive, conglomerate layer was found within the Duncan greenstone along the east shore of Maud Lake. In 1959, accompanied by Frarey, the writer visited one of these exposures within the greenstone in the Echo Bay area. Here, conditions were found to be almost exactly similar to the conditions at Maud Lake.

Collins' (1925) stratigraphic sequence for the Bruce Group has been used generally for work along the north shore. It consists of five units: the Mississagi quartzite, Bruce conglomerate, Bruce limestone, Espanola greywacke, and the Serpent quartzite. Alterations in the sequence have been suggested by Roscoe (1957) and Pienaar (1958). In the Sault Ste. Marie map-area, the writer has divided the Bruce Group into east and west sections. The east section is quite similar to that of Collins except that, here, the Espanola, in the form described by Collins, is absent. In the west, McConnell's Driving Creek Formation has been classified, by the writer, as Mississagi. The Duncan greenstone, although no definite data are obtainable, has been placed equivalent in age to the Bruce limestone and Espanola greywacke. The Aweres Formation is correlated with the Serpent Formation. Along the west shore of Legge Lake, a small outcrop of calcareous material was found in contact with the Duncan greenstone. Shearing is very evident so the thought, that perhaps this was material introduced hydrothermally along a fault zone, was suggested. Thin sections of the material show it to contain clastic fragments. In hand specimen, a few rounded grains were detected. If this material is Bruce limestone it would indicate that, actually, the Duncan greenstone lies on top of the Bruce limestone, or possibly that vulcanism occurred at about the same time as deposition of the Bruce limestone, and possibly the Bruce conglomerate.

The Bruce Group rocks overlie the basement granite gneiss with marked angular unconformity. They are, in turn, overlain by the Cobalt Group which, in most cases, shows only minor angular discordance with the underlying beds. In the Sault Ste. Marie map-area, the contact with the basement rocks is generally absent. Along Surrette Lake, the contact appears as a thick, regolith zone. The contact appears to be undulating, the Huronian rocks probably being laid down on a surface having a relief of two or three hundred feet. Within the Bruce Group itself, it appears that there were several shorter periods of erosion. Where the Bruce conglomerate overlies the Mississagi, it appears to pass conformably upward over a distance of about four feet. Near the top, the Mississagi suddenly becomes coarser and more argillaceous. Near the base, the Bruce conglomerate is formed of arkose pebbles about two to three inches in diameter. The Bruce conglomerate appears to grade upward into the Bruce limestone with no apparent unconformity. The lower beds of Bruce limestone are more siliceous. In the Sault Ste. Marie map-area, the Bruce limestone appears to have been laid bare to erosion. Limestone is found, in most places, to give way to a massive, polymictic conglomerate. Near Echo Lake, the contact with the conglomerate appears to be irregular, indicating possible erosion before deposition of the conglomerate; the presence of limestone pebbles also indicates prior erosion. The conglomerate does not appear to show any angular unconformity. In the west, the Bruce limestone was apparently disrupted by minor, local volcanic activity. Contact relations with the Mississagi quartzite seem to indicate that, along the east shore of Maud Lake, the Duncan greenstone overlies eroded Mississagi quartzite directly. As mentioned before, along Legge Lake, the limestone was found beneath the greenstone and between the greenstone and the Mississagi quartzite. It would appear that, in much of the area covered by Duncan greenstone, the Bruce limestone and conglomerate have been stripped away by erosion, and the Duncan laid directly upon the Mississagi. The Duncan marker beds, the quartz pebble layers near the base of the Duncan, may possibly represent Bruce conglomerate, and this would mean that the Duncan greenstone was deposited at the same time as the Bruce limestone and Bruce conglomerate. The writer infers that the Duncan greenstone is equivalent in age to the Bruce limestone and conglomerate, and that these were deposited under very shallow water conditions . In the Echo Lake area, Frarey (1959) has found Bruce limestone overlying the lava belt.

Before the deposition of the Serpent quartzite, there appears to have been widespread erosion in the Sault Ste. Marie area. As mentioned, the Duncan greenstone overlies eroded Mississagi, but the Duncan greenstone itself has been eroded before deposition of the Aweres conglomerate and quartzite. The Aweres Formation is correlated, in the Sault Ste. Marie area, with the Serpent quartzite. Where the Aweres is found to be overlying the Duncan, the first 200 to 300 feet of Aweres is almost entirely composed of greenstone fragments. The contact zone is very irregular and indicates erosion with a relief of possibly as much as 300 feet. In the south, just northwest of the Garden River, erosion has completely removed the Duncan greenstone so that Mississagi quartzite is found in direct contact with the Aweres. In this region, the lower portion of the Aweres consists largely of pebbles of Mississagi quartzite. Towards the north, near the Algoma Central railway, the quantity of greenstone pebbles increases considerably. Where the belt crosses the Algoma Central railway, the conglomerate is composed almost entirely of greenstone pebbles which are cemented in a matrix of chloritic material. Here, the upper one hundred feet of the Duncan greenstone shows interbeds of conglomerate and greenstone.

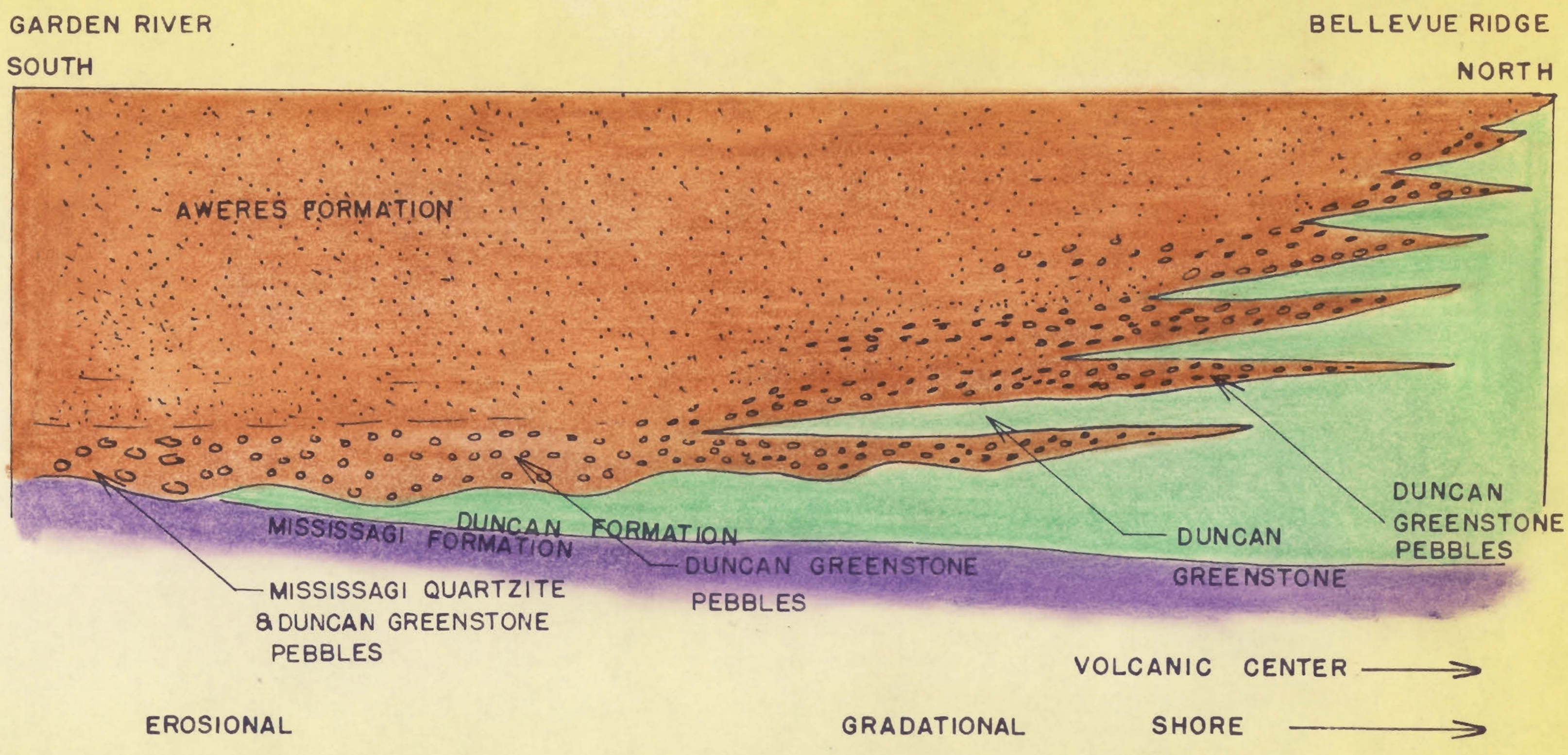
This would indicate that, in the north, vulcanism continued after the beginning of Aweres time. In the south, vulcanism had completely subsided before deposition of the early Aweres conglomerate; the conglomerate thus lies upon the eroded Duncan greenstone (Figure 14). In the north, it appears that the Duncan greenstone represents deposition from the time of formation of the Bruce conglomerate to the time of formation of the Lower Aweres conglomerate.

After deposition of the Serpent and Aweres, it appears that the land was laid bare to erosion. In the Echo Lake area, the Gowganda conglomerate appears to be lying on a surface which may have as much as 1000 feet relief. West of Echo Lake, the Gowganda appears to be filling depressions in the eroded Serpent surface. Nowhere is the Gowganda in contact with the Aweres so no estimation of this contact erosion can be made.

The Bruce Group, then, shows several disconformities within itself. These have not been recognized further towards the east. These unconformities within the Bruce Group are assumed, by the writer, to be more of a local nature, and do not truly represent the sequence in the Bruce for the north shore.

The term Bruce Group is used in the report to define the sediments formerly classified as Bruce Series. Where the term Bruce Series is used, it is used in reference to previous work.

FIGURE 14



DUNCAN AWERES CONTACT

(a) Mississagi Formation

The term Mississagi was originally introduced by Alexander Winchell in 1888 to represent the basal part of the Bruce Group. The term has been in general usage since to represent the lowest formation of the Bruce Group. Collins (1925) termed the lower conglomerate section of the Mississagi, where it outcrops near Sudbury, the Ramsay Lake. Collins (1936) definitely placed the Ramsay Lake as the lowest member of the Bruce Group; he placed it unconformably above the Sudbury Series. Coleman (1913), the first to mention the Ramsay Lake, placed it unconformably above the Sudbury Series, but in the Sudbury Series he included a thick succession of quartzite which was called the Wanapetei. This was later correlated as Mississagi. Roscoe (1957), in detailed mapping in the Blind River area, has divided the Mississagi into a Lower Elliot Group, which he further divided into the Matinenda (lower) and Nordic (upper) Formations, and the Mississagi Group, which he divided into the Whiskey (lower) and Ten Mile (upper) Formations.

In the Sault Ste. Marie map-area, McConnell (1926) recognized the Mississagi at the base of the Bruce Group. Also, he named the Driving Creek Formation which he found at the base of his Soo Series. Current mapping shows that McConnell's Mississagi is actually part of the Serpent Formation. The Driving Creek Formation of McConnell has been correlated, by the writer, with the Mississagi.

The most complete section of Mississagi was measured from the creek leaving Elizabeth Lake on the southwest side to the west along the northern edge of Section 14, Duncan Township. Here, the lowest unit of the Mississagi is found in the outcrops in the creek. It occurs as a highly sheared, slightly radioactive, polymictic conglomerate. The thickness measured in the creek bed was about twenty feet. About fifty feet inland from the falls at the exit of Elizabeth Lake, more basal Mississagi beds were found. Here, it occurs as fairly well bedded, polymictic conglomerate, arkose, and quartzite beds. All of these are slightly radioactive, with the arkose and conglomerate beds being more so. The conglomerate and arkose are found in beds about ten feet thick, and they are interbedded with quartzite beds of about the same thickness. Towards the top of this hill, the section consists of a well bedded, fine to medium-grained, feldspathic quartzite showing a fairly high content of sericite. Here, minor cross-bedding occurs. The total thickness of the lower conglomerate phase of the Mississagi, measured from the creek bed to the zone where feldspathic quartzite becomes predominant, consists of fifteen feet of conglomerate, twenty-five feet covered, fifteen feet of conglomerate, ten feet of quartzite, and ten feet of conglomerate. From here, the section consists mainly of feldspathic quartzite, fine arkose, and siltstone. Conglomerate zones are common, especially near the base where one particular conglomerate, about four feet thick, shows boulders of granite and quartzite up to eight inches in diameter. The total thickness of greywacke, feldspathic quartzite, and conglomerate of the Middle Mississagi was measured at 300 feet, although the exact thickness is questionable because the upper contact is masked by overburden. Above the Middle Mississagi feldspathic quartzite, the section changes to a well cross-bedded, clear arkose, and feldspathic quartzite; this is excellently displayed on a large cliff face. The beds range, in thickness, from about one inch to massive, cross-bedded sections about four feet. The Upper Mississagi is fairly uniform in composition. Greywacke beds occur locally, but are generally less than one foot thick. Near the Duncan greenstone contact, the Mississagi becomes somewhat coarser, and the material is somewhat more angular. The total thickness of the Upper Mississagi is 235 feet, with 35 feet representing the coarser section at the top. A detailed section of the Mississagi west of Elizabeth Lake is shown in Table No. 10.

(b) Bruce Conglomerate

The Bruce conglomerate, although of major importance east of Sault Ste. Marie, occurs only in scattered localities in the Sault Ste. Marie map-area. Collins (1914) applied the term Bruce conglomerate; it was originally called the Lower Slate conglomerate by Logan and Murray.

In the Sault Ste. Marie map-area, the Bruce conglomerate follows the Mississagi quartzite with only slight angular unconformity. About 1000 feet inland from the southeast corner of Trotter Lake, Bruce conglomerate overlying Mississagi quartzite shows a regolith zone about seven inches thick. Here, the top of the Mississagi appears to show an undulating, erosional surface.

West of Echo Lake, the Bruce conglomerate is again found in contact with Mississagi quartzite. Here again, the upper part of the Mississagi appears to show a slightly undulating surface. Here on a cliff face, an almost complete section of the Bruce conglomerate was measured. The lower portions of the Bruce were found, here, to consist of a coarse boulder conglomerate with a dark greywacke matrix; this is confined

Table No. 10

Detailed Section of Mississagi Formation West of Elizabeth Lake.

Coarse feldspathic quartzite, Minor greywacke, beds generally less than one foot in thickness.	35 feet	Upper Mississagi
Fine to medium grained well sorted feldspathic quartzite and arkose, well cross-bedded, minor greywacke zones, beds 2 inches to 4 feet thick.	200 feet	
Overburden	50 feet	Middle Mississagi
Medium grained arkosic quartzite, and greywacke, generally poorly sorted, matrix high in sericite, generally thick bedded, beds 2 to 4 feet, thin conglomerate zones.	200 feet	
Coarse polymictic conglomerate, showing granite, quartzite and black chert pebbles.	4 feet.	
Medium grained arkosic quartzite, greywacke, generally poorly sorted, matrix high in sericite.	46 feet	
Interbedded polymictic conglomerate and arkose.	10 feet	Lower Mississagi
Interbedded feldspathic quartzite and greywacke.	10 feet	
Interbedded polymictic conglomerate and arkose.	15 feet	
Overburden	25 feet	
Interbedded polymictic conglomerate and arkose, generally highly sheared.	15 feet	
Total Thickness	610 feet	

to the bottom twenty feet. Greywacke zones are minor. The upper part of the Bruce conglomerate includes more greywacke than conglomerate. Stratification is generally poor with the conglomerate zones gradually changing to greywacke with no indication of a bedding plane. Near the top, a more conglomeratic phase, about ten feet thick, was noted; the exact top of the conglomerate was covered by a talus slope. In this cliff section, the total thickness of the Bruce conglomerate is about fifty feet.

A section of Bruce conglomerate of similar thickness was noted south of Meniss Lake. Here, the section is so incomplete as to make it impossible to describe in any detail.

To the east, at Quirke Lake, Collins (1925) reported thicknesses of about 125 feet. Near Panache Lake, where it is highly folded and faulted, he feels that it may attain a thickness of as much as 500 to 1000 feet. The Bruce conglomerate has been referred to as a tillite by some writers.

(c) Bruce Limestone

The Bruce limestone was first named by N. H. Winchell (1891). The Bruce limestone and the accompanying Bruce conglomerate have been used as marker beds throughout the north shore area because they both have very characterisitic features. The deeply corrugated weathering surface, the fine-grained nature, and the siliceous beds are very typical of the limestone.

Collins (1925) classified the Bruce limestone as a subdivision of the Espanola Formation, with the Espanola being formed of a lower Bruce limestone, a middle Espanola greywacke, and an upper Espanola limestone. Although he brought each of these units under the Espanola Formation, he also termed each of these individual units a formation.

In the cliff face west of Echo Lake (Figure 4), the Bruce conglomerate passes upward through a non-calcareous, siliceous greywacke, into a calcareous, siliceous greywacke, and then into a finely laminated siltstone. This siltstone usually occurs in laminae about one millimeter thick. Flowage within the rock has disrupted many of the beds so that now they appear highly crumpled. This lower, silty, non-calcareous section comprises about five feet. Above this, the rock occurs as finely laminated limestone and calcareous siltstone. The limestone laminae generally are found to be completely free of silt fragments. The silty laminae, which may contain as high as fifty per cent silt fragments, generally are darker and usually contain small amounts of pyrite. Above this laminated material, the beds become more massive with some beds reaching a thickness of about two feet. Near the top of the cliff, a bed about two feet thick stands as a fairly prominent ridge. The upper part of the section, here, is disrupted by a basic intrusion. Further to the west along this ridge and further up in the stratigraphic section, the limestone again becomes finely laminated siltstone and limestone.

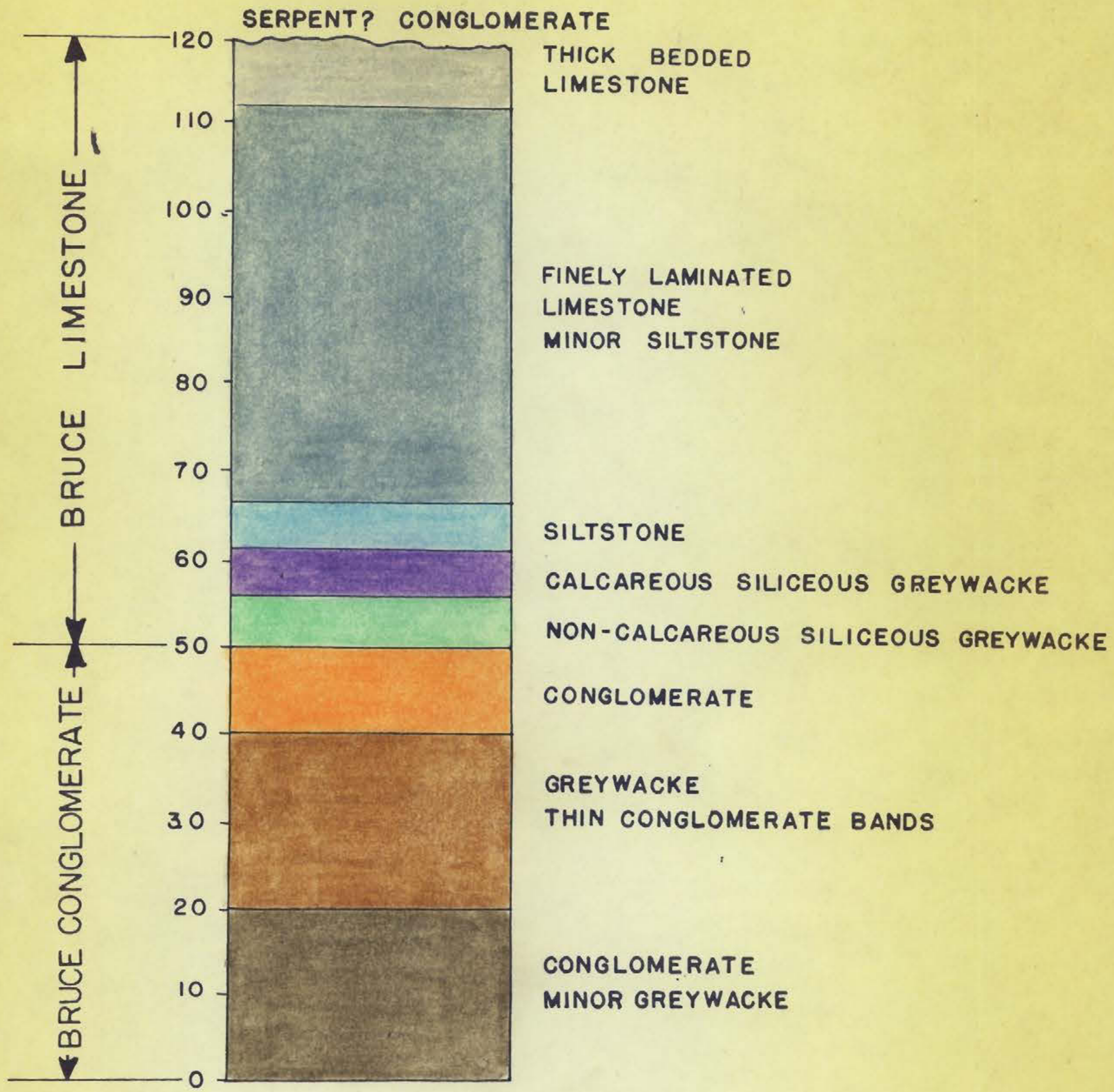
The top of the section was observed on Caribou Point, Echo Lake, where it is represented by a moderately contorted siltstone. The contact between this and the overlying Serpent(?) conglomerate is quite irregular. Pebbles of Bruce limestone occur within the lower section of this conglomerate.

The total thickness of Bruce limestone in the Sault Ste. Marie map-area is approximately 100 feet. In the cliff west of Echo Lake, a section of about 60 to 70 feet in thickness can be measured (Figure 15).

(d) Duncan Greenstone

The Duncan greenstone was first recognized by McConnell (1926) in his mapping of the Sault Ste. Marie area. He placed it in his Soo Series directly above the Driving Creek quartzite (Mississagi).

FIGURE 15



SECTION OF BRUCE CONGLOMERATE AND

BRUCE LIMESTONE WEST OF ECHO LAKE

Prior to McConnell's mapping, no volcanics had been found in the Huronian rocks, although Collins (1925) identified a greenstone in the Thessalon area, but mapped it as cross-cutting and placed it equivalent to the Keweenawan basic intrusives. Frarey (1959) has mapped similar material on the Echo Lake map-sheet, but he assumes it to be of volcanic origin and has placed it stratigraphically below the Bruce conglomerate. In the Sault Ste. Marie area, the greenstone is found to rest directly upon the Mississagi, following a somewhat undulatory contact. The Duncan greenstone contacts are described in detail in the general section on the Bruce Group.

The writer has placed the eruption of the Duncan greenstone concurrent with the Bruce conglomerate and Bruce limestone and, possibly, on into the Aweres. It appears that some volcanic material erupted during sedimentation of the early part of the Aweres. McConnell mentions that, in places, the Duncan and the Driving Creek (Mississagi) are separated by a thin carbonate band which may possibly indicate that the Duncan is, in part, later than the Bruce limestone.

Because of poor outcropping, a Duncan greenstone section is difficult to obtain. West of Maud Lake, the basal section of the Duncan occurs as a highly sheared, chloritic rock about five feet thick. Above this, massive greenstone with minor amygdules is prevalent for another fifteen feet. Here, there is a characteristic marker bed consisting of quartz pebble conglomerate and arkose layers about ten to fifteen feet in total thickness. Individual beds are from one foot to three feet thick. Above this, the Duncan greenstone is again a massive greenstone, but, in places, it appears highly amygdaloidal, with amygdules up to two inches across being quite common. Further south along the lake shore and higher up in the stratigraphic section, the Duncan greenstone is markedly pillowed.

The total thickness of the Duncan greenstone was not determined. McConnell (1926) infers considerable thickness, but apparently he was measuring schistosity rather than bedding planes. From Maud Lake across to the Aweres contact, several small flexures cross the greenstone so that an estimation of true thickness is difficult to obtain. Measurements along the Algoma Central railway seem to indicate a thickness of about 2000 feet, but this thickness has been accentuated by folding. The Duncan is definitely thicker in the northern portion where it is standing at slightly steeper angles. The writer believes, from measurements made northwest of Garden River, that the greenstone is possibly less than 300 feet thick, and even this may be an overestimation.

The quartz pebble conglomerate beds in the basal part of the Duncan are very characteristic of the Duncan. South of Driving Lake, McConnell reported them in the greenstone at about the same level above the Mississagi as those on Maud Lake. Frarey also reports similar, quartz pebble conglomerates ten to fifteen feet above the base of the Thessalon greenstone north of Bruce Mines, Ontario.

(e) Conglomerate (Espanola Greywacke?)

In the Sault Ste. Marie map-area wherever the Bruce limestone was found, a polymictic conglomerate was found between the limestone and the Serpent Formation. This conglomerate lies unconformably upon the Bruce, and contains several fragments of the Bruce limestone. Frarey (1959), accompanied by the writer, visited a similar conglomerate just east of Ophir Post Office, about twenty miles north of Bruce Mines, Ontario. Here in a series of outcrops, the Mississagi, Bruce conglomerate, Bruce limestone, polymictic conglomerate, and Serpent can be found.

Collins (1925) and others, in mapping along the north shore of Lake Huron, have found a greywacke and limestone formation between the Bruce limestone and the Serpent quartzite. This formation was termed the Espanola by Collins (1914), and subdivided into a lower greywacke and an upper limestone. He also included the Bruce limestone in the lower unit of this Espanola Formation.

The age of the conglomerate in the Sault Ste. Marie map-area is doubtful. It is definitely post-Bruce limestone as evidenced by the presence of pebbles of the limestone. Whether or not it represents the Espanola greywacke or limestone is questionable. It seems more likely that it is a basal conglomerate deposited at the beginning of the Serpent sedimentation. Thus it would be comparable in age to the conglomerate along the western boundary of the Duncan greenstone, where a conglomerate zone about 100 to 500 feet wide forms the basal member of the Aweres Formation, and is composed largely of fragments of underlying, Bruce Group material. Frarey (1959), on the Echo Lake map-sheet, has placed this conglomerate at the base of the Serpent. He found a sequence on the southeast side of Echo Lake similar to that at Caribou Point.

The conglomerate consists of coarse, polymictic beds, generally massive, with little indication of bedding. On the west side of Echo Lake, the thickness varies between ten feet and one hundred feet with the thickness changing rapidly over a short, lateral distance. This would seem to indicate considerable erosion of the Bruce limestone surface.

The overlying contact with the Serpent was not seen anywhere. If this is similar to that described by Frarey on the south side of Echo Lake, the conglomerate is actually basal Serpent, and the conglomerate would grade into the quartzite.

(f) Serpent Formation

Collins (1925) noted that previous to 1914 no mention had been made of the upper, thick quartzite of the Bruce Group. In 1914, he named it the Serpent from exposures near Quirke Lake. McConnell (1926), in mapping the Sault Ste. Marie area, classified none of the quartzite as Serpent. Most of the quartzite south-east of the Garden River he placed in the Mississagi Formation. Frarey (1959), in mapping the Echo Lake map-area, has found that the Serpent Formation is more widespread than originally reported by Collins (1925).

The Serpent generally appears as massive, feld-spathic quartzite beds showing few sedimentary structures. The Mississagi, on the other hand, is characteristically highly cross-bedded, especially in the upper portions.

The lower part of the Serpent shows a decidedly white colour and represents unglazed porcelain. As Collins (1925) mentions, this feature is almost sufficient to separate this quartzite from the other quartzite in the area. Southwest of the polymictic conglomerate, on the west side of Echo Lake, and along the lake, the quartzite shows this characteristic feature. The delicate lamination of the Lower Serpent as described by Collins. was not detected here. These outcrops are fairly coarse-bedded with several beds of a thickness of four feet. Collins' early descriptions mention that the Serpent quartzite, unlike the Mississagi quartzite, shows very few conglomerate zones in the lower portion. In the Sault Ste. Marie map-area, the only conglomerate pebble layer found in the Lower Serpent was a 1/4 inch thick layer, south of Echo Lake.

The best section of Serpent quartzite is found west from Echo Lake towards Meniss Lake. The white, porcelaneous, thick-bedded section immediately above the basal conglomerate is about 100 feet thick. This is followed, to the west, by a glossy quartzite which is bluish on the fresh surface; it is very thick bedded. A few argillite beds, about two inches thick, occur near the top of this bluish unit; these are generally marked by some ripple marking. The total thickness of the bluish unit is about 175 feet. The bluish unit is succeeded by a feldspathic quartzite which forms the upper unit of the Serpent Formation. The upper part of this feldspathic quartzite is marked by a few quartz pebble layers about two inches thick. This upper feldspathic quartzite measures about 300 feet in thickness and thus gives a total thickness of 575 feet for the Serpent Formation. This is considerably less than generally reported for the Serpent east of Sault Ste. Marie. In the Blind River area, Collins (1925) reported a thickness of about 1100 feet. The thickness in the Sault Ste. Marie area appears to have been reduced by erosion prior to the deposition of the Cobalt Group. As stated previously, the Gowganda conglomerate appears to have been deposited on an eroded Serpent surface showing considerable relief. Pockets of Gowganda found within large areas of Serpent seem to indicate a relief of about 500 feet.

(g) Aweres Formation

The Aweres Formation, the upper subdivision of McConnell's Soo Series (1926), has been correlated by the writer as Serpent, although the lithology, in general, does not correspond to the Serpent found west of Echo Lake. The Aweres is found stratigraphically above the Duncan in Aweres and Duncan Townships. The contact between the Duncan and Aweres is quite irregular indicating that the Aweres was laid down on a surface of fairly high relief. In the south, in the Garden River Indian Reserve, pre- Aweres erosion has removed all of the Duncan greenstone so that the Aweres is in contact with the Mississagi. The Aweres appears to be more extensive than the Duncan greenstone and the Mississagi quartzite, and, in the west, it overlies the basement directly.

The Aweres Formation thickens considerably towards the east. In the south, in the Garden River Indian Reserve, the outcrop width has apparently been reduced through faulting. Further north, the Aweres is folded into gentle anticlines and synclines which give a false impression of thickness.

The lower 200 to 300 feet of the Aweres, along the contact with the Duncan greenstone, is a coarse, pebble conglomerate consisting almost entirely of greenstone pebbles. Towards the south end of the belt where the Aweres is in contact with the Mississagi, Mississagi-type pebbles become numerous in the Lower Aweres. Along the west boundary of the Aweres Formation near Heyden, on the Algoma Central railway, the basal unit of the Aweres is represented by a coarse conglomerate containing pebbles mostly of quartz and granite. Very few greenstone pebbles were obtained, and these, in general, bear no resemblance to the Duncan greenstone. The lower section of the Aweres along the Duncan contact is generally massive, although, in places, cross-bedding does occur.

A section of Aweres was measured from between Mabel and Surrette Lakes eastward to the Duncan greenstone contact. Starting from the Duncan greenstone contact, the lower 300 feet is found to be a coarse, pebble conglomerate consisting largely of greenstone pebbles, but also containing pebbles of the Mississagi, some of which show cross-bedded structure. The bedding is very thick; cross-bedding is present in a few places. Above this, the Aweres is a coarse arkosic and feldspathic quartzite with minor pebble layers. The total thickness of this layer is 700 to 800 feet, but folding may have exaggerated the thickness. Near Mabel Lake, the basal Aweres beds are again located; here, the thickness has been greatly reduced by faulting. The basal conglomerate beds, here, are heavily sheared. East of the south end of Surrette Lake, the basal Aweres is a polymictic conglomerate; greenstone and quartzite pebbles are not frequent; most of the pebbles are of a granite composition.

A section was also measured from the granite

contact along the northwest shore of Trout Lake to Alexander Lake at the contact of the Duncan greenstone. The basal beds are well exposed at the west end of Maki Lake. Here, the Aweres consists of a polymictic conglomerate containing fairly well rounded pebbles. The pebbles are generally of a granitic composition, and are either red or grey in colour. A few, basic, schist pebbles were also detected. At the west end of Trout Lake and for about 300 feet along the Trout Lake Road, the Aweres appears as a highly siliceous, greywacke conglomerate which, in places, resembles very closely the Bruce conglomerate. Here, pebbles larger than one inch are not common. Much of this material would actually be classed as greywacke. The basal, conglomerate section appears to vary widely in thickness over a short distance, but probably is in the order of 300 to 500 feet thick. The overlying, greywacke beds are about 300 feet thick.
The greywacke beds are overlain, along the north shore of Trout Lake, by medium-grained, clean feldspathic quartzite. Minor, quartz pebble layers, most being only about two to four inches thick, occur within the quartzite. This feldspathic quartzite has a marked resemblance to the Upper Serpent beds found west of Echo Lake and north of Wigwas Lake. Cross-bedding and ripple marks are very rare in this section. The bedding

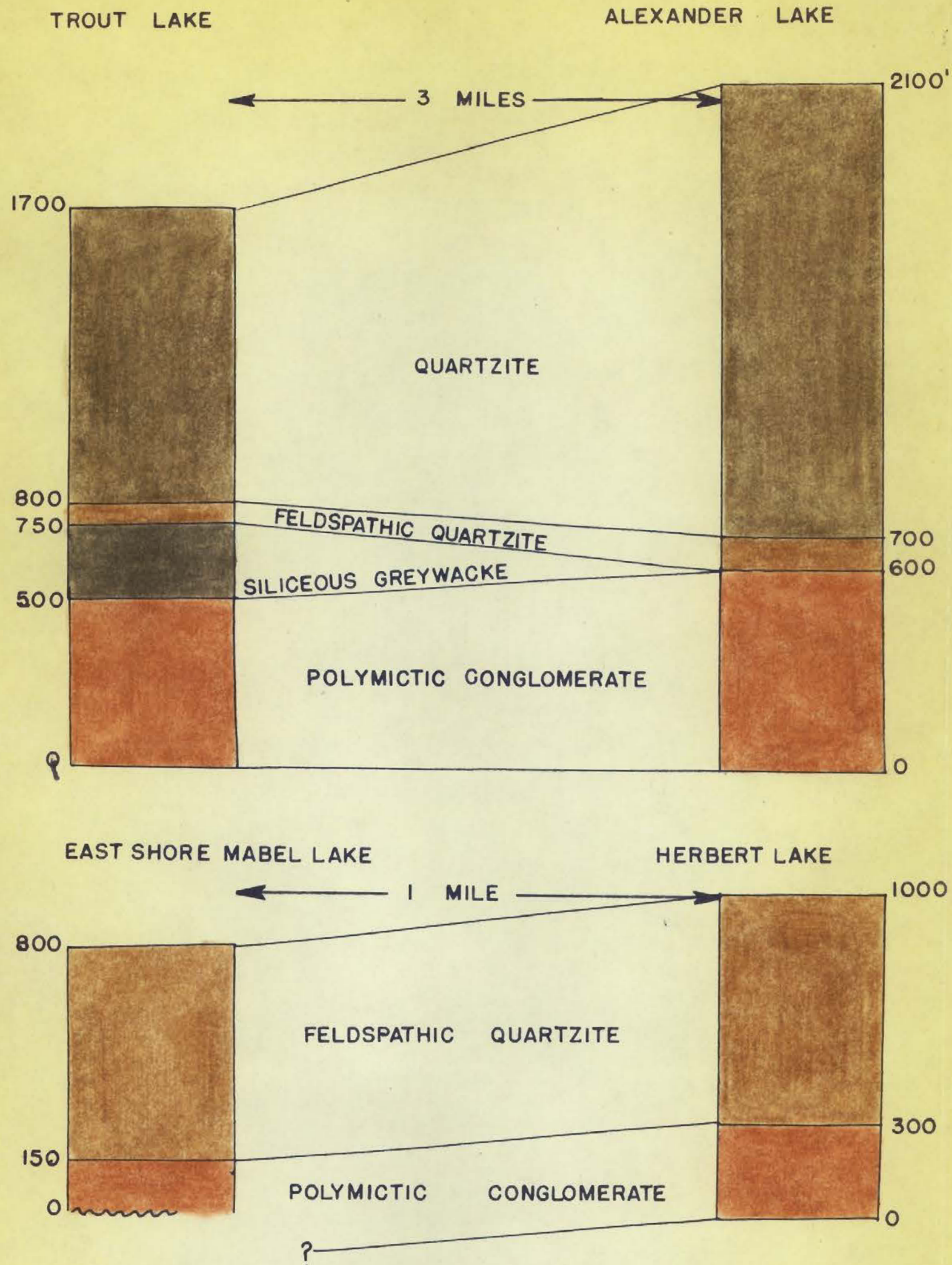
is generally thick, with beds two or more feet in thickness, but local beds only two to three inches in thickness occur regularly. About 2000 feet east of the west end of Trout Lake, the dips of the quartzite change to west as one crosses a synclinal axis. This, then, seems to indicate the apparent thickness of the Aweres. The total thickness of the quartzite, here, seems to be in the order of 800 to 1000 feet. The total thickness of the Aweres, measured through Trout Lake, is approximately 1600 to 1800 feet.

From the synclinal trough eastward towards Alexander Lake, large thicknesses of quartzite are crossed. Low dips, in combination with repetition caused by gentle folding, seem to be the cause of this large, apparent thickness. About 500 feet west of Alexander Lake, the coarse, polymictic conglomerate containing numerous greenstone fragments is again present (Figure 16).

COBALT GROUP

The Cobalt Group contains formations which are very characteristic of the Huronian along the north shore, and which are easily traced over very large distances. The Cobalt Group was originally called the Upper Slate Conglomerate by Logan and Murray (1863 - Geology of Canada). The term Cobalt Series was first introduced by Miller (1911) in the Cobalt district,

FIGURE 16



STRATIGRAPHIC SECTIONS

AWERES FORMATION

and was used by Collins (1914) in the north shore area. Cooke (1920) found an erosional unconformity between the Cobalt Series and the Bruce Series representing a time interval sufficient for the removal of 1700 feet of sediments in some places; he found little or no structural unconformity. Near Sudbury, Cooke (1926) found that the Bruce Group could be traced for about 40 miles north of Lake Huron, but that the Cobalt could be traced for 165 miles. J. E. Thomson (1957) notes that the Cobalt Group was laid down on a surface of considerable relief so that, now, outliers of Cobalt sediments and exposed patches of basement rocks within the boundaries of the main basin are quite characteristic.

Miller (1911) at first used the term Cobalt Series, in the legend on his maps, as corresponding to the time-term, Lower Huronian, and the term Lorrain as corresponding to Middle Huronian. In 1913 he redefined the Cobalt Series to include the Lorrain rocks.

The Cobalt Group, in general, has been divided into two formations: a lower, greywacke - slate conglomerate, and an upper, thick quartzite unit. The name Gowganda was suggested by Collins (1917) to represent the lower part of the Cobalt Series. In the Cobalt area, there has been a tendency to divide the Gowganda into two divisions: a lower unit related to glaciation, and an upper unit of normal, water-laid sediments. The name Lorrain is used to define the upper quartzite unit.

R. Thomson (1957), in mapping in the Cobalt area, has divided the Gowganda into a lower, Coleman Formation and an upper, Firstbrook Formation, placing each equivalent in importance to the Lorrain. Roscoe (1957) has preferred to use a new name in defining the Cobalt Group; he has introduced the term Dunlop Group to represent the Gowganda Formation and overlying, quartzite formations. In studying the contact between the Dunlop and the underlying groups, he found contradictory evidence. At Quirke Lake, he found the underlying Quirke Group to be about 1800 feet thick, but, near Elliot Lake, it was only 125 feet thick. Nearly 1700 feet of slate present at Quirke Lake, including the Serpent quartzite and all but the basal sections of the Espanola Formation, are missing at Elliot Lake. Collins (1925) contended that this was because of erosion prior to the deposition of the Cobalt Series. Between Quirke and Elliot Lakes, Roscoe found that, in several places, the contact between the Serpent Formation and the Gowganda Formation was gradational. This suggest an interfingering relationship rather than an unconformity, and this, he states, is incompatible with the concept of the regional, erosional break between the Bruce Group and the Cobalt Group. He concludes that uplift and erosion may have occurred locally, but also notes that the sections missing at Elliot Lake may never have been deposited.

Lavas have not been reported in the Cobalt Group except in Leonard Township, Ontario, where a rhyolite is described as part of the Gowganda Formation (1957, Stockwell).

Collins (1915) has correlated the Lorrain Formation in the north shore area with the Lorrain quartzite of the Cobalt region. In the Bruce Mines area, he found that the topmost member of the Gowganda Formation passed conformably up into the Lorrain. Near Rock Lake, north of Bruce Mines, he found about thirty feet of red quartzite at the contact between the Gowganda greywacke and the Lorrain quartzite. However, in the Onaping map-area, Collins (1917) noted a local disconformity between the Gowganda and the Lorrain. Collins (1925), in the Bruce Mines area, found the Lorrain to consist of about 200 feet of impure quartzite at the base, followed by red to white, feldspathic quartzite which became whiter and less feldspathic towards the top. Near the middle of the formation, he found numerous beds of a red jasper conglomerate from one foot to five feet thick. He found massive beds from two to eight feet thick. In the Bruce Mines district, Collins found several hundred feet of a thin-bedded, cherty quartzite above the Lorrain. Near Ottertail Lake in the Bruce Mines area, he reported a thickness of 700 feet for this banded, cherty quartzite. In the northwest corner of Plummer Township, Bruce Mines area, the banded, cherty quartzite gives way to a thick-bedded, white quartzite similar to the Lorrain. Logan and Murray (1863) estimated this to range up to 1500 feet in thickness.

In the Cobalt area, R. Thomson (1957) found the Lorrain to be considerably different than that described by Collins in the north shore area. He found, in the Cobalt area, a formation of quartzite and arkose varying from white to sea green, and showing cross-bedding. The maximum, proven thickness of the Lorrain in the Cobalt area is 1050 feet in Henwood Township.

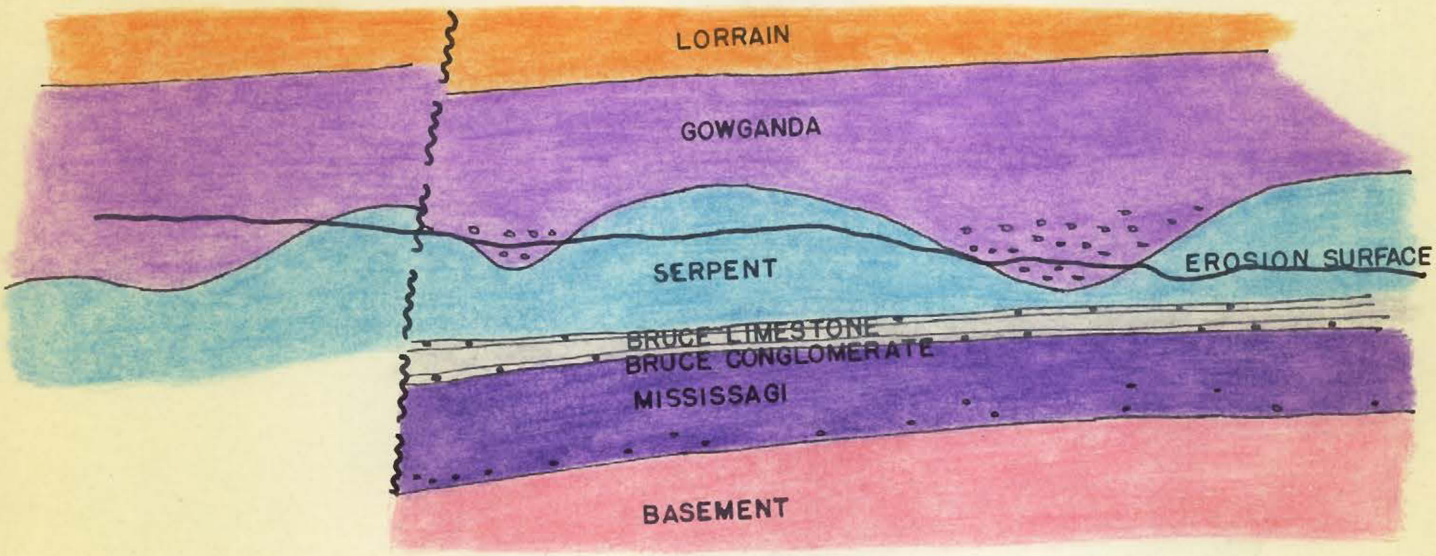
The term Cobalt Group is used in this report to define the sediments formerly classified as the Cobalt Series. Where the term Cobalt Series is used, it is used in reference to previous work.

(a) Gowganda Formation

In the Sault Ste. Marie area, the Gowganda conglomerate was observed to be overlying the Serpent in several places. Wherever the contact relations were observed, a slight, angular disconformity was identifiable. The lower section of the Gowganda consists of a polymictic conglomerate showing little or no sorting and no bedding structure. West of Echo Lake, about 100 feet of conglomerate occurs with no indication of bedding planes. Here, the conglomerate, with gentle dips towards the southwest, appears to be lying upon an eroded, Serpent quartzite which shows a relief of possibly as much as 500 feet (Figure 17). The contacts are very sharp with the Upper Serpent quartzite being cut off abruptly against the Gowganda. In a few places west of Echo Lake, the bedding in the Serpent was actually seen to be truncated by the overlying conglomerate.

The pebbles in the basal beds range from ten to twelve inches in diameter down to sand size; they are cemented by a greywacke matrix. Quartzite pebbles of the underlying Huronian formations are common, but red granite pebbles are by far the most abundant. In the Echo Lake area, it is difficult to estimate the thickness of the lower conglomerate; it is quite variable in thickness as related to the relief of the underlying Serpent. The average thickness, here, is estimated to be 200 feet, but, locally, it may attain

Figure 17



CROSS SECTION· GOWGANDA FORMATION SERPENT FORMATION

CONTACT WEST OF ECHO LAKE

a thickness of 800 feet. In Van Koughnet Township, the basal Gowganda shows minor stratification, and, in places, the conglomerate is interbedded with arkose layers. In the western part of Section 26, Van Koughnet Township, there is conglomeratic material which may actually be Aweres rather than Cobalt. Its relation to the overlying argillite has led the writer to include it as basal Gowganda conglomerate.

Most of the Gowganda Formation, in the Sault Ste. Marie area, consists of a thin, slaty greywacke or argillite material with few pebbles. Locally, the pebble content may increase to as much as twenty per cent, but the argillite still shows the laminated structure. In places, shearing has produced a pencil structure in the argillite. This is especially so in the escarpment north of Echo Bay.

The argillite can be traced from the east end of Wigwas Lake southward to the escarpment north of highway 17. Here, a thickness of 3800 feet of argillite was measured; this has more than likely been increased by faulting. Further west, the width, from Wigwas Lake to the edge of the escarpment, was measured at about 2200 feet. This seems to be more reasonable for the thickness, but here again the beds have been disrupted by faulting. In the north, in Deroche

Township, the thickness of the argillite is difficult to obtain because the lower contact is against a major fault zone, and the upper contact is obscured by drift. A thickness of 2700 feet was measured from Northland south to the Bellevue Ridge.

Upper Gowganda quartzite was detected in only two locations along the escarpment north of Echo Bay. Here, about fifty feet of finely-laminated, red quartzite was detected. This is essentially free of the pebbles that are so characteristic of the laminated argillite. In the Rankin Location, north of Crystal Creek, the Upper Gowganda occurs as a thinly-laminated, red quartzite. Here, about seventy feet of red quartzite was measured.

(b) Lorrain Formation

The contact between the Gowganda Formation and the Lorrain Formation is masked everywhere by overburden. Collins (1925) reports that the topmost member of the Gowganda Formation passes unconformably up into the Lorrain at all observed points.

Around the Echo Bay area, a considerable thickness of Lorrain quartzite was detected. South of Bar Creek, just at the east edge of the map-area, the Lorrain appears as an impure, reddish quartzite.

From descriptions of the basal Lorrain, and by tracing this unit into the Echo Lake map-area, this is taken to be basal Lorrain. These basal Lorrain beds are strikingly similar to the Palaeozoic sandstones near Sault Ste. Marie. A thickness of about 200 feet of the reddish quartzite was measured. Above this, the quartzite appears as the characteristic white quartzite of the Lorrain showing local, jasper pebble layers. A thickness of 4100 feet of quartzite was measured, but this may have been increased through faulting. About 2000 feet from the base, jasper pebble layers are abundant.

Frarey (1959) reports, in the Echo Lake area, that the lowest member is a zone of siltstone and greywacke several hundred feet thick. He recorded a thickness, north of Echo Lake, of 5000 feet. The top of the section was not observed in the Echo Lake area. Near the southern edge of Section 26, Van Koughnet Township, basal beds of Lorrain are found to be resting upon the Gowganda, but faulting and brecciation are so intense as to make contact relations unintelligible. This section had previously been recorded by McConnell as Palaeozoic. It appears that the upper quartzite of the Gowganda grades into impure beds of the Lower Lorrain. An incomplete section of the Upper Lorrain can be seen on the Bellevue Ridge.

Bain (1924) describes the area of Huronian sediments in Deroche Township as an alluvial fan. He contended that the source for these sediments was a mountainous area to the south, and not the older Precambrian to the north as is usually thought. He concluded that this area was on the edge of a sinking geosyncline. He found the Huronian sediments folded into a tight, overturned syncline plunging west along an axis which strikes N75°W. Here, he recorded a thickness of 2560 feet for the Lorrain Formation. North of the Bellevue Ridge, he recorded a thickness of 0 to 620 feet of Gowganda conglomerate, and 680 feet of Gowganda greywacke.

In the Algoma Central railway quarry, he recorded a thin bed of siliceous limestone associated with an upper, sericitic, cherty material (Plate XXXV1). This, he infers, is formed from mud galls which have been reorganized; the presence of mud galls indicates oscillating wind action and marine conditions.

PALAEOZOIC

Sandstones, suspected of being of Cambrian age, are found in scattered outcrops in the flatlands around the St. Mary's River and Goulais Bay areas.

Plate XXXV1: Massive quartzite with thin sericitic cherty bands. Upper part of Lorrain Formation. Algoma Central Railway quarry.

McConnell (1926) classified the sandstone as Cambrian and named it the Lake Superior sandstone. According to Lane and Seaman (1907), the term Lake Superior sandstone was first used by Houghton; the term Sault Ste. Marie sandstone was used much later, and is used less. In Michigan, Lane and Seaman recorded the following section:

Table No. 11 Palaeozoic Section

SERIES		FORMATION	
NEOCAMBRIAN SARATOGAN (Potsdam)	LAKE SUPERIOR	Jacobsville - Redstone	0-1500' sandstone, red and brown and striped with streaks of red clay shale. Conglomerate where over older formations.
		---- Hiatus ----	
		Freda	900' red sandstone with some felsitic and basic debris and salt water.

In the upper quartzite layer, Lane and Seaman report ripple marking and the presence of Fucoides (?) duplex, Lingulepis prima, and Lingulepis antiqua. Dikelocephalus misa, Dikelocephalus (Hall), and Lingulepis prima formis occur at Iron Mountain, Michigan.

At Marquette, Michigan, Murray reports Pleurotomaria laurentina (?). The upper part of this sandstone has been estimated, by Houghton, to be 100 feet thick.

DuBois (1959) has attempted a correlation of Keweenawan rocks of the Lake Superior region by palaeo-magnetic methods. He notes that Hamblin (1958) has found, in the basal conglomerate of the Jacobsville Formation, pebbles of a sandstone which closely resembles the Freda sandstone (Upper Keweenawan), and he has suggested that near Sault Ste. Marie there is an unconformity between the Jacobsville and a sandstone very similar to the Freda sandstone. He notes that the Jacobsville is overlain unconformably by Upper Cambrian sandstone. The studies show the Freda sandstone and the Nonesuch shales of the western Lake Superior region to be of Upper Keweenawan age. He found the Jacobsville from the Sault Ste. Marie area to agree with the Upper Keweenawan sediments, but the sediments of the same formation from the Keweenawan Peninsula appear to be somewhat younger. Therefore, he suggests that there is a possibility that either the Jacobsville represents a considerable length of time or there is a time break within the formation. In general, DuBois notes that both of the pole positions for the Jacobsville are sufficiently similar to the Upper Keweenawan pole positions to suggest that the Jacobsville belongs to the Upper Keweenawan rather than to the Cambrian.

In the Sault Ste. Marie area, outcroppings of the sandstone are so sparse as to make useless any attempts at producing a section. The beds are generally four to five feet thick, and show cross-bedding and ripple marking; they are generally flat lying. The lower beds appear to be more red in colour. McConnell (1926) recorded that drill holes had penetrated the sandstone to depths up to 710 feet. The basal conglomerate beds were not found outcropping in the Sault Ste. Marie area. Frarey (1961), in the Echo Lake area, reports a poorly-cemented basal conglomerate near Bar River. McConnell (1926) reported a basal conglomerate in Horseshoe Bay, north of Sault Ste. Marie.

CHAPTER V

STRUCTURE

STRUCTURE

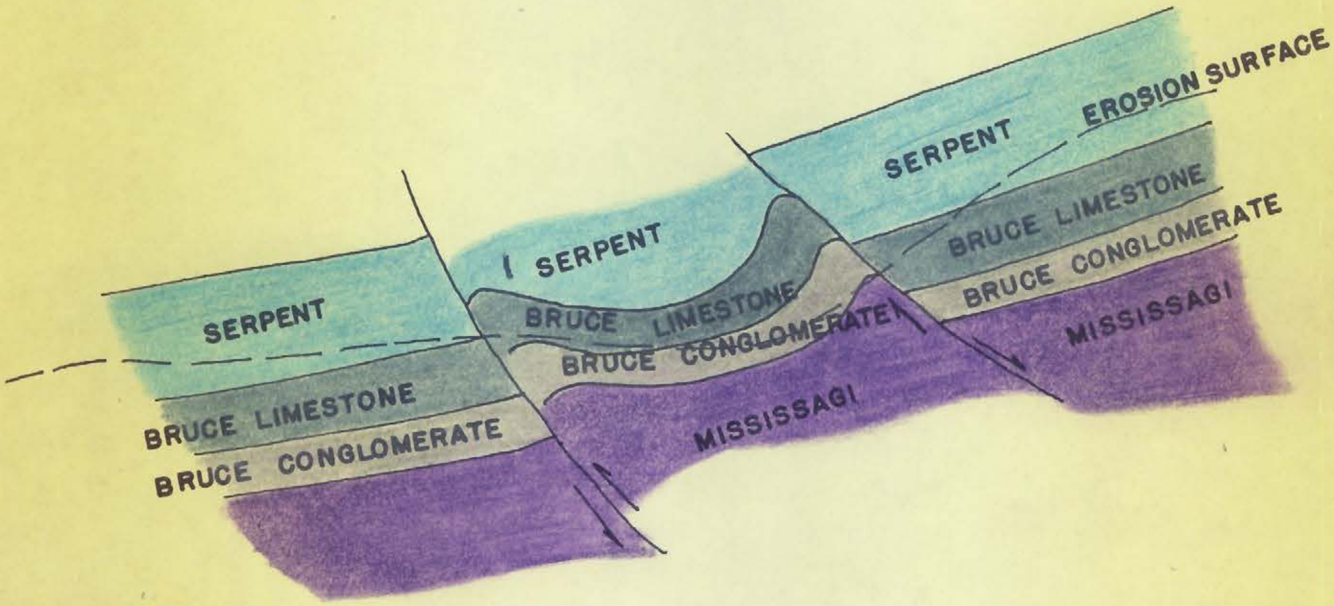
In the Sault Ste. Marie area, the main units consist of a moderately deformed series of sedimentary and volcanic rocks, called the Huronian and classified as Proterozoic, overlying a basement of highly deformed rocks. The basement rocks are now highly metamorphosed to schist and gneiss, and have been folded intensely so that now they stand at steep dips. The Huronian rocks are themselves overlain unconformably by unmetamorphosed, flat-lying sandstones of supposed Cambrian age. Post-Huronian, igneous activity is shown by the numerous dykes cutting the Huronian rocks, and the presence of extrusive material in the Gros Cap area which contains fragments of quartzite of apparent Huronian age. The basement rocks generally strike between north and northwest, and show steep dips towards the northeast generally, although in a few, small localities, especially in the northwest part of Pennefather Township, the dips are towards the west. Along highway 17 north, in Tarentorus Township, it appears that, possibly, an anticlinal axis has been crossed. In the area of Mabel and Surrette Lakes, the dips are generally in the order of 45^{o} to 75^{o} towards the northeast, but on the west side of highway 17, dips towards the west appear more regularly. It appears that an anticlinal axis may follow approximately the direction of highway 17 north from Odena. In general, fold-like structures in the basement are lacking. The major hornblende schists in Duncan and Anderson Townships show pillows with dips towards the east. This would indicate an anticlinal axis towards the west. Actually, several anticlinal and synclinal belts may occur within the schist belt since it has been isoclinally folded.

In the area southeast of the Garden River, the Huronian rocks are homoclinal, consistently dipping southwest at various, moderate angles. Folding in this section is local, and, in many places, appears to be related to thrust faulting. North of Boss and Wigwas Lakes, the Bruce limestone and Bruce conglomerate are overturned in an anticline which plunges steeply towards the west. Here, in about one-half mile of width, the Bruce limestone and Bruce conglomerate have been folded steeply between two thrust faults. West of Trotter Lake, a small, anticlinal flexure has brought the Bruce limestone and the overlying, polymictic conglomerate through the overlying Serpent. The dip angles, in this case, are quite low. West of Echo Lake, where the Bruce limestone and Mississagi quartzite have been thrust up through the overlying Serpent, the rock shows a slight synclinal structure (Figure 18). Here, it appears that a wedge of Lower Huronian sediments has been thrust relatively upwards through the overlying Serpent. Schistosity along the border zones indicates the dips to be in the order of 45° to 60°. Dragging in the limestone beds, along the fault zone, is evident in a few places. Collins (1925) reported that, in the Bruce Mines, Blind River, and Panache Lake areas, folding was noted to increase in intensity from north to south.

In general, in the south section, any folding which does occur shows an axial plane striking only a few degrees north or south of an east-west direction, and shows gentle plunges.

Along the Bellevue Ridge, the rocks are folded into a synclinal structure, the south limb of which has been sheared off as a result of thrust faulting of the Huronian rocks over the granite rocks. To the north, the north limb has been disrupted, near Mabel Lake, by thrust faulting. The axis of the syncline strikes N 75° to 80° W. In the west section of the ridge, north of Bellevue Station, some of the south limb still remains, although it has been disrupted

FIGURE 18



BRUCE LIMESTONE & UNDERLYING FORMATIONS THRUST UP THROUGH SERPENT FORMATION

FAULTING PROBABLY INCLUDES BASEMENT ROCKS by faulting. It indicates a plunge of about 8° to 10° towards the west. The plunge angle of the fold is actually difficult to determine because many of the dips, especially those north of Bellevue Station, have been altered through faulting. Near Northland Lake, thrust faulting has removed much of the north limb so that, here, only a thin section of the Gowganda now remains. The fault block of Huronian sediments constituting the Bellevue Ridge, and including from Van Koughnet Township eastward to Northland Lake, has been thrust relatively southward, and is separated on the east and west ends by vertical, strike-slip faults at angles of about 45° to the main thrust movement. In the vicinity of Maple Lake, local folding is quite prominent in the Gowganda argillite. One small syncline with the south limb disrupted by faulting shows a plunge of 18° along a line striking N63°W.

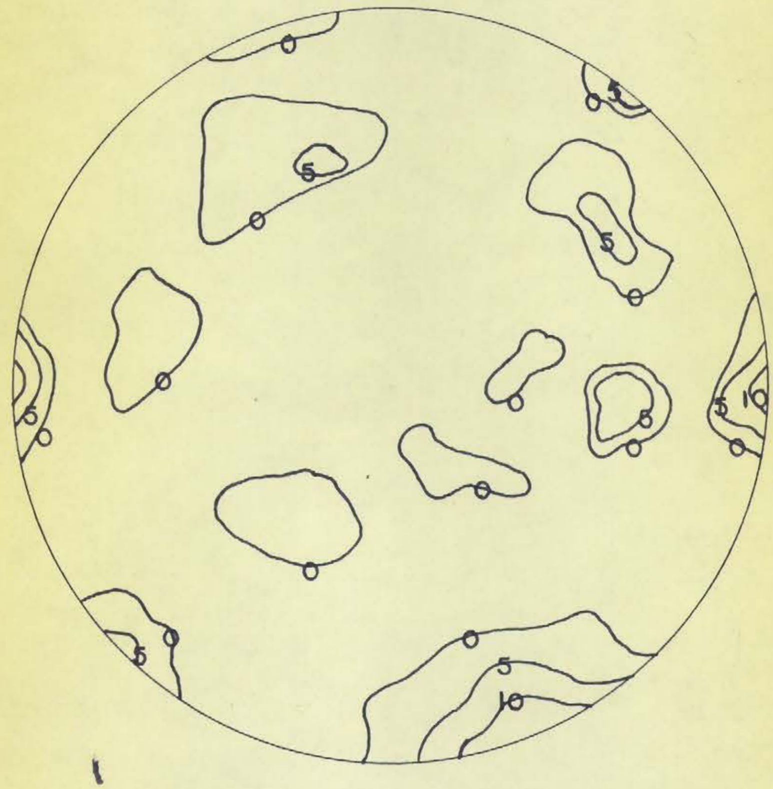
South of Dead Horse Lake, the Mississagi has been pushed relatively up through the overlying Duncan greenstone by two faults about 2500 feet apart. Here, the Mississagi has been folded into a series of tight anticlines and synclines. Drag movement along the west fault indicates downward movement of the central block. Broad anticlines and synclines are characteristic of the structure of the Huronian section, previously described as the Soo Series by McConnell and found in Duncan and Aweres Townships. Locally, folding has been so intense that the beds are standing at steep angles. A section from Maud Lake to Surrette Lake shows a small anticline, a syncline, and then another anticline (Figure 13). The folding towards the west has been disrupted by a major, north-west-trending fault. In the anticline to the west, the dips on the limbs are less than 5° in places. The plunges in these folds appear to be almost flat, but local fluctuations have resulted in domes and basins. From Maud Lake towards Ann Lake, a small cross fold has resulted in a section of the Mississagi quartzite projecting into the belt of greenstone. Most of this is due apparently to the change in plunge along the fold axis. Towards the north, the folding becomes slightly stronger. In the north, the anticline on the east has been removed by faulting.

JOINTING

Most of the Huronian quartzites in the Sault Ste. Marie area show very prominent jointing, especially where they are close to fault zones. The quartzite of the Bellevue Ridge shows prominent jointing, and this appears to increase closer to the fault contacts. During the three field seasons, joints were measured at 475 locations. Figure 19 is a contoured, polar plot of these joints. There are three major sets of vertical joints: a north - south set, a north - north - west set, and a north - east set. Also, there appears to be several sets of joints dipping about 70°. The north - north - west set varies between 60° and 90° as does the north - east set. Movements on the former set are dominantly right-hand, while on the latter set they are dominantly left-hand. Such displacements are consistent with a general, north-south compressive force. In Townships 137 and 138 in the Blind River area, Robertson found five major sets of joints, and concluded that they were formed from north-south compressive forces. He found that the obtuse angle between the two sets faced north-south. The minor sets, he concludes, represent tension and release joints.

The diabase dykes were plotted. It was found that the majority of them follow a general northwest direction, with steep dips. This is consistent with dyke sets of Robertson. Robertson found a relationship between dyke orientation, and the axial plane of folds; he found that dykes on the north limb dipped

FIGURE 19



CONTOURED POLAR PLOT OF JOINTS

SAULT STE MARIE MAP-AREA

steeply north while those on the south limb dipped steeply south for a syncline.

FAULTS

Faults are numerous throughout the Sault Ste. Marie area; some begin and end within the area, while others pass completely through the area. The lineaments on air photographs were investigated in the field, and faults or shear zones marked where shearing, shattering, brecciation, or displacement were noted.

Two major types of faults were found: (1) thrust faults or reverse faults, and (2) steeply dipping faults. Several of the faults appear as broad, straight valleys which are traceable for many miles and which show major rock changes across the fault, but with no evidence of shearing. For much of its length, in the Sault Ste. Marie map-area, the Garden River fault appears to follow one of these valleys.

The steeply dipping faults strike either north-west or northeast. The major thrust faults have strikes that trend more closely to an east-west direction.

Thrust Faults And Reverse Faults

The Goulais River appears, essentially, to parallel a zone of thrust fault movement where the Huronian rocks have been thrust over the granite, to the south, and the basement schists have been thrust over the Gowganda argillite, to the north. The movement is represented by a series of parallel thrust movements (Figure 4).

The dip angles on the thrust are difficult to obtain, but the fracture cleavage and schistosity developed in the Gowganda, north of the Bellevue Ridge, would indicate angles of about 60° to the north. The thrust fault on the south side of the Bellevue Ridge shows a dip angle of about 45° towards the north. Thrusting along the south side of the Bellevue Ridge has removed the south limb of the syncline which forms the Bellevue Ridge. This thrust fault is terminated at its east end by a steeply dipping fault which is parallel to the long direction of Northland Lake. The brecciation at the junction of the two faults has produced an ideal location for mineral deposition.

In the southeast corner of the map-area, local thrust faulting has, in places, moved the Bruce Group rocks over the Cobalt Group rocks. North of Wigwas and Boss Lakes, the Bruce limestone has been thrust southward over the Gowganda argillite. This has caused intense folding within the Bruce limestone.

Steeply Dipping Faults

Steeply dipping faults which strike northwest and northeast are characteristic of the Sault Ste. Marie map-area. In places, the northeast set is cut by the northwest set, but in other localities the exact opposite is the case. Some of these faults tend towards a more northerly strike.

The Garden River fault appears to be one of these steeply dipping faults. Its movement has not been determined, but it apparently has both strike slip and dip slip components. Other steeply dipping faults identified include the fault through Mabel and Surrette Lakes, and several in the basement schist belt north of the Garden River.

CHAPTER V1

ECONOMIC GEOLOGY

ECONOMIC GEOLOGY

The Sault Ste. Marie district has been, from the early days of the Canadian mining industry, very active as a mineral prospecting area. Of the hundreds of mineral showings reported from the area covered by the Sault Ste. Marie map-sheet, only one has proven to be of definite economic imortance, although several others have been investigated fairly intensively. Prospecting has revealed showings of copper, lead, zinc, molybdenum, cobalt, nickel, asbestos, gold, silver, iron, uranium, and thorium. Giving an indication of the extent to which mineralization has taken place is the fact that, altogether, over fifty mineral showings have been reported from the area within three miles of Reserve Lake. Shear zones and brecciated zones are the hosts for most of the showings, but several have been reported to be associated with the massive, gabbroic intrusives in the Huronian rocks. Mining operations have exploited several of these showings, but at the present time no active mine is located within the limits of the Sault Ste. Marie map-area. Mines which have operated in the area include the Jardun Mines, Jarvis Lake Lead Mines, the Breitung Mine, the Williams Mine, and the San Antonio Mine. The larger deposits will be described in some detail; showings of possible economic importance are plotted on Figure 4.

LEAD ZINC DEPOSITS

Small showings of galena and sphalerite, generally connected with narrow shear zones, are characteristic of the area around the Jardun Mines. Some of them have been sampled, but in general they have remained untouched because of their evident small size. Near the east end of Maple Lake, Deroche Township, the Kirby - Legge deposit shows mineralization which is localized by shearing developed by thrust faulting. The deposit is mainly galena but does contain some sphalerite. A similar deposit, in the parts of Lots 4 and 5 north of the Searchmont highway, Concession 4, Deroche Township, was being investigated by diamond drilling in the summer of 1961.

Jardun Mines

The property of Jardun Mines, which is located in parts of Jarvis and Duncan Townships and is situated immediately south of Weashkog Lake, was discovered sometime around 1870. The present mining claims cover an area of approximately 3300 acres, most of which is covered by dense bush and inaccessible by road.

In 1875, the Victoria Consolidated Silver Company commenced operations on the Victoria lode, and subsequently opened the Victoria No. 1 vein to a depth of 410 feet with two shafts and eight levels, and the Cascade vein to a depth of 230 feet (Plate XXXVll). R. Bell visited the mine area in 1876 and found two veins being worked at that time, one of which was solid galena which widened from three inches across at the surface to nineteen inches across at the bottom of a fifteen-foot shaft. A sample of galena, collected by Bell, from the ore pile reportedly contained 168 ounces of silver per ton of galena. Production from these two shafts, known as the Victoria Mine and the Cascade Mine, was intermittent between 1878 and 1917, and at no time was it very substantial. Piles of concentrates, accidentally spilled during transportation, can still be found along the old road, between the mines and Garden River. Operations ceased in 1917, and little or nothing was done with the property until 1951 when it was acquired by Jardun Mines Limited, a company composed largely of United States' business men and doctors.

Three years of exploration work resulted in the blocking out of 330,000 tons of ore in three zones. Two new shafts, one in a major shear zone

Plate XXXVll: Headframe above original workings of the Victoria No. 1 vein, Jardun Mines.

south of Weashkog Lake and the second southeast of the old Victoria Mine (Plate XXXV111), and a new 250 ton mill were put into operation (Plates XXX1X, XL, and XL1). Production from the new shafts began early in 1954. By the end of 1955, 75,000 tons of ore, containing 4.95% Pb, 4.08% Zn, 1.62 oz/ton Ag, some copper, and minor gold and cadmium, had been produced. The recession in 1957, accompanied by a fall in metal prices and overproduction, caused the closing of the mines at that time.

Rumours, prevalent in the area, suggest that high-grading of the ore has left the remainder of the deposit of much too lean a yield for any possible reworking. It does not appear that in these three years of operation the Jardun Mines succeeded in realizing a profit. The total production seems inadequate to compensate for the three million dollars spent in the development of the two shafts and the building of the mill and other plant facilities. In the summer of 1960 all the plant equipment was removed and most of the buildings were demolished. The north shaft was capped at this time. At no time during field mapping were the shafts accessible as both had become filled with water (Plate XL11). All data relating to the mines was attained through

Plate XXXV111: Main shaft of Jardun Mines. Sunk near the location of the original Victoria shaft.

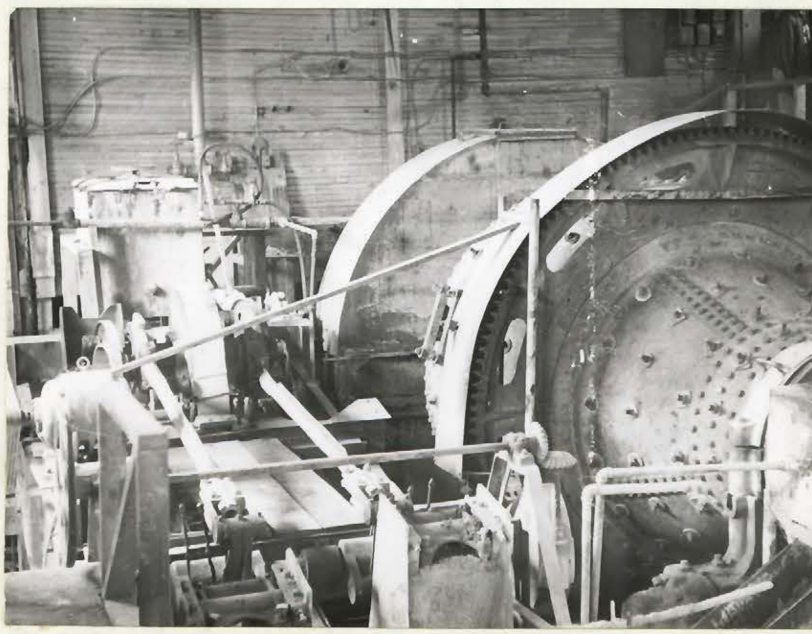


Plate XXX1X: Interior of mill, Jardun Mines, showing ball mill and classifier.

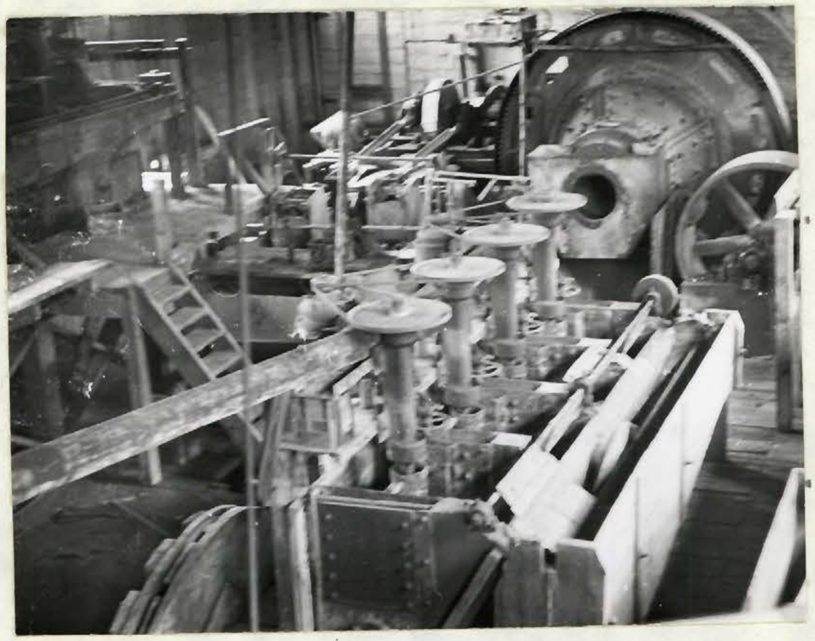


Plate XL: Interior of mill, Jardun Mines, showing flotation cell bank.

Plate XLl: Tailings behind Jardun Mines mill. Reportedly contains recoverable amounts of gold.

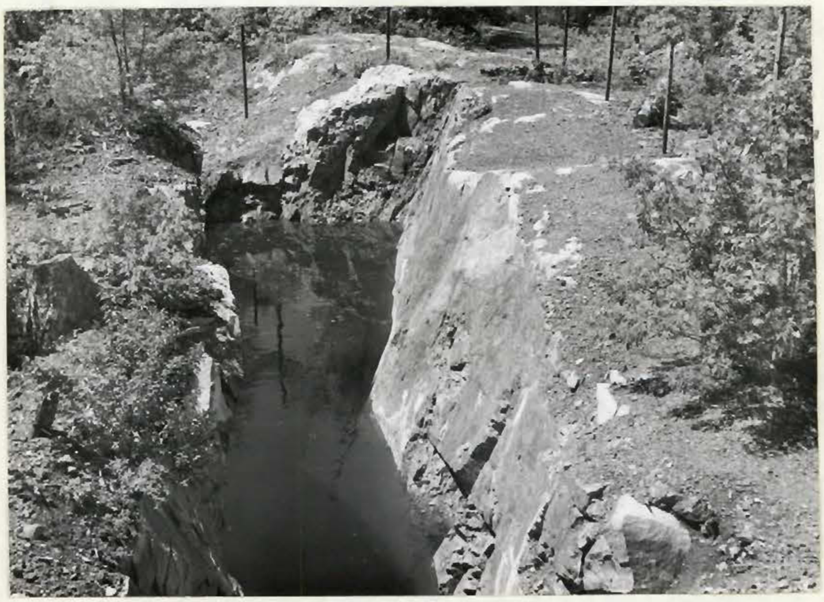


Plate XL11: Stope of Jardun Mines north shaft, Weashkog Lake, where it has broken through to surface.

surface investigation. Burns (1956) has mapped the mine area in some detail, and his map was checked in the field by the writer.

The Jardun deposits are small, complex, sulphide deposits of both replacement and fissure filling origin. The mines are located along a major fracture in a granitic batholith and are associated with large inclusions of amphibolite (Plates XL111 and XL1V). The largest of these inclusions lies just north of Sand Lake and is approximately 150 feet wide and 1000 feet long. It trends a few degrees east of north. The inclusions are composed mainly of actinolite and hornblende, some of which appears to be a secondary alteration of a pyroxene. This alteration gives the rock a felty appearance. The alteration is so intense as to make identification of the pyroxene difficult. Burns (1956) suggests that it may be pigeonite. The small optic angle indicates that the pyroxene is most likely of the pigeonite variety. Pyroxene grains in which the cores have been altered to chlorite are numerous. The bright blue, interference colour indicates that this chlorite is of the penninite variety. Most of the chlorite, though, appears to be an alteration product of biotite. In places, the biotite has a

Plate XLlll: Shear zone cutting amphibolite inclusion and showing brecciation of the amphibolite. Light coloured material is of a granitic composition.

Plate XLlV: Main shear zone Jardun Mines. Photograph taken 100 feet west of north shaft.

patchy, green -brown pleochroism indicating conversion to chlorite. Microcline and plagioclase (An 17 - 29) comprise up to forty per cent of the rock, the microcline content being considerably higher near the borders of the inclusions indicating the introduction of potash.

In areas where the inclusions are quite numerous, the granite has a higher mafic content, and this content increases considerably as the borders of the inclusions are approached. This would indicate a partial assimilation of the inclusions, or possibly a complete assimilation of some smaller inclusions during the intrusion of the granite.

No inclusions of Huronian rocks, or indications that fragments of the Huronian have become incorporated in the granite mass, were found. Inclusions of granite gneiss are quite characteristic, although they are not normally associated with the ore deposits. The amphibolite inclusions appear to be remnants of the hornblende schist series which is found about three miles to the east.

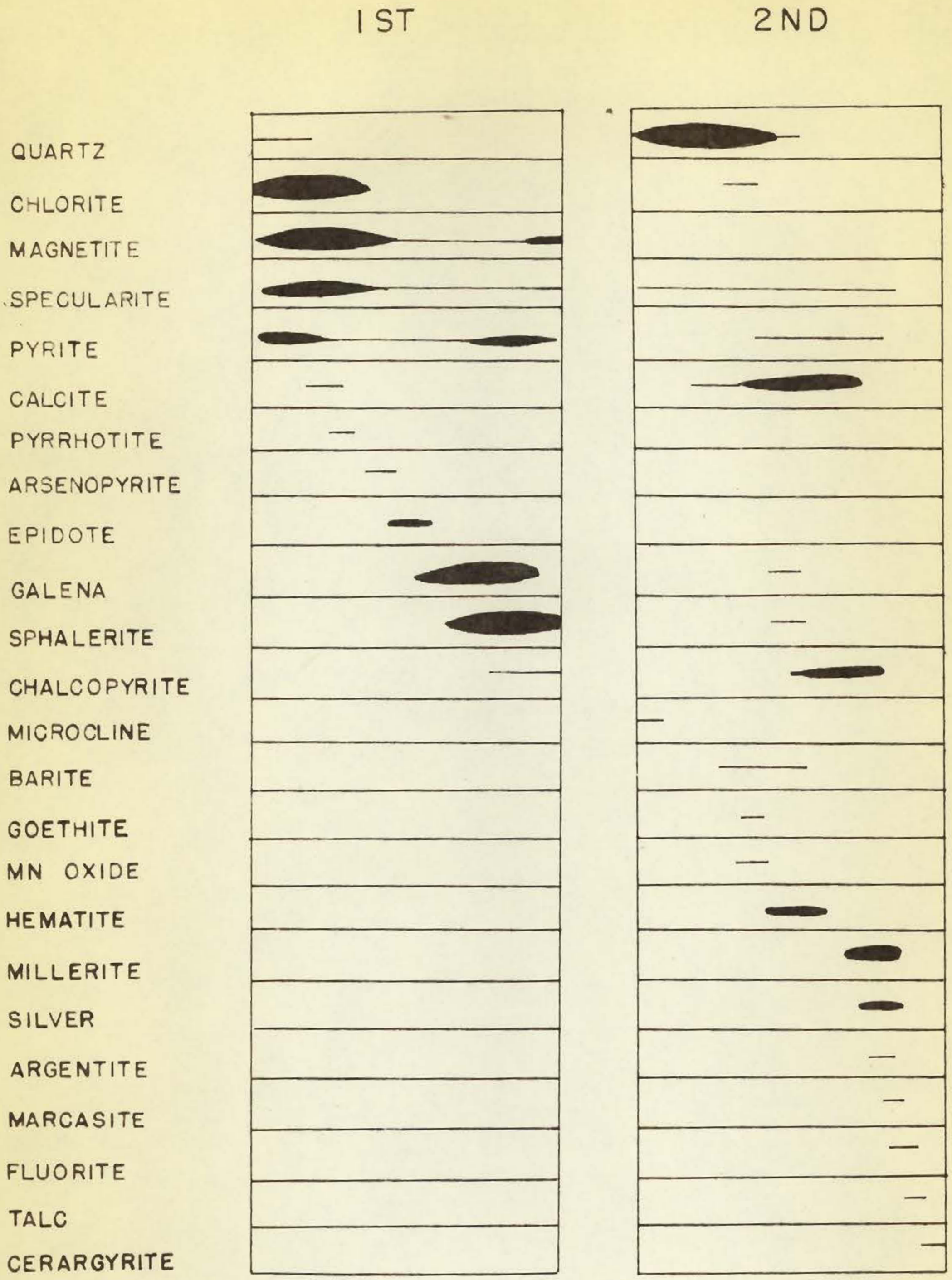
Quartz diabase dykes, sills, and small stocks are numerous in the granite mass. The strikes seldom vary more than a few degrees from northwest, and the dips are steep towards the northeast. They are composed largely of labradorite which is now somewhat altered to epidote, and pigeonite (?), which is now highly altered to biotite, chlorite, and magnetite. Quartz-free diabase dykes are also quite common, but they show north - south strikes and vertical dips. Laths of sodic labradorite, two to four millimeters in length, are numerous. Burns (1956) has found that these have cores of carbonate and rims of penninite. Many of these quartz-free diabase dykes have a porphyritic texture. They are seldom more than three feet wide.

The granite is cut by numerous faults, the most prominent of which strikes N15°W and dips 70° to the west. It is along this fault that many of the ore bodies have been localized, especially where the brecciation has been intense near rock contacts. According to Burns, the movement on the fault is normal and possibly recurrent as evidenced by the large amount of fracturing in the ore zones themselves. A smaller, parallel fault is located one quarter of a mile east of the main fracture. Number one and number two veins are located on the main fracture; number four vein is located where the major fracture is displaced by a cross fault. This cross fault strikes N65°W and dips 43° to the south. Burns measured a net displacement of two hundred feet on this fault, with the south side having moved down and slightly to the west. Near Weashkog Lake, the cross fault horsetails into a more northerly-striking fault.

(a) Ore Deposits

The ore deposits of the Jardun Mines are marked by three periods of mineralization, the first period of mineralization being after emplacement of the quartz diabase and prior to emplacement of the quartz-free diabase. Wall rock alteration was intense in this phase and was accompanied by the deposition of galena, sphalerite, pyrite, pyrrhotite, chalcopyrite, arsenopyrite, epidote, quartz, and calcite. Continued fault movement brecciated this earlier-deposited, lead zinc ore, and, in places, produced open fissures. The quartz-free diabase dykes apparently preceded this fault movement for they are offset, in places, by the movement. The second period of mineralization was mainly of the fracture-filling type. Quartz, calcite, vuggy carbonates, barite, chlorite, microcline, chalcopyrite, pyrite, specularite, botryoidal hematite, goethite, and manganese oxides were deposited at this time. Burns also reports marcasite, millerite, native silver, argentite, cerargyrite, fluorite, and talc, but none of these was detected in the present investigation. Fragments of wall rock, completely enclosed by vein material, are common in these veins. The third period of mineralization was of a minor nature. Small quantities of bornite and covellite were deposited at this time. Burns also reports chalcocite and suggests that this period of mineralization represents supergene enrichment. This mineralization was detected to a maximum depth of one hundred feet (Burns, 1956). Figure 20 represents the age relationships between the various minerals in the deposit (after Burns). During the current investigation a similar sequence was detected, although as stated previously some of the minor constituents were not observed.

Epidotization and silicification of the country rock, to a width approximately equal to the width of the central sulphide-bearing sections of the individual veins, is indicated. This alteration generally appears as a greyish yellow or pale green bleached zone in the surrounding granite. Carbonatization and sericitization are of a local nature. The boundaries between the ore zones and the surrounding granite are normally quite sharp. In the number



Mineralization Sequence in the Ore of Jardun Mines
(After Burns)

Figure 20

four zone, where stoping has broken through to the surface, the contact zone is less than one-half inch thick. The ore appears to be contained entirely within the shear zones. In the number one zone, Burns found several, peculiar " jasper dykes " which contained quartz, sericite, and partially altered feldspar in a groundmass of chalcedonic quartz. These, he believes have formed through the silicification of fault gouge.

According to Burns, the ore deposits were introduced, possibly, in middle or early Keweenawan time. He found them to be younger than the quartz diabase and older than the quartz-free diabase. Wilson (1955) records an age of 1.3 billion plus or minus 200 million years for galena from a similar deposit in Township 169, fifty miles to the east. This age was determined by lead 208/204 and 206/204 methods.

<u>Jarvis Lake Lead Mines</u>

The deposits of the Jarvis Lake Lead Mines lie along the northwestern shore of Jarvis Lake, in Concession 6, Lot 7, Jarvis Township. The history of the development of the deposits appears to be unrecorded.

The workings occur as a series of small pits, the maximum size of which is about ten feet by eight feet by six feet, spread over a distance of about one-half mile. A small furnace to treat the ore was constructed about one-half mile north of the lake. The total production was probably in the order of 500 to 2000 tons of ore.

Localization of the mineralization is controlled by a northerly-striking shear zone which dips steeply to the east, and which may possibly be the same shear zone that passes through the Jardun Mines area. Mineralization of replacement and fracture-filling types occurs in sheared and brecciated basic inclusions. In the surrounding granite, the deposition is of little consequence, and consists of a few small fracture fillings where shearing has left open fissures.

The ore consists almost entirely of galena, but also contains minor sphalerite, chalcopyrite, pyrrhotite, pyrite, and arsenopyrite. Quartz and calcite are abundant in the ore zones and apparently have been introduced at a time contemporaneous with the metallic mineralization. The deposition appears to have occurred in one phase, and shows a sequence: pyrite, pyrrhotite, arsenopyrite, galena, sphalerite, and chalcopyrite. The maximum width of the ore zone is two feet, but generally the width is about three to four inches. In places, this narrow ore zone is composed of solid galena.

Boss Lake Prospect

South of Boss Lake, in the Garden River Indian Reserve, mineralization has occurred within the Bruce limestone where it has been faulted into a contact position with the Gowganda argillite. The shear zone along which the brecciation has occurred strikes N70°W and dips towards the north at an undetermined angle. The Bruce limestone appears to have been thrust over the Gowganda. Burns (1956) infers that this is the same fault zone that passes through Jardun Mines. This Boss Lake fault is actually related to the large thrust faults of the area whereas the Jardun fault is a vertical, strike-slip type. A few, small, prospect pits have been opened up along the fault zone.

Mineralization is of the galena - sphalerite type with minor pyrite. It appears to be mainly fracture fillings in the brecciated zones in the limestone, although locally the crystalline limestone has been replaced.

Lead Zinc Showings

Small showings of galena and sphalerite are characteristic of the area around Jardun Mines. Some of these have been sampled, but, in general, they have remained untouched because of their evident small size.

Near the east end of Maple Lake, Deroche Township, the Kirby-Legge deposit has been investigated. Here, mineralization is localized by shearing developed during thrust faulting. The deposit is mostly galena but does contain some sphalerite.

A similar deposit in Deroche Township, Concession 4, Lots 4 and 5, north of the Searchmont highway, was being investigated by diamond drilling in the summer of 1961.

IRON DEPOSITS

The presence of the Algoma Steel Corporation mills in the city of Sault Ste. Marie has resulted in a fairly intensive search for iron deposits in the surrounding district. Here, with the mills so near, even a small deposit of a sufficient grade could be exploited at a profit. The discovery of iron ranges such as the Helen, the Josephine-Bartlett, the Ruth, the Lucy, the Eleanor, and the Goulais River, in the district of Algoma, shows that prospecting has been profitable. The major iron ranges are generally related to cherty iron-formations of early Precambrian age. In the Sault Ste. Marie map-area, only two small mines, the Breitung and the Williams, have operated. These consist of specularite hematite replacement and fracture-filling deposits in brecciated Huronian rocks.

In 1960, a drilling program revealed zones of specularite hematite south of the Bellevue Ridge, Deroche Township.Although the exact location of these drill holes was not determined in field mapping, they apparently lie close to the main thrust fault south of the Bellevue Ridge. These deposits are probably similar to those of the Breitung Mine.

The Breitung Mine and the Williams Mine will be described in some detail.

Breitung Mine

The Breitung Mine, owned by the Breitung Iron Mining Company, Marquette, Michigan, is situated on Northland Lake (formerly Loon Lake) in Lot 4, Concession 1, Deroche Township, at the east end of the Bellevue Ridge. Mining operations began in 1899 and continued until 1921. The ore was transported to Northland by a spur of the Algoma Central railway. The mine workings consisted of an open pit about twenty feet by twenty feet by fifteen feet, and two small adits; in one of these adits the stoping has broken through into the open pit. At present, the upper adit is accessible; the entrance to the lower adit has completely collapsed. The main adit is about 80 feet above the lake, and the lower adit is about 75 feet above the lake. Brunton (1921) reports an overall grade of ten to fifteen per cent iron for the deposit, but he notes that interest was mainly in a few high-grade pockets which ran as high as forty to fifty per cent iron.

Bain (1923) has classified the rocks of the Breitung Mine area as Keewatin, and describes them as tuffs showing good, slaty cleavage. He describes volcanic bombs in the tuffs, and at the Breitung Mine he notes that these bombs have not been sheared or deformed to any marked degree. X ray diffraction studies of these slaty rocks show them to be composed of quartz, feldspar, chlorite, and illite, a combination characteristic of the Gowganda argillite. Northwest of the mine, in the unbrecciated area, several, red granite pebbles, two to four inches in diameter, were found in the slate. It seems fairly definite that these brecciated rocks of the Breitung Mine area are Gowganda argillite.

The Breitung Mine is located in an intensely brecciated zone of Cobalt argillite, and is bordered on the south by a large granitic batholith. The brecciation has occurred at the intersection of two major faults, an east-west thrust fault along the south side of the Bellevue Ridge and a steeply dipping, northwest-striking fault along the west shore of Northland Lake. Northland Lake actually appears to follow a fault zone, and shearing may occur over a considerable width. Shearing on the east shore of the lake suggests a fault along that shore. South of the mine, the granite batholith has been sheared in an east-west direction, but it does not show the intense brecciation which is so characteristic of the argillite. Brunton (1921) recognized the presence of this major fault south of the Bellevue Ridge.

Near the Breitung Mine, the Gowganda Formation has been faulted into position against the granite, but three quarters of a mile towards the west the Lorrain quartzite is in fault contact with the granite. In the Bellevue Ridge, the Cobalt Group rocks have been folded into a broad syncline which has been breached on its south limb by the thrust fault. In the Northland Lake area, the thrust fault has completely removed the south limb as well as the Lorrain quartzite of the north limb so that the Gowganda Formation is in contact with the granite.

The slates have been brecciated perpendicular to their east-west bedding. Bain (1923) notes that displacement along these zones is small. The breccia is composed of very coarse fragments, some being as large as one foot across, but most being in the order of one quarter of an inch to an inch in diameter. The cement in the breccia is mostly specularite hematite, but it is accompanied by some quartz. According to Bain, the breccia zones are due to local stresses set up by the intrusion of the diabase dyke along the axis of the fold after the movement had ceased. This dyke is located within the Lorrain quartzite and parallels the trend of the Bellevue Ridge. Current mapping shows this dyke to be disrupted about one mile west of the mine by the main, east-west thrust fault.

The fault zones appear to have acted as channelways along which the mineralizing solutions could pass. These solutions are probably related to the diabase, but they are of a post- diabase intrusion phase. The fractures within the diabase show specularite hematite deposition. From the west end of the Bellevue Ridge to Northland Lake, the fracture zones and joints within the Lorrain Formation show specularite hematite deposition, and, locally, the deposition of the hematite amounts to several tons. In the Sault Ste. Marie map-area, wherever these diabase dykes occur they contain fractures filled with specularite hematite. In MacDonald Township, south of Bar Creek, a small diabase dyke cuts the Lower Lorrain quartzite, and the quartzite shows numerous fractures which are filled with specularite hematite.

Bain (1925) has shown that the specularite hematite is associated with the granite mass to the south. He states, " Since the granite contains specularite as apparently an end product of its own consolidation it is believed to have given up much more in aqueous solutions and vapors. Granite in which specularite is most abundant contains no ferromagnesian minerals ans since the biotite has practically the same specific gravity as the feldspars it is highly improbable that the difference represented by its lack of the mineral can be due to differentiation. The difference is apparently due to resorption of the mica with the liberation of hematite dust. "

This of course requires that the granite batholith be of a post-Huronian age, but current mapping shows it to be of early Precambrian age.

(a) Ore Deposits

The main ore body of the Breitung Mine shows widespread fracture filling and replacement by specularite hematite. Some fragments of the argillite, especially the smaller fragments, have been almost completely replaced. The fragments in which mineralizing solutions have penetrated along the bedding planes appear like banded iron-formation. Quartz and calcite occur to a minor extent.

The specularite hematite is generally quite fine grained. Locally, it is somewhat botryoidal.

Williams Mine

The Williams Mine is located at the intersection of Anderson, Jarvis, Deroche, and Hodgins Townships. The showings were discovered in 1901; in 1903, a shaft was sunk 212 feet to the sump from the bottom of which a diamond drill hole was driven another 300 feet. The mine was worked from two levels: a one hundred foot level and a two hundred foot level. In the two years that the mine operated, 500 tons of ore was shipped on sleighs to Northland.

The mine is located at a point where the Gowganda conglomerate and argillite, the granite batholith, and the basement schists are in contact. The shearing is so intense along the contact between the granite and the Gowganda that brecciation of the Gowganda has resulted. Specularite hematite has been deposited in the brecciated argillite and conglomerate, and to a lesser extent in the basement schists.

The mineralization is quite similar to the mineralization of the Breitung Mine. Minor sulphides, pyrite, and pyrrhotite were identified in the surface showings.

Midge Lake Prospect

Brunton (1921) reports that in 1921 a prospect, owned by E. P. Mason and located just south of Midge Lake, was investigated by stripping and diamond drilling. The deposit is controlled by fracturing at the contact between the granite and the diabase. A series of specularite-bearing quartz veins is localized in the shear zones.

COPPER

Copper prospects are abundant throughout much of the Sault Ste. Marie area, but none are of economic importance. Most of these deposits are chalcopyrite-bearing quartz veins associated with shear zones, but a few are related to the large gabbroic intrusives, especially those southeast of Echo Lake. In Aweres Township, west of highway 17, a series of prospect pits has been opened up along a major fault zone. Here, chalcopyrite mineralization in quartz veins occurs over a width of 50 feet and a length of about 300 feet. The surrounding rock is mainly a chlorite schist. Abandonned equipment, including an old, steam tractor, suggests that the exploration work has included diamond drilling, although no core was located. The local residents appear to know nothing about the history of the pits.

The Rankin Mine (McConnell, 1926) is a similar sort of deposit, with chalcopyrite in a quartz vein associated with a shear zone. It is located in the northern part of the Rankin Location a few yards south of the Huronian - granite contact. Here, the contact shows intense shearing over a width of about 25 feet, and the quartz veins appear in fractures related to this shearing. According to McConnell, three pits were sunk in promising veins, but mineralization was too inconsistent.

Brunton (1921) mentions a small mine on Maple Lake, Deroche Township (the San Antonio Mine). During the current mapping, no mine was located at this spot, although the old buildings at the lake were still visible. Southwest from Maple Lake, a quartz vein containing chalcopyrite has been almost completely mined out. This is possibly what Brunton refers to as the San Antonio Mine. The vein occurs in a fault zone in the Gowganda argillite, and has been mined across a width of five to ten feet.

Austin Gold Mines

The Austin Mining Location comprises Lots A, B, and C of the Garden River Indian Reserve, and is situated immediately north of Echo Lake. These lots lie in a general east-west direction, and include an area of 600 acres. Most of the area lies within the Echo Lake map-area (Frarey, 1956).

The mining properties were first developed around 1881 at which time a small wharf was constructed on Echo Lake and a three quarter mile tote road was pushed through to the mining area. Chapman (1881), in a private report to the Austin Mining Company, states that in 1881 the workings consisted of a shaft, 12 by 10 feet and 24 feet deep, and an adit, 8 feet by 9 feet, driven at a comparatively low level upon the course of the vein so as to intersect the shaft at a distance of about 900 feet and a depth of 220 feet. At that time, the adit had been driven 12 or 13 feet.

The mineralization consists of a series of quartz veins containing chalcopyrite and bornite, in an area of highly chloritic Gowganda argillite. The vein is traceable along a strike S60°E for a distance of over two miles. It dips between 28° and 30° to the south. North of Echo Lake, the vein shows a surface width of eight to nine feet, but where the vein enters the Sault Ste. Marie map-area on the east shore of Trotter Lake it has narrowed to only a few inches in width; here, it still contains chalcopyrite and bornite. Early exploration work revealed a grade of 11.27% copper with a trace of silver and gold. Chapman, after completion of his investigation, reported that ore to a value of over two million dollars was available at the mine. This appears to have been exaggerated since very little work was done in the mine after 1900.

URANIUM THORIUM

Several showings of an uraniferous-bearing, quartz-pebble conglomerate occur along the east shore of Maud Lake in the Garden River Indian Reserve. As far as the writer could determine, these showings have not been recorded previously, although in a conversation with H. G. Morris, a prospector in the area, he mentioned uraniferous - thorium-bearing rocks near Maud Lake.

The conglomerate is interbedded with amygdaloidal volcanic rocks, and forms a part of the Duncan greenstone Formation. The conglomerate is situated approximately 15 feet stratigraphically above the base of the formation which has a total thickness of about 200 feet.

The conglomerate unit consists of thin beds of conglomerate, arkose, and greywacke which are interbedded. The individual beds in the unit are no thicker than two feet, but they aggregate to a total thickness of fifteen feet. Locally, the upper part of the conglomerate shows thin volcanic layers interbedded with arkose.

Thin section examination indicates that this conglomerate is quite similar to the Blind River, uraniferous conglomerates, and to a radioactive conglomerate described by Frarey (1959), in the Echo Lake map-area.

The weathered surface is rust coloured because of the high pyrite content of the matrix. The conglomerate contains well-rounded, glassy, quartz pebbles with a maximum size of 1 1/2 inches; a few granite pebbles with a diameter of up to 2 inches were noted. The arkosic layers contain almost fifty per cent fresh feldspar and show angular, quartz fragments. Each individual bed is fairly well sorted as to size.

Thin section analysis showed the matrix of the conglomerate to consist mainly of subrounded grains of quartz of a fairly uniform grain size, cemented by chlorite and sericite which, in places, comprises as much as seventy per cent of the rock. The quartz is strained with an optic angle of about 4°. Mortar structure is slightly developed.

The arkosic beds show considerable quartz, but the quartz is less abundant than the feldspars, microcline, orthoclase, and plagioclase. The minor, detrital grains include garnet, zircon, titanite, pyrite, and magnetite.

SILICA

The upper beds of the Lorrain Formation are an exceptionally pure quartzite. According to Collins

(1925), the quartzite is sufficiently pure to be used as an acid-fluxing material in nickel - copper smelting at Sudbury. It may also be used for the manufacture of ferro-silicon, and is probably also sufficiently indurated to serve for making silica brick.

The quartzite has been quarried from one locality in the Sault Ste. Marie map-area. The Wright and Company quarry in the Bellevue Ridge, Deroche Township, operated for several years but is now closed down. Excavation work has removed the northeast side of the ridge adjacent to the Algoma Central railway so as to expose clean beds of Lorrain quartzite over a vertical distance of 100 feet. In 1920, almost 10,000 tons of quartzite was shipped to Sault Ste. Marie for use as a flux in the blast furnaces. Brunton (1921) reports that the overall grade of the material shipped to Sault Ste. Marie was 96.55% Si, 2.57% Fe, 0.61% Al_2O_3, and 0.41% lime. Locally, he found the silica content to be as high as 98%.

In more recent years, much of the material from the quarry has been used as railroad ballast. The large quantities of slag available for ballast in the Sault Ste. Marie area have probably contributed to the closing of the quarry.

BUILDING STONE

Many of the old, stone buildings in the city of Sault Ste. Marie were made from locally-quarried stone. The mottled red and white Palaeozoic sandstone along the St. Mary's River has proven to be quite satisfactory as a building stone. The mottled colour produces a picturesque, ornamental stone as is shown by buildings such as the Abitibi Pulp and Paper Company offices and the Anglican Cathedral.

Most of the mottled sandstone is now obtained from quarries in the St. Joseph Island area, but earlier buildings were constructed of stone obtained from small quarries located about one mile west of Sault Ste. Marie.

Coleman (1899) described a quarry in Bruce limestone northwest of Garden River. The quarry was closed at the time of Coleman's investigation. The particular location shows dense, blue-grey, crystalline limestone with minor cherty bands. A rusty brown weathered surface with the cherty bands standing as ridges is quite typical.

In recent years, the jasper conglomerate of the Lorrain Formation has proven to be of interest as an ornamental stone. Because of its appearance when polished, this stone was selected for the corner stone of the new Geological Survey building in Ottawa. No attempt has been made to quarry this stone in the Sault Ste. Marie area.

SAND AND GRAVEL

The action of the Pleistocene glaciers has left the Sault Ste. Marie district with an abundance of good gravel and sand deposits. The escarpment which lies a few miles north of Sault Ste. Marie and which parallels the St. Mary's River is marked by numerous deltaic and beach gravel deposits. Meltwater rivers from the receding glaciers have deposited these gravels as they entered a large glacial lake, the waters of which used to cover the plain along the St. Mary's River. These deltaic deposits are now being used to supply most of the gravel requirements of the city of Sault Ste. Marie. The larger deposits will be described in some detail.

Garden River Indian Reserve

Two large gravel deposits have been worked in the Garden River Indian Reserve. In 1900, the Canadian Pacific Railway opened a large pit just north of the village of Garden River. Material from this pit was used primarily for the construction of a causeway across Echo Bay.

The gravel appears to have been deposited as a delta of a river which was probably the ancestor of the present Garden River. It may possibly represent a segment of a baymouth bar across the flooded estuary of the Garden River.

The deposit consists of well cross-bedded sands and fine gravels, with the occasional, very large boulder. Slump structures are common. The sand is composed largely of quartz, with micas, hornblende, and feldspars occurring less frequently. The pebbles are mainly of a granitic composition.

The overall length of the pit is about 400 to 500 feet, and it shows a face of about 100 feet (Plate XLV). A branch line of the Canadian Pacific Railway services the pit. The pit is still under lease to the railway and is used to provide ballast for the lines in the district.

A second pit is located about 200 feet north of the old road through the Garden River Indian Reserve to Echo Lake. Sands and gravels occur highly crossbedded in layers from one-half inch to two feet thick. Coarse, gravel layers are quite common and occur more frequently here than in the pit north of Garden River. At the time of deposition

Plate XLV: Canadian Pacific Railway gravel pit north of Garden River. Boulders that have been removed from the gravel are in a pile in foreground.

of this gravel, the Echo River valley was covered by the waters of a glacial lake, and this gravel deposit probably resulted from the growth of a headland spit into the lake.

Crystal Falls Area

Some of the largest gravel deposits in the Sault Ste. Marie area are located in the vicinity of Crystal Falls and the Hiawatha Park Crown Game Preserve. The deposits are part of a large delta which was deposited by the predecessor of Crystal Creek. Sections of cross-bedded sands and gravels are well exposed in many of the pits (Plate XLVl). These pits are now being used to supply the gravel requirements of the city of Sault Ste. Marie.

West of Sault Ste. Marie

Several, small, gravel pits have been excavated along the escarpment west of Sault Ste. Marie towards Gros Cap. These are similar in origin to the Crystal Falls deposit, but they are much smaller. They are being used to supply fill for the Township roads.

The shore of the St. Mary's River, from Gros Cap to Sault Ste. Marie, is lined by good sand beaches.

Plate XLV1: Typical gravel pit in Crystal Falls area. Cross-bedded sands and gravels are typical.

North of Sault Ste. Marie

North of Sault Ste. Marie, the gravel deposits are of lesser importance except for one deposit at Odena Siding. This deposit is located along the south-facing escarpment north of Sault Ste. Marie. Cross-bedded sands and gravels are well exposed, but here, unlike many of the other deposits, the very coarse beds do not occur. The deposit appears to be related to a river which flowed in the general direction of the present Root River.

The construction material for the new Trans-Canada Highway was obtained from this pit.

BRICK CLAY

The varved clay that occurs along most of the major rivers and underlies the St. Mary's River plain is, in places, of sufficiently good quality for the manufacture of ordinary clay brick. This clay was deposited in the large glacial lakes which once covered much of the lowland area. A kiln for the manufacture of clay brick is located along the northern outskirts of Sault Ste. Marie.

The clay is grey to reddish in colour, and contains numerous concretions. Along the Goulais River and Garden River valleys, the concretions are extremely numerous. In the upper parts of the Goulais River and the Garden River, the clays are interbedded with sand, and, here, slumpage structures are quite common (Plates lV and V).

Collins (1925) sent two samples of clay from the Rydal Bank area north of Bruce Mines to the Ceramics Division, Mines Branch. The results showed that the red clay is hard to dry and has too high a percentage for shrinking. The grey clay was shown to have good firing qualities, but its working qualities, especially for the manufacture of tile, are not good. A mixture of the two clays proved to be the best procedure for the manufacture of brick and tile.

CHAPTER V11

SUMMARY AND CONCLUSIONS

SUMMARY AND CONCLUSIONS

GENERAL GEOLOGICAL HISTORY

The geological history of the Sault Ste. Marie map-area may be summarized as follows:

The hornblende schists, which have resulted from strong metamorphism of volcanic and pyroclastic rocks, are the oldest rocks in the area. These volcanic rocks have been subjected to strong folding with accompanying granite intrusion. With increasing age, the granite has been gradually converted to a granite gneiss. Later, after the conversion of the granite to granite gneiss, renewed igneous activity resulted in the intrusion of many quartz monzonite stocks and small batholiths. This all appears to have been part of a major, mountain-building period. Erosion gradually peneplained the area, with the development of a residual soil over the surface.

At the beginning of Huronian time, shallow seas encroached upon the eroded, mountain remnants. The direction from which the Huronian sediments were derived is a major problem. Various workers have placed the source either to the northwest or to the south. The deposition appears to have been disrupted at several times since disconformities are frequent in the Sault Ste. Marie area. These disconformities are more numerous here than at the eastern end of the Huronian belt, and this would tend to indicate an origin from the northwest.

The deposition of the Duncan greenstone appears to have been followed by a period of erosion during which time a surface showing a relief of about 200 feet was developed. A similar erosion surface is found above the Bruce limestone which, in this report, is placed as approximately equivalent in age to the Duncan greenstone. The Serpent and Aweres Formations, thus, were laid down on an eroded surface with no Espanola Formation present such as is found further towards the east. The deposition of the Serpent and Aweres was followed by a period of erosion during which time a relief of about 500 feet was developed. Prior to the deposition of the Cobalt Group, the area was slightly folded so that the Cobalt Group rests upon eroded and tilted sediments.

In Keweenawan time, many dykes were intruded, and along the coast of Lake Superior a thick sequence of lavas was deposited. Following the completion of the sedimentary sequence, the area was compressed north to south, and major fault zones and folds were developed. The intrusion of the diabase dykes was probably related to this period of deformation.

From the time of the deposition of the Cobalt Group, the northern area appears to have been continuously under erosion. About one mile north of Sault Ste. Marie, a major, east-west escarpment appears to have developed with possible relation to a major fault zone. This escarpment appears to have formed the shoreline during all succeeding periods of inland flooding. In early Palaeozoic or late Keweenawan time, the area up to the escarpment was covered by an inland sea; as a result, sandstone was deposited. Any later Palaeozoic rocks, if deposited in the area, have been removed by erosion.

The area appears to have been under constant erosion since early Palaeozoic time. Most recently it has been subjected to continental glaciation.

ORIGIN OF HURONIAN SEDIMENTS

The origin of the Huronian sedimentary material has divided Huronian geologists into two main groups: those who postulate that the material came from highlands to the north, and those who postulate that it came from a highland area towards the south. Collins and Quirke (1930), in a famous memoir of the Geological Survey of Canada, have suggested that, in fact, the Huronian represents a less metamorphosed equivalent of the Grenville Series to the southeast. Near Killarney, where the Huronian sediments were originally thought to be separated from the gneissic material by a fault zone, they found the gneisses to be, in large part, transformed Huronian sediments. They found the Huronian sediments to graduate into massive, granitic material which resembles the sediments both mineralogically and chemically. They believe that the granite is simply a part of the transformed, sedimentary material which has become liquid and has recrystallized, whereas the gneisses, in large part, have formed from the sediments without departing from the solid state. The more intense metamorphism southeast of the contact suggested to Collins and Quirke that the country here represents a still deeper horizontal section of the earth's crust, and support is lent to this opinion by the signs of dislocation which occur along the contact line. They assume that the amount of vertical displacement is great. It is suggested that the metamorphism is not due so much to the intrusion of the granite as to the conditions that exist at those depths where batholiths are formed and intruded.

McDowell concluded that most of the Mississagi is of fluvial origin. The Lower Mississagi, with its unsorted pebble layers suggests fluvial origin, but the well sorted pebble horizons of the Upper Mississagi seem to indicate a beach gravel for the origin. Thus he sees a gradual change from fluvial deposits in the Lower Mississagi to beach-type deposits in the Upper Mississagi.

Bain (1925) and Wilson (1948) postulated that the Huronian rocks were derived from the Grenville Mountains to the southeast. Bain found the following evidence which led him to conclude that the sediments were derived from the southeast:

(1) The boulders from any formation in the Huronian decrease in size from the south to the north, and in the case of the Bruce conglomerate they disappear altogether.

(2) The Mississagi Formation increases from nothing in the north to 6000 to 10,000 feet in the south. All the formations are thicker in the south.

(3) It appears that successive uplifts of variable magnitude affected the Huronian geosyncline. In each case, the uplift affected the beds further to the north. After each successive uplift, the area of maximum deposition moves away from the upland developed, that is towards the north.

(4) The cross-bedding in the Mississagi indicates that the streams were moving from the south to the southeast at the time that the bed was deposited.

(5) The folding becomes less violent away from the source of the sediments, that is towards the north.

In mapping in the Sault Ste. Marie area, the following conditions led the writer to conclude that the sediments were derived from the northwest:

(1) The Sault Ste. Marie map-area shows far more stratigraphic breaks and more missing formations than is found further east.

(2) The formations are considerably thinner in the Sault Ste. Marie area than to the east. This is undoubtedly a result of the numerous, small disconformities.

(3) Some formations are entirely missing in the Sault Ste. Marie area.

(4) The relation of the Duncan greenstone - Aweres Formation contact indicates land towards the north.

APPENDIX

BIBLIOGRAPHY

Abraham,E.M., 1953, Geology of Parts of Long and Spragge Townships, Blind River Uranium Area, District of Algoma, Ont. Dept. of Mines Prelim. Rept. 1953-2.

Abraham, E.M., 1957, The North Shore of Lake Huron from Gladstone to Spragge Township, Proterozoic in Canada, Royal Soc. Can. Spec. Pub. No. 2, pp. 59-62.

Airth, M.W., & Olson, E.R., 1958, Algom-Nordic Development to Production, C.I.M.M. vol. LXl, pp. 666-667.

Alcock, F.J., 1930, Zinc and Lead Deposits of Canada, Geol. Surv. Can. Econ. Geol. Ser. No. 8, pp. 282-285.

Allen, R.C., & Barrett, L.P., 1914, Evidence of the Middle-Upper Huronian Unconformity in the Quartzite Hills at Little Lake Michigan, Jour. Geol. vol. 22, pp. 574-581.

Anderson, R.C., 1957, Pebble and Sand Lithology of the Major Wisconsin Glacial Lakes of the Central Lowland, Bull. Geol. Soc. Amer. vol. 68, pp. 1415-1450.

Antevs, E., 1925, Retreat of the Last Ice Sheet in Eastern Canada, Geol. Surv. Can. Mem. 146.

Arnold, R.G., 1954, A Preliminary Account of the Mineralogy and Genesis of the Uraniferous Conglomerate of Blind River Ontario, Master of Applied Science Thesis, University of Toronto.

Bain, G.W., 1923, The Specular Haematite Deposits and Huronian Formations of Deroche Township, Ont., Master of Arts Thesis, Columbia University.

Bain, G.W., 1924, Alluvial Fan Deposits in the Upper Huronian, Amer. Jour. Sci., 5th Series, vol 8, pp. 54-60.

Bain, G.W., 1925, Is the Huronic Gowganda Conglomerate of Glacial Origin?, Pan. Amer. Geol. vol. 44, pp. 369-386.

Bain, G.W., 1925, Source of Original Huronian Sediments, Pan. Amer. Geol., vol. 44, pp. 187-198.

Bain, G.W., 1925, Tectonics of Original Huronian of Webbwood, Ontario, Pan. Amer. Geol., vol. 44, pp. 95-120.

Bain, G.W., 1926, Chemistry of Killarney Magma of Sudbury, Pan. Amer. Geol., vol. 45, pp. 277-294.

Bain, G.W., 1926, Killarneyan Intrusives of Sudbury, Pan. Amer. Geol., vol. 45, pp. 109-124.

Bain, G.W., 1927, Huronian Stromatoporoid-like Masses, Pan. Amer. Geol., vol. 47, pp. 281-284.

Bain, G.W., 1927, Geology and Problems of Webbwood Area, Canada, Doctor of Philosophy Thesis, Columbia University.

Baldwin, D.C., 1951, Late Pleistocene Clays of the Sault Ste. Marie Area and Vicinity, Unpublished Master of Science Thesis, University of Illinois, Urbana.

Barlow, A.E., 1890, On the Contact of the Huronian and Laurentian Rocks North of Lake Huron, Amer. Geol., vol. 6, pp. 19-32.

Barlow, A.E., 1892, On the Relations of the Laurentian and Huronian on the North Side of Lake Huron, Amer. Jour. Sci., 3rd Ser., vol 44, pp. 236-239.

Barlow, A.E., 1893, Relations of the Laurentian and Huronian Rocks North of Lake Huron, Bull. Geol. Soc. Amer., vol. 4, pp. 313-332.

Barlow, A.E., 1897, Report on the Geology and Natural Resources of the Area Included by the Nipissing and Timiskaming Map Sheet, Geol. Surv. Can. Ann. Rept., 1897, pt. I.

Barlow, A.E., 1903, Copper Cliff Sheet, Geol. Surv. Can., North Half, Publication No. 824, South Half, Publication No. 825.

Barlow, A.E., 1904, Origin, Geological Relations, and Composition of the Nickel and Copper Deposits of the Sudbury Mining District, Geol. Surv. Can., Rept. No. 873.

Barlow, A.E., 1907, Origin, Geological Relations, and Composition of the Nickel and Copper Deposits of the Sudbury Mining District, Geol. Surv. Can., Rept. No. 961.

Barlow, A.E., 1907, Nipissing and Timiskaming Map Sheets, Geol. Surv. Can., Rept. No. 962.

Bateman, J.D., 1955, Recent Uranium Developments in Ontario, Econ. Geol., vol. 50, pp. 361-372.

Bayley, R.W., 1959, A Metamorphosed Differentiated Sill in Northern Michigan, Amer. Jour. Sci., vol. 257, pp. 408-430.

Bechan, W.J., 1959, On the Occurrence of Uranium in Ancient Conglomerates, Econ. Geol., vol 54, pp. 325-333.

Beland, R.M., 1944, Petrography of the Ruth, Josephine, and Goulais River Iron Ranges, District of Algoma, Ontario, Master of Arts Thesis, University of Toronto.

Bell, J.M., 1904, Report on the Michipicoten Iron Range, Doctor of Philosophy Thesis, Howard University.

Bell, R., 1875-76, Report on an Exploration in 1875 Between James Bay and Lakes Superior and Huron, Geol. Surv. Can. Rept. of Prog. 1875-76, pp. 294-342.

Bell, R., 1887-88, Exploration Around Lake Timiskaming, Abitibi, Montreal River and Upper Waters of the Ottawa, Geol. Surv. Can. Ann. Rept., vol. III, p. 23A.

Bell, R., 1889, The Huronian System in Canada, Presidential Address, Royal Soc. Can. Proc., Trans., vol. 6, pp. 3-13.

Bell, R., 1890-91, Report on the Sudbury Mining District, Geol. Surv. Can. Ann. Rept., pt. F.

Bell, R., 1891, Sudbury Mining District, Geol. Surv. Can., Rept. 326, to acc. sheet No. 130.

Bell, R., 1891, The Laurentian and Huronian Systems North of Lake Huron, First Ann. Rept., Bur. of Mines, Ont., pp. 63-94.

Bell, R., 1891, Geol. Surv. Can. Ann. Rept., vol 5, pt. 1A, pp. 4-44.

Bell, R., 1892-93, Summ. Rept., Geol. Surv. Can. Ann. Rept. 1892-93, vol. 6A, pt. A, pp. 30-33.

Bell, R., 1894, Summ. Rept., Geol. Surv. Can. Ann. Rept. 1894, vol. 7 A, pp. 52-55.

Bell, R., 1898, The Contact of the Laurentian and Huronian North of Lake Huron, Amer. Geol., vol. 2, pp. 135-136.

Bell, R., 1898, Fossil-Like Forms in the Sault Ste. Marie Sandstone, Science, N57, p. 80.

Bell, R., 1898, Report of the Geology of the French River Sheet, Ontario, Geol. Surv. Can. Ann. Rept., vol. 2, pt. 1, p. 29.

Bell, J.M., 1906, The Possible Granitization of Acidic Lower Huronian Schists on the North Shore of Lake Superior, Jour. Geol., vol. 14, pp. 233-242.

Berry, L.G., 1940, Geology of Langmuir-Sheraton Area, Ont. Dept. Mines, vol. 49, pt. 4.

Bigsby, J.J., 1821, Geological and Mineralogical Observations on the Northwest Portion of Lake Huron, Amer. Jour. Sci., 1st Ser., vol. 3, pp. 245-272.

Bigsby, J.J., 1863, On the Cambrian and Huronian Formations, Quart. Jour. Geol. Soc. London, vol. 19, pp. 36-52.

Bowen, N.L., 1910, Diabase and Granophyre of the Gowganda Lake District, Ontario, Jour. Geol., vol. 18, pp. 658-674.

Brooks, T.B., 1876, On the Youngest Huronian Rocks South of Lake Superior and the Age of the Copper-Bearing Series, Amer. Jour. Sci., 3rd Ser., vol. 11, pp. 206-211.

Brooks, T.B., 1876, Classified List of the Rocks Observed in the Huronian Series South of Lake Superior, Amer. Jour. Sci., 3rd Ser., vol. 12, pp. 194-204.

Bruce, E.L., 1932, Geology of the Townships of Janes, McNish, Pardo, and Dana, Ont. Dept. of Mines, vol. 41, pt. 4, pp. 1-28.

Brunton, S.,1922, Deroche, Hodgins, Gaudette and Shield Townships, Algoma District, Ontario, Geol. Surv. Can., Summ. Rept. 1921, pt. D, pp. 27-33.

Brunton, S., 1924, Gowganda Silver District, Can. Mining Jour., vol. 45, No. 19, pp. 452-453.

Burrows, A.G., 1909, The Gowganda and Miller Lakes Silver Areas, Ont. Bur. Mines, Ann. Rept. 18, pt. 2, pp. 1-20.

Burrows, A.G., 1909, South Lorrain Silver Area, Ont. Bur. Mines, Ann. Rept. 18, pt. 2, pp. 21-31.

Burrows, A.G., 1920, Matachewan Gold Area, Ont. Dept. of Mines, Ann. Rept. 29, vol. 29, pt. 3, pp. 53-64.

Burrows, A.G., 1920, Gowganda Silver Area, Ont. Dept. of Mines, Ann. Rept. 29, vol. 29, pt. 3, pp. 77-88.

Burrows, A.G., 1922, Gowganda and Other Silver Areas, Ont. Dept. of Mines, Ann. Rept. 30, vol. 30, pt. 3, 54pp. (Map 30b, 1921).

Burrows, A.G., 1926, Gowganda Silver Area, Ont. Dept. of Mines, Ann. Rept. 35, vol. 35, pt. 3, pp. 1-61. (Map 35d).

Burrows, A.G., & Rickaby, H.C., 1934, Sudbury Nickel Field Restudied, Ont. Dept. of Mines, vol. 43, pt. 2, 44pp. (Maps 43d & 43e).

Burwash, E.M.T., 1914, The Geology of Michipicoten Island, Doctor of Philosophy Thesis, University of Toronto.

Card, K.D., 1959, The Uranium Bearing Huronian Sediments of the Sudbury District, Unpublished Bachelor of Science Thesis, Queen's University.

Chenning, W.F., 1847-48, Report of an Exploration of Several Points on the St. Mary's River, Executive Documents, 1st Session, 30th Congress, Washington, No. 2, vol. 2, pp. 199-209.

Coleman, A.P., 1898, Clastic Huronian Rocks of Western Ontario, Bull. Geol. Soc. Amer., vol. 9, pp. 223-228; Ont. Bur. of Mines, Rept. 7, pp. 151-160; Science, NS. 7, p. 81.

Coleman, A.P., 1899, Michipicoten Iron Range, Ont. Bur. of Mines, Rept. 8, pp. 254-258.

Coleman, A.P., 1899, Copper Region of the Upper Lakes, Ont. Bur. of Mines, Ann. Rept., vol. 8, pt. 2, pp.121-174.

Coleman, A.P., 1900, Upper and Lower Huronian in Ontario, Bull. Geol. Soc. Amer., vol. 11, pp. 107-114.

Coleman, A.P., 1901, Iron Ranges of the Lower Huronian, Ont. Bur. of Mines, Ann. Rept. 10, vol. 10, pp. 181-212.

Coleman, A.P., 1902, The Huronian Question, Amer. Geol., vol. 29, pp. 327-334.

Coleman, A.P., 1906, Precambrian Nomenclature, Jour. Geol., vol. 14, pp. 60-64.

Coleman, A.P., 1907, A Lower Huronian Ice Age, Amer. Jour. Sci., 4th Ser., vol. 23, pp. 187-192.

Coleman, A.P., 1907, Glacial Periods and Their Bearings on Geological Theories, Bull. Geol. Soc. Amer., vol. 19, pp. 347-366.

Coleman, A.P., 1908, Ancient Ice Ages and Their Bearing on Astronomical Theories, Royal Astronomical Soc. Can., vol. 2, pp. 132-135.

Coleman, A.P., 1908, The Lower Huronian Ice Age, Jour. Geol., vol. 16, pp. 149-158.

Coleman, A.P., 1909, On the Lower Huronian Ice Age, Can. Mining Jour., vol. 30, pp. 694-695.

Coleman, A.P., 1912, The Lower Huronian Ice Age, Int. Geol. Cong. 11, Stockholm, 1910 Congress, pp. 1069-1072.

Coleman, A.P., 1913, The Whiskey Lake Area, Ont. Bur. of Mines, Ann. Rept., vol. 22, pt. 1, pp. 146-154.

Coleman, A.P., 1913, The Massey Copper Mine Area, Ont. Bur. of Mines, Ann. Rept., vol. 22, pt. 1, pp. 155-160.

Coleman, A.P., 1914, The Precambrian Rocks North of Lake Huron, Ont. Bur. of Mines, Ann. Rept., vol. 23, pt. 1, pp. 202-236.

Coleman, A.P., 1914, The Sudbury Series and its Bearing on Precambrian Classification, Int. Geol. Cong. 12, Compte Rendus, pp. 337-398.

Coleman, A.P., 1915, The Climatic Conditions of the Early Precambrian, Brit. Astronomical Rept., vol. 84, p. 359.

Coleman, A.P., 1926, Ice Ages, Recent and Ancient, MacMillan Co., New York, 276 pp.

Collins, W.H., 1909, Preliminary Report on Gowganda Mining Division, District of Nipissing, Ontario, Geol. Surv. Can., Publication No. 1075, 47 pp.

Collins, W.H., 1909, Montreal River District, Geol. Surv. Can., Summ. Rept. 1908, pp. 115-120.

Collins, W.H., 1910, The Florence Lake and Montreal River District, Ontario, Geol. Surv. Can., Summ. Rept. 1909, pp. 168-172.

Collins, W.H., 1911, Montreal River District, Geol. Surv. Can., Summ. Rept. 1910, pp. 196-202.

Collins, W.H., 1913, The Geology of the Gowganda Mining Division, Geol. Surv. Can., Memoir 33.

Collins, W.H., 1914, A Classification of the Precambrian Formations in the Region East of Lake Superior, Int. Geol. Cong. 12, Canada, pp. 399-408. (Advance Copy 1913).

Collins, W.H., 1914, Geology of a Portion of Sudbury Map Area, South of Wanapetei Lake, Ontario, Geol. Surv. Can., Summ. Rept. 1913, pp. 189-195.

Collins, W.H., 1914, The Huronian of Timiskaming Region, Canada, Geol. Surv. Can., Mus. Bull. No. 8, 27pp.

Collins, W.H., 1914, A Reconnaissance of the North Shore of Lake Huron, Geol. Surv. Can., Summ. Rept. 1914, pp. 81-82.

Collins, W.H., 1915, North Shore of Lake Huron, Geol. Surv. Can., Summ. Rept. 1915, pp. 136-137.

Collins, W.H., 1916, North Shore of Lake Huron, Geol. Surv. Can., Summ. Rept. 1916, pp. 183-185.

Collins, W.H., 1916, The Age of the Killarney Granite, Geol. Surv. Can., Mus. Bull. No. 22, 12pp.

Collins, W.H., 1917, Onaping Map Area, Geol. Surv. Can., Memoir 95.

Collins, W.H., 1925, Lake Panache Sheet, Geol. Surv. Can., Publication No. 1971. (To acc. Memoir 143).

Collins, W.H., 1925, Bruce Mines Sheet, Geol. Surv. Can., Publication No. 1969.

Collins, W.H., 1925, Blind River Sheet, Geol. Surv. Can., Publication No. 1970.

Collins, W.H., 1925, North Shore of Lake Huron, Geol. Surv. Can., Memoir 143. (Reprinted 1956).

Collins, W.H., 1928, Southwestern Part of the Sudbury Nickel Irruptive, Geol. Surv. Can., Summ. Rept. 1928, pt. C, pp. 12-16.

Collins, W.H., 1929, Panache Sheet, Geol. Surv. Can., Map 220A-2173, 1 mile-1 inch.

Collins, W.H., 1935, Lake Huron Sheet, Geol. Surv. Can., Map 154A, 3rd Edition.

Collins, W.H., 1936, The Sudbury Series,Bull. Geol. Soc. Amer., vol. 47, pp. 1675-1690.

Collins, W.H., 1937, Timiskaming Sub-province, Bull. Geol. Soc. Amer., vol. 48, pp. 1427-1458.

Collins, W.H., 1937, Correlation of the Sudbury Series, Bull. Geol. Soc. Amer., vol. 48.

Collins, W.H., 1938, Espanola Sheet, Geol. Surv. Can., Map 291A, 1 mile-1 inch.

Collins, W.H., 1938, Copper Cliff Sheet, Geol. Surv. Can., Map 292A, 1 mile-1 inch.

Cooke, H.C., 1920, A Correlation of the Precambrian of Northern Ontario and Quebec, Jour. Geol., vol. 28, pp. 304-332.

Cooke, H.C., 1920, Between the Archean and the Keweenawan is the Huronian, Trans. Roy. Soc. Can., vol. 20, pt. 4, pp. 17-37.

Cooke, H.C., 1941,New Precambrian Correlations Indicated from Recent Work at Sudbury, Ontario, Trans. Roy. Soc. Can., 3rd Ser., vol. 32, pt. 4.

Cooke, H.C., 1946, Problems of Sudbury Geology, Ontario, Geol. Surv. Can., Bull. 3, 77pp.

Cooke, H.C., 1946, Chelmsford Map Area, Sudbury District, Ontario, Geol. Surv. Can., Map 871A, 1 mile-1 inch.

Cooke, H.C., 1946, Falconbridge Sheet, Geol. Surv. Can., Map 872A, 1 mile-1 inch.

Cooke, H.C., 1947, Geology and Economic Minerals of Canada, Econ. Geol. Ser., No. 1, pp. 11-36.

Crowell, J.C., 1957, Origin of Pebbly Mudstone, Bull. Geol. Soc. Amer., vol. 68, pp. 993-1010.

Dapples, E.C., & Romenger, J.F., 1945, Orientation Analysis of Fine-grained Clastic Sediment, Jour. Geol., vol. 53, pp. 246-301.

Davidson, C.F., 1953, On the Occurrence of Uranium in Ancient Conglomerate, Econ. Geol., vol. 52, pp. 668-692.

Davis, S.N., 1958, Size Distribution of Rock Types in Stream Gravel and Glacial Till, Jour. Sed. Petrol., vol. 28, pp. 87-94.

Derry, D.R., 1960, Evidence of the Origin of the Blind River Uranium Deposits, Econ. Geol., vol. 55, pp. 906-927; Prog. Rept., Econ. Geol., vol. 53, pp. 918-919; Bull. Geol. Soc. Amer., 1958, vol. 69, p. 1553.

Douglas, G.V., 1926, Whiskey Lake Area, District of Algoma, Ontario, Ont. Dept. of Mines, Ann. Rept. 34, pt. 4, pp. 34-39. (Map 34c, 1925).

Dreimanis, A.,1958, Beginning of the Nipissing Phase of Lake Huron, Jour. Geol., vol. 66, pp. 591-594.

Driscoll, E.G., 1959, Evidence of Transgressive - Regressive Cambrian Sandstones Bordering Lake Superior, Jour. Sed. Petrol., vol. 29, pp. 5-15.

DuBois, P.M., 1959, Correlation of Keweenawan Rocks of Lake Superior District by Paleo-magnetic Methods, Proc. Geol. Assoc. of Can., vol. 11, pp. 115-128.

Eade, K.E., 1949, The Huronian Rocks of Northwestern Ontario, Master of Science Thesis, McGill University.

Emmons, R.C., 1927, Wakomata Lake Area, Algoma District, Ontario, Geol. Surv. Can., Summ. Rept. 1926, pt. C, pp. 1-15. (Map 194A).

Fairbairn, H.W., 1933, Geology of the Ashagami Lake Area, Ont. Dept. of Mines, vol. 48, pt. 10.

Fairbairn, H.W., 1941, The Relation of the Sudbury Series to the Bruce Series in the Vicinity of Sudbury, Ontario, Ont. Dept. of Mines, vol. 50, pt. 6, 13pp. (Map 50g).

Fairbairn, H.W., 1941, The Bruce Series in Falconbridge and Dryden Townships, Ont. Dept. of Mines, vol. 50, pt. 6, pp. 14-17.

Fairbairn, H.W., 1959, Rb-Sr Feldspar Ages in Granite Rocks of Sudbury, Blind River, Ontario, Canada, Bull. Geol. Soc. Amer., vol. 20, pp. 1599-1600, abstract.

Flint, R.F., 1957, Glacial and Pleistocene Geology, J. Wiley & Sons, New York.

Frarey, M.J., 1959, Revised Stratigraphy and Structure of the Huronian Rocks of the Echo Lake Area, Sault Ste. Marie District, Ontario, Can. Prospectors & Developers Assoc. Meeting, March 1959, (unpublished).

Frarey, M.J., 1959, Geology, Echo Lake Sheet, Algoma District, Ontario, Geol. Surv. Can., Map 23-1959.

Frarey, M.J., 1960, Geology, Wakwekobi Lake Sheet, Algoma District, Ontario, Geol. Surv. Can., Map 3-1960.

Glen, J.W., Donner, J.J., & West, R.G., 1957, On the Mechanisms by Which Stones in Till Become Oriented, Amer. Jour. Sci., vol. 255, pp. 194-205.

Graham, A.R., 1932, Tyrrel - Knight Area, Ont. Dept. of Mines, vol. 41, pt. 2, pp. 25-61.

Graton, L.C., 1903, Up and Down the Mississagi, Ont. Bur. of Mines, Ann. Rept., vol. 12, pp. 157-172.

Hamblin, W.K., 1950, The Cambrian Sandstones of Northern Michigan, Geol. Surv. Mich., Publication 51, pp. 1-146.

Harding, W.D., 1939, Flack Lake Area, Ont. Dept. of Mines, Ann. Rept., vol. 48, pt. 2, Map 48k.

Harrington, B.J., 1876-77, Report of Progress, Geol. Surv. Can., p. 483.

Harrison, P.W., 1957, A Clay Till Fabric, Its Character and Origin, Jour. Geol., vol. 65, pp. 275-308.

Harrison, P.W., 1957, New Technique for Three Dimensional Fabric Analysis of Till and Englacial Debris Containing Particles From 3 to 4 mm. in Size, Jour. Geol., vol. 65, pp. 98-105.

Hart, R.C., Harper, H.G., & Algom Field Staff, 1955, Uranium Deposits of the Quirke Lake Trough, Algoma District, Ontario, Can. Inst. Mining Met., pp. 260-265.

Hart, R.C., Harper, H.G., & Algom Field Staff, 1957, Quirke Lake Trough, Structural Geology of Canadian Ore Deposits, Can. Inst. Mining Met., vol. 2, pp. 316-324.

Hase, D.H., 1957, Upper Huronian Sedimentation in a Portion of the Marquette Trough, Michigan, Jour. Geol., vol. 63, pp. 561-574.

Hay, R.E., 1961, Sault Ste. Marie, District of Algoma, Preliminary Map 26-1961, Geol. Surv. Can.

Hays, 1905, Special Committee on Precambrian Nomenclature for the Lake Superior Region, Geol. Surv. Can., Summ. Rept. 1904, pp. 18-28; Jour. Geol., vol. 13, pp. 89-104.

Holmes, C.D., 1941, Till Fabric, Bull. Geol. Soc. Amer., vol. 52, pp. 1299-1384.

Holmes, S.W., 1957, Pronto Mine, Structural Geology of Canadian Ore Deposits, Can. Inst. Mining Met., vol. 2, pp. 324-344.

Holmes, S.W., 1958, The Uranium Bearing Conglomerates of the Blind River, Algoma Area, Can. Mining Jour., vol. 29, pp. 103-108.

Hore, R.E., 1910, On the Glacial Origin of Huronian Rocks of Nipissing, Ontario, Jour. Geol., vol. 18, pp. 459-467.

Hore, R.E., 1912, Geology of the Cobalt District, Ontario, Trans. Amer. Inst. Mining Eng., vol. 17, pp. 480-499.

Hore, R.E., 1913, Cobalt Conglomerate, Mining Mag., vol. 8, p. 43.

Hore, R.E., 1913, Ripple Marked Huronian Quartzite at Nipissing Mine, Cobalt, Ontario, Mich. Acad. Sci., Rept. 15, p. 59.

Hotchkiss, W.O., 1923, The Lake Superior Geosyncline, Bull. Geol. Soc. Amer., vol. 34, pp. 669-678.

Hough, J.L., 1958, Geology of the Great Lakes, University of Illinois Press, Urbana, Illinois, 310pp.

Hough, J.L., 1958, Fresh Water Environment of Deposition of Precambrian Banded Iron Formation, Jour. Sed. Petrol., vol. 28, pp. 414-430.

Hriskevich, M.E., 1952, A Study of the Distribution of Cr, O, Ni, Co, and Cu in the Nipissing Diabase Sheet of Cobalt, Ontario, Ont. Research Council, Rept. No. 8-6-52.

Hughson, M.R., 1954, Mineralogical Report on a Composite Diamond Drill Core Sample From Algom Uranium Mines Ltd., Rept. No. Sr. 257-54, Radiation Division, Dept. of Mines & Tech. Surv., Ottawa.

Hurst, M.E., 1928, Ranger Lake and Garden River Area, District of Algoma, Ont. Dept. of Mines, vol. 37, pt. 3, pp. 53-78.

Ingall, E.D., 1903, Geology of the Bruce Mines District, Geol. Surv. Can., Summ. Rept. 1902-1903, pp. 244-254.

Ingall, E.D., 1904, Bruce Mines District, Geol. Surv. Can., Summ. Rept. 1903, Ann. Rept. 15, pp. 195-196.

Ingall, E.D., & Dines, Theo., 1905, Geology of the Country Around Bruce Mines, Geol. Surv. Can., Summ. Rept. 1904, pp. 179-190.

Irving, J.D., 1884, Metamorphism in the Huronian of the Northwest, Science, vol. 4, p. 327.

Irving, R.D., 1876, Note on the Youngest Huronian Rocks South of Lake Superior, Amer. Jour. Sci., 3rd Ser., vol. 2, p. 493.

Irving, R.D., 1879, Note on the Stratigraphy of the Huronian Series of Northern Wisconsin and on the Equivalency of the Huronian of the Marquette and Puokee Districts, Amer. Jour. Sci., 3rd Ser., vol. 17, pp. 393-398.

Irving, R.D., 1887, Is There a Huronian Group, Amer. Jour. Sci., 3rd Ser., vol. 34, pp. 204-216, 249-263, 366-374.

James, H.L., 1958, Stratigraphy of Pre-Keweenawan Rocks in Parts of Northern Michigan, U.S. Geol. Surv., Prof. Paper 314-C.

Joubin, F.R., 1954, Uranium Deposits of the Algoma District, Ontario, Can. Inst. Mining Met., pp. 673-679.

Joubin, F.R., 1954, Trans. Can. Inst. Mining Met., vol. 57, pp. 431-437.

Joubin, F.R., & James, D.H., 1956, The Algoma District, Can. Mining Jour., vol. 77, p. 85.

Joubin, F.R., & James, D.H., 1957, Algoma Uranium District, Structural Geology of Canadian Ore Deposits, vol. 2, Can. Inst. Mining Met., pp. 305-315.

Kerr, H.L., 1906, Explorations in Mattagami Valley, Ont. Bur. of Mines, Ann. Rept., pt. 1.

Kerr, J.W.M., 1945, Siderite Deposits in the Michipicoten District, Master of Arts Thesis, University of Toronto.

Kindle, E.M.? 1917, Recent and Fossil Ripple Marks, Geol. Surv. Can., Mus. Bull. 25, pp. 1-56.

Knight, C.W., 1907, Other Timiskaming Cobalt Areas, Ont. Bur. of Mines, vol. 16, pt. 2, pp. 117-118.

Knight, C.W., 1909, On the Lower Huronian Ice Age, Can. Mining Jour., vol. 30, pp. 727-728.

Knight, C.W., 1911, Geology of the Cobalt District, Amer. Inst. Mining Eng., Bull. 60, pp. 1035-1037.

Knight, C.W., 1911, The Laurentian System, Ont. Bur. of Mines, Rept. 20, pp. 280-284.

Knight, C.W., 1915, The North Shore of Lake Huron, Ont. Bur. of Mines, Ann. Rept., vol. 24, pt. 1, pp. 216-241.

Knight, C.W., 1922, Geology of the Mine Workings of Cobalt and South Lorrain Silver Areas, Ont. Dept. of Mines, Ann. Rept., pt. 2, vol. 30.

Krumbein, W.C., 1939, Preferred Orientation of Pebbles in Sedimentary Deposits, Jour. Geol., vol. 47, pp. 673-706.

Krumbein, W.C., 1941, Measurement of Geological Significance of Shape and Roundness of Sedimentary Particles, Jour. Sed. Petrol., vol. 2, pp. 64-72.

Kuenen, P.H., & Migliorine, C.J., Turbidity Currents as a Cause of Graded Bedding, Jour. Geol., vol. 58, pp. 91-127.

Kuenen, P.H., 1953, Significant Features of Graded Bedding, Amer. Assoc. Petroleum Geol., vol. 40, pp. 1044-1066.

Lane, A.C., 1911, The Keweenaw Series of Michigan, Michigan Geol. & Biol. Surv., Public. 6, Geol. Ser. 4, Vols. 1 & 2.

Lane, A.C., & Seaman, A.C., 1907, Notes on the Geological Section of Michigan, Part 1, The Pre-Ordovician, Jour. Geol., vol. 15, pp. 680-695.

Lawson, A.C., 1893, The Correlation of the Precambrian Rocks of the Region of the Great Lakes, Univ. of California, Dept. of Geol., Bull., vol. 10, No. 1, 19p.

Lawson, A.C., 1929, Some Huronian Problems, Bull. Geol. Soc. Amer., vol. 40, pp361-383.

Leith, C.K., 1927, Lake Superior Precambrian, Bull. Geol. Soc. Amer., vol. 38, pp. 749-752.

Leith, C.K., Lund, R.J., & Leith, A., 1935, Precambrian Rocks of the Lake Superior Region, United States Geol. Surv., Prof. Paper 184.

Leverett, F., 1911, Surface Geology of the Northern Peninsula of Michigan, Michigan Geol. & Biol. Surv., Public. 7, Geol. Ser. 5.

Leverett, F., 1929, Moraines and Shore Lines of the Lake Superior Region, United States Geol. Surv., Prof. Paper 154-A.

Logan, W.E., 1847-48, Report of the Geological Survey of Canada on the North Shore of Michigan, Exec. Documents, 1st Session, 20th Congress, Washington, vol. 2, No. 2, pp. 183-189.

Logan, W.E., 1849, Report of the Geological Survey of Canada on the North Shore of Lake Huron, pp. 8-20.

Logan, W.E., 1857, Geol. Surv. Can., Rept. of Progress, pp. 1-12.

Logan, W.E., 1857, On the Division of the Azoic Rocks of Canada into Huronian and Laurentian, Proc. Amer. Assoc. Adv. Sci., 117th meeting, pt. 2, pp. 44-47.

Logan, W.E., 1863, Geology of Canada, Geol. Surv. Can., pp. 50-66.

Mair, J.A., Maynes, A.D., Patchett, J.E., & Russell, R.D., 1960, Evidence on the Origin and Age of the Blind River Uranium Deposits, Geophys. Research, vol. 65, pp. 341-348.

Mandarino, J.A., 1952, The Claystone Concretions of the Sault Ste. Marie Michigan area, Rocks & Minerals, vol. 27, pp. 461-467.

Marsden, R.W., 1953, Correlation of the Precambrian Rocks of the South Shore of Lake Superior, Bull. Geol. Soc. Amer., vol. 64, p. 1451.

Marsden, R.W., 1955, Precambrian Correlation in the Lake Superior Region in Michigan, Wisconsin, and Minnesota, Proc. Geol. Assoc. Can., vol. 7, pp. 107-116.

Marshall, H.I., 1947, Geology of Midlothian Township, Ont. Dept. of Mines, vol. 56, pt. 5.

Matheson, A.F., 1932, Geology of Michipicoten River Area, District of Algoma, Ont., Can., Doctor of Philosophy Thesis, University of Minnesota.

McAllister, R.F., 1951, Varved Clays of the Goulais River Valley of Ontario, Master of Science Thesis, University of Illinois.

McConnell, R.G., 1926, Sault Ste. Marie Area, District of Algoma, Ont. Dept. of Mines, vol. 35, pt. 2, pp. 1-52.

McDowell, J.P., 1957, The Sedimentary Petrology of the Mississagi Quartzite in the Blind River Area, Ont. Dept. of Mines, Geol. Circular, No. 6.

McFarlane, T., 1866, Report on the East Shore of Lake Superior, Ontario, Geol. Surv. Can., Rept. of Prog. 1863-66, pp. 115-164.

McFarlane, T., 1867-68, On the Geological Formations of Lake Superior, Can. Nat., No. 53, pp. 177-201, & pp. 241-256.

McKellar, P., 1888, The Correlation of the Animikie and Huronian Rocks of Lake Superior, Proc. Roy. Soc. Can., vol. 5, pp. 63-73.

Miller, W.G., 1901, Iron Ranges of the Lower Huronian, Ores of the Eastern Huronian Belt, Ont. Bur. Mines, vol. 10, 201p.

Miller, W.G., 1913, Cobalt and Adjacent Areas, Can. Mining Jour., vol. 34, pp. 87-90.

Miller, W.G., 1914, The Precambrian Rocks North of Lake Huron, Ont. Bur. Mines, vol. 23, pt. 1, pp. 202-203.

Milne, U.G., 1958, The Non-Radioactive Heavy Minerals of the Mississagi Conglomerate, Master of Science Thesis, University of Toronto.

Moore, E.S., 1926, Batchawana Area, District of Algoma, Ont. Dept. of Mines, vol. 35, pt.2, pp. 53-85.

Moore, E.S., 1926, Mississagi Reserve and Goulais River Iron Ranges, District of Algoma, Ont. Dept. of Mines, vol. 34, pt. 4, pp. 1-33, Map 34d, 1925.

Moore, E.S., 1926, Origin of a Keweenawan Boulder Conglomerate, Bull. Geol. Soc. Amer., vol. 37, p. 157.

Moore, E.S., 1929, Ore Deposits Near the North Shore of Lake Huron, Ont. Dept. of Mines, vol. 38, pt. 7, pp. 1-51.

Murray, A., 1848, On the North Shore of Lake Huron, Geol. Surv. Can., Rept. of Prog. 1847-48, pp. 93-124.

Murray, A., 1849, On the Geology of Parts of the Coast of Lake Huron, The Spanish River, etc., Geol. Surv. Can., Rept. of Prog 1848-49, pp. 7-46.

Murray, A., 1857, On the Topographical and Geological Features of the Region Between the Ottawa River and Georgian Bay as well as North of Lake Huron, Geol. Surv. Can., Rept. of Prog., 1853-56, pp. 59-190.

Murray, A., 1857, On the Coast at the Mouth of French River, Georgian Bay, On Echo Lake and its Environs, and on the Limestone of Bruce Mines, Geol. Surv. Can., Rept. of Prog. 1857, pp. 13-27.

Murray, A., 1858, On the Country Between the Thessalon River and Lake Huron, and Between the Thessalon and Mississagi, Geol. Surv. Can., Rept. of Prog. 1858, pp. 67-100.

Murray, A., 1859, Copper Bearing Rocks North of Lake Huron, Geol. Surv. Can., Summ. Rept. 1858, pp. 64-104.

Nanz, R.H., 1953, Chemical Composition of Precambrian Slates with Notes on the Geochemical Evolution of Lutites, Jour. Geol., vol. 61, pp. 51-64.

Newell, W.D., 1957, Supposed Permian Tillites in Northern Mexico are Submarine Slide Deposits, Bull. Geol. Soc. Amer., vol. 68, pp. 1569 -1576.

Nuffield, E.W., 1955, Geology of the Montreal River Area, Ont. Dept. of Mines, vol. 64, pt. 3.

Oetking, P.F., 1951, The Relation of the Lower Paleozoics to the Older Rocks in the Northern Penninsula of Michigan, Doctor of Philosophy Thesis, University of Wisconsin.

Pearson, W.T., Phemister, T.C., & Thomson, J.E., 1960, Dryden Township, District of Sudbury, Ont. Dept. of Mines, Prelim. Map 56.

Phemister, T.C., & Grant, J.A., 1960, Heelon Township, District of Sudbury, Ont. Dept. of Mines, Prelim. Map. 55.

Phemister, T.C., & MacGregor, I.D., 1960, Broder Township, District of Sudbury, Ont. Dept. of Mines, Prelim. Map. 57.

Phemester, T.C., & Grant, J.A., 1960, Dill Township, District of Sudbury, Ont. Dept. of Mines, Prelim. Map. 58.

Pettijohn, F.J., 1943, Archean Sedimentation, Bull. Geol. Soc. Amer., vol. 54, pp. 925-972.

Pettijohn, F.J., 1952, Precambrian Tillite, Menominee District, Michigan, Bull. Geol. Soc. Amer., vol. 63, p. 1289.

Pettijohn, F.J., 1957, Sedimentary Rocks, 2nd Edition, Harper & Bros., New York, 529p.

Pettijohn, F.J., 1957, Paleocurrents of Lake Superior Precambrian Quartzites, Bull. Geol. Soc. Amer., vol. 68, pp. 469-480.

Pettijohn, F.J., & Bastron, H., 1959, Chemical Composition of Argillites of the Cobalt Series (Precambrian) and the Problems of Soda-Rich Sediments, Bull. Geol. Soc. Amer., vol. 70, pp. 593-599.

Picard, M.D., 1957, Criteria for Distinguishing Lacustrine and Fluvial Sediments in Tertiary Beds of Unita Basin, Utah, Jour. Sed. Petrology, vol. 27, pp. 373-377.

Pienaar, P.J., 1958, Stratigraphy, Petrography and Genesis of the Elliot Group including the Uraniferous Conglomerates, Quirke Lake Syncline, Blind River Area, Ont., Doctor of Philosophy Thesis, Queen's University.

Pumpelly, R., Raphael, & Van Hise, C.K., 1892, Observations upon the Structural Relations of the Upper Huronian, Lower Huronian, and Basement Complex on the North Shore of Lake Huron, Amer. Jour. Sci., 3rd Ser., vol. 43, pp. 224-232.

Quirke, T.T., 1915, Geology of Espanola District, Ont., Doctor of Philosophy Thesis, University of Chicago.

Quirke, T.T., 1917, Espanola District, Ontario, Geol. Surv. Can., Memoir 102, 87p.

Quirke, T.T., 1920, Moncrieff and Hess Townships, Ont., Divisional Summary Report, Geol. Surv. Can., Public. No. 1865.

Quirke, T.T., 1922, Wanapetei Lake Map Area, Sudbury District, Ontario, Geol. Surv. Can., Summ. Rept., 1921, pt. D, pp. 34-50.

Quirke, T.T., 1924, Huronian Complex near Killarney Ontario, Bull. Geol. Soc. Amer., vol. 35, pp. 89-90, 1925, Pan. Amer. Geol., vol41, pp. 144-145.

Quirke, T.T., 1924, Correlation of Huronian and Grenville Rocks, Jour. Geol., vol. 32, pp. 316-335.

Quirke, T.T., 1924, Correlation of Huronian and Grenville Rocks of Southeast Ontario, Pan. Amer. Geol., vol. 42, p. 308.

Quirke, T.T., 1926, Huronian Grenville Relations, Amer. Jour. Sci., 5th Ser., vol. 7, pp. 165-173.

Quirke, T.T., 1930, Delemere Sheet, Geol. Surv. Can., Map. 238A.2204.

Quirke, T.T., & Collins, W.H., 1930, The Disappearance of the Huronian, Geol. Surv. Can., Memoir 160, 129p.

Ramdohr, P., 1958, Ein Gold - und Uranlagerstatten des Witwatersrandes in einem Vergleich mit den neuen Uran vorkommen in Blind River District, Geologie, vol. 10, pp. 35-37.

Rice, W.A., 1940, Geology of the Blind River, Spragge Area, North Shore of Lake Huron, Ont., Doctor of Philosophy Thesis, Yale University.

Robertson, J.A., 1960, The General Geology of the Blind River Area, Master of Science Thesis, Queen's University.

Robertson, D.S., & Steenland, N.C., 1960, On the Blind River Uranium Ores and Their Origin, Econ. Geol., vol. 55, pp. 659-694.

Robertson, D.S., 1962, Thorium and Uranium Variations in the Blind River Ores, Econ. Geol., vol. 57, pp. 1175-1184.

Roscoe, S.M., 1956, Geol. Surv. Can., Topical Report No. 4.

Roscoe, S.M., 1956, Geology and Uranium Deposits, Quirke Lake, Elliot Lake, Blind River Area, Ont., Geol. Surv. Can., Paper 56-7, 21p.

Roscoe, S.M., 1957, Stratigraphy, Quirke Lake - Elliot Lake Section, Blind River Area, - The Proterozoic in Canada - Roy. Soc. Can., Spec. Public., No. 2, pp. 54-58.

Roscoe, S.M., & Steacy, H.R., 1958, On the Geology and Radioactive Deposits of the Blind River Region Trans. Second Inter. Cong. Atomic Energy, Geneva, vol. 2, pp. 474-483.

Roscoe, S.M., 1959, Monazite as an Ore Mineral in Elliot Lake Uranium Ores, Can. Mining Jour., vol. 60, pp. 65-66.

Roscoe, S.M., 1959, On the Thorium - Uranium Ratios in Conglomerates and Associated Rocks near Blind River, Ont., Econ. Geol., vol. 54, pp. 511-512.

Roscoe, S.M., 1960, Huronian Uraniferous Conglomerates, Econ. Geol., vol. 55, pp. 410-414.

Schwarzacher, W., 1951, Grain Orientation in Sands and Sandstones, Jour. Sed. Petrology, vol. 21, pp. 162-172.

Selwyn, A.R.C., 1876, Huronian of Canada, Amer. Jour. Sci., Ser. 3, vol. 12, p. 461.

Selwyn, A.R.C., 1888, The Huronian of Canada, Amer. Geol., vol. 2, pp. 61-62.

Selwyn, A.R.C., 1889, Two Systems Confounded in the Huronian, Amer. Geol., vol. 3, pp. 339-340.

Setler, R.F., & Chapman, C.A., 1955, Microfabrics of Till from Ohio and Pennslyvania, Jour. Sed. Petrology, vol. 25, pp. 262-269.

Sheeran, H.W., 1952, The Geology of the Lac Aux Sables-Shakewa Lake Area, Districts of Algoma and Sudbury, Ont. Dept. of Mines, Prelim. Rept. 1952-3.

Shepard, F.P., 1937, Origin of the Great Lakes Basins, Jour. Geol., vol. 45, pp. 76-88.

Shepps, V.A., 1958, Size Factors. A Means of Analysis of Data from Textural Studies of Till, Jour. Sed. Petrology, vol. 28, pp. 482-485.

Shiklebeer, H.A., & Cumming, G.L., 1956, The Bearing of Age Determinations on the Relation between the Keewatin and Grenville Provinces, Roy. Soc. Can., Spec. Pub. 1, pp. 54-73.

Spiroff, K., 1952, Residual Minerals in Keweenawan Conglomerate, Rocks and Minerals, vol. 27, pp. 243-246.

Stieff, L.R., Stearn, T.K., Cialella, C.M., and Wair, J.T., 1956, Preliminary Age Determination of some Uranium Ores from the Blind River Area, District of Algoma, Ont., Can., Bull. Geol. Soc. Amer., vol. 67, Abstract, pp. 1736-1737.

Taylor, F.B., 1897, Notes on Abandoned Beaches on the North Coast of Lake Superior, Amer. Geol., vol. 20.

Thomson, J.E., 1952, Geology of Baldwin Township, Sudbury Mining Division, Ont., Ont. Dept. of Mines, vol. 61, pt. 4.

Thomson, J.E., 1953, Geology of the Mamainse Point Copper Area, Ont. Dept. of Mines, vol. 62, pt. 4.

Thomson, J.E., 1953, Problems of Precambrian Stratigraphy West of Sudbury, Trans. Roy. Soc. Can., 3rd. Ser., vol. 47, sec. 4, pp. 61-70.

Thomson, J.E., 1957, Proterozoic Rocks of the Southern Part of the Canadian Shield, The Proterozoic in Canada, Roy. Soc. Can., Spec. Pub., No. 2, pp. 33-37.

Thomson, J.E., 1957, The Questionable Proterozoic Rocks of the Sudbury Espanola Area, The Proterozoic in Canada, Roy. Soc. Can., Spec. Pub., No.2, pp. 48-53.

Thomson, J.E., 1957, The Proterozoic of the Original Huronian, The Proterozoic in Canada, Roy. Soc. Can., Spec. Pub., No. 2, pp. 63-65.

Thomson, J.E., 1960, Uranium and Thorium Deposits at the Base of the Huronian System in the District of Sudbury, Ont. Dept. of Mines, Geol. Rept., No. 1.

Thomson, R., 1957, The Proterozoic of the Cobalt Area, The Proterozoic in Canada, Roy. Soc. Can., Spec. Pub., No. 2, pp. 40-45.

Tolman, C., 1927, The Geology of the Big Eddy Lake Area, District of Sudbury, Ont., Doctor of Philosophy Thesis, Yale University.

Tyler, S.A., Marsden, R.W., Grout, F.F., & Thiel, G.A., 1940, Studies of Lake Superior Precambrian by Accessory Mineral Methods, Bull. Geol. Soc. Amer., vol. 51, pp. 1429-1538.

Tyler, S.A., & Twenhofel, W.H., 1952, Sedimentation and Stratigraphy of the Huronian of Upper Michigan, Pt. 1, Amer. Jour. Sci., vol. 250, pp. 1-27, Pt. 2, Amer. Jour. Sci., vol. 250, pp. 118-151.

Tyler, S.A., Barghoorn, E.S., Barrett, L.D., 1957, Anthracite Coal from Precambrian Upper Huronian Black Shale of the Iron River District, Northern Michigan, Bull. Geol. Soc. Amer., vol. 68, pp. 1293-1304.

Upham, W., 1890, Glacial Lakes in Canada, Bull. Geol. Soc. Amer., vol. 2, pp. 243-276.

Van Hise, C.R., 1911, The Geology of the Lake Superior Region, United States Geol. Surv., Monograph 52, 641 p.

Van Hise, C.R., & Leith, C.K., Precambrian Geology of North America, United States Geol. Surv., Bull. 350, pp. 403-447.

Wanless, R.K., & Trail, R.J., 1956, Age of Uraninite from Blind River, Ont., Nature, vol. 178, pp. 249-250.

Wetherill, G.J., Davis, G.L., & Aldrith, L.T., 1957, Age Measurements in Rocks North of Lake Huron, Amer. Geophys. Union, Program of 28th Ann. Meeting, pp. 39-40..

Whitney, J.D., 1857, Remarks on the Huronian and Laurentian Systems of the Canadian Geological Survey, Amer. Jour. Sci., 3rd. Ser., vol. 23, pp. 305-314.

Willmott, A.B., 1898, Michipicoten Mining Division, Ont. Bur. of Mines, Rept. 7, pp. 184-206.

Willmott, A.B., 1901, The Michipicoten Huronian Area, Amer. Geol., vol. 28, pp. 14-19.

Willmott, A.B., 1904, The Contact of the Archean and Post Archean in the Region of the Great Lakes, Jour. Geol., vol. 12, pp. 40-42.

Wilson, M.E., 1913, The Cobalt Series, Its Character and Origin, Jour. Geol., vol. 21, pp. 121-141.

Wilson, M.E., 1913, The Significance of Recent Developments in the Precambrian Straaigraphy of the Lake Superior - Lake Huron Region, Jour. Geol., vol. 21, pp. 385-398.

Wilson, M.E., 1958, Precambrian Classification and Correlation in the Canadian Shield, Bull. Geol. Soc. Amer., vol. 69, pp. 757-774, Jour. Geol., vol. 11, p. 651.

Wilson, W.J., 1906, Report on the Region Between Lake Temagami and Spanish River, Geol. Surv. Can., Summ. Rept., 1905, pp. 82-84.

Winchell, A., 1887, Observations in the Typical Huronian Region of Canada, Sixteenth Ann. Rept., Geol. and Nat. History Surv. of Minnesota, pp. 145-171.

Winchell, A., 1890, Recent Observations on some Canadian Rocks, Amer. Geol., vol. 6, pp. 360-370.

Winchell, A., 1891, A Last Word with Huronian, Bull. Geol. Soc. Amer., vol. 2, pp. 85-124.

Winchell, N.H., 1887, The Original Huronian, Sixteenth Ann. Rept., Geol. and Nat. History Surv. of Minnesota, pp. 12-40.

Winchell, N.H., 1889, Further Observations of the Typical Huronian and on the Rocks about Sudbury, Ontario, Eighteenth Ann. Rept., Geol. and Nat. History Surv. of Minnesota, pp. 47-59.

Woolverton, R.S., 1950, The Camray Discovery Dyke and Associated Uranium Deposits, Master of Science Thesis, McGill University.