Preliminary Redefinition of the Cobalt Group (Huronian Supergroup), in the Southern Geologic Province, Ontario, Canada

Written by: ***Steven D.J. Baumann, Teresa Arrospide, Adam E. Wolosyzn***

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Edited by: ***Elisabeth Michaels***

Cover Photo: *Lower Echo River Member* of the *Lorrain Formation* at its type section. Apparent dip of bedding is from upper left to lower right in the photo.
Photo taken by Steven D.J. Baumann on 7-20-2010

Table of Contents

Topic **Page**

Table of Contents

Attachments are located at the end of the publication and are denoted with letters of the alphabet.

Figures

Page or Attachment

Tables

Photos

Abstract

The *Cobalt Group* is the succession of rocks at the top of the *Huronian Supergroup*. Their thickness varies from a maximum of 14,500 feet (in the Sault Ste. Marie Area) to about 29,800 feet (Cobalt Plain Area). They are by far, the thickest group in the *Huronian*, but the least understood. Understanding these rocks is key to searching for minable minerals. Since the area of the Pre-cambrian in the Southern Province is complicated by faulting, the stratigraphy of the *Cobalt Group* needs to be better understood than it is at present. This preliminary report addresses some of the present inadequacies of the present classification system of the *Cobalt Group*. Herein, several new members, tongues, and lenses are proposed. We retain the basic four formations already named within the *Cobalt Group* (the *Gowganda*, the *Lorrain*, the *Gordon Lake*, and the *Bar River Formations*). These proposed units are tentative because more work needs to be done to test the validity of at least one of the new units. Plus further input is needed from geologists in Ontario.

Photo 1:
Lorrain Formation, West Side of Route 638, northbound

Taken: 9-6-2010
By: Steven D.J. Baumann

Introduction

The *Huronian Supergroup* is one of the most economically important group of rocks in the Midwest. It is known to contain gold, silver, copper, iron, and even uranium. The focus of this report is the least explored *Cobalt Group*, which is the upper most and youngest group of the *Huronian Supergroup*. Uranium is suspected to be present in the base of the lowermost *Gowganda Formation* of the *Cobalt Group*. Iron and possibly copper are present in all of the other formations. The *Cobalt Group* is unique within the Huronian as it is the first group of rocks where extensive red beds first appear in the Midwest. This is because around the time of deposition for these rocks, significant free oxygen appears in the atmosphere, for the first time in Earth's history. This further increases the likelihood for minable iron bearing minerals within the *Cobalt Group*.

In order to mine these resources we need to understand the structural geology of the area. This is important because minerals tend to concentrate along structures in sedimentary rocks. Such as along faults, anticlines, synclines, and around igneous intrusions within the rocks. On a regional scale the structure of the *Cobalt Group* is pretty well understood. However, locally, due to lack of exploration, vegetation cover, lakes, and manmade structures, detailed local maps are good general guides at best. In order to better understand local structures there needs to be a more detailed effort among exploration companies to take good logs and cores. In order to concentrate drilling activities in profitable areas we need to be able to rule out certain areas. We can't focus exploration efforts without a better understanding of local geologic structures and without first having a detailed stratigraphic understanding of the rock units within an area.

The *Huronian* rests in the Southern Geologic Province which includes the entire *Huronian* in Ontario, and extends west through the Upper Peninsula, Northeastern Minnesota, and the very Northwest tip of Wisconsin. In Ontario, the Southern Province is bounded to the east by the Grenville Province and to the north by the Superior Province.

Over the past 40 years many useful maps from Sault Ste. Marie to the Cobalt Plain (the extent of the *Huronian*), have been produced. Within these isolated mapped areas, many useful geologic members within the formations of the *Cobalt Group* have been described. The problem is, little effort has been made to correlate and name these members in a practical and useful manner, until now.

Purpose

This publication attempts to define useful members, tongues, and lenses within the *Cobalt Group*. What is meant by the word "useful"? We define "useful" as a classification scheme that is detailed enough to get a general geological understanding of the *Cobalt Group* without going into too much detail. We want the units defined within this paper to be recognized not only by Ph.D.'s who have been studying the rocks for 30 years, but by professionals new to the area. We want individuals to be able to recognize these units even if they are studying poor exposures in the field, or from scant drill cuttings as opposed to complete core runs.

This publication builds on decades of detailed research conducted mostly by geologists in Ontario, and attempts to define useful units within the formations of the *Cobalt Group*, without significantly redefining the general framework. For example, the *Cobalt Group* has traditionally been divided into four formations. This paper will not change that. We will use the 2005 "North American Stratigraphic Code" (the Code) as our criteria for classifying units and we will try to stick to the 1969 Federal-Provincial Huronian Stratigraphic Committee's guidelines. Our new designations will have type sections and will be based off the detailed work of others who have mapped the area. New members, lenses, and tongues will be widely traceable and will hopefully be easily recognized in future exploration activities.

This is a preliminary assessment of useful stratigraphic units. Herein, names and type sections are proposed. The reason that this is not the final assessment is because there needs to be some confirmation work done on some of the proposed units. In addition, input from local Canadian experts is still needed.

Method

A combination of field work and research was conducted in the Spring, Summer, Fall, and Winter of 2010. Most of the field work was conducted by the authors and focused mostly around the Sault Ste. Marie Area. There was not enough time to explore the entire Southern Province, so detailed research had to be conducted. Fortunately, the Ontario Geological Survey has done an excellent job over the past 100 years trying to decipher the *Huronian Supergroup*. Other independent organizations have also made great strides over the past 50 years, such as the "Institute on Lake Superior Geology" and the "Midwest Institute of Geosciences and Engineering", through greatly detailed field guides and outcrop descriptions. Most of this publication is the product of the study by several generations of geologists and explorers along the north shore of Lake Huron.

Cobalt Group

The *Cobalt Group* is the uppermost succession of rocks within the *Huronian Supergroup*. These rocks are exposed in Ontario mostly just north of Lake Huron (see Figures 1A and 1B). The *Cobalt Group* is the youngest of the *Huronian* groups and consists of four formations, of which only one has been divided into formal members. Figure 2, is a generalized stratigraphic column of the *Huronian Supergroup*. There is a need to divide the four formations into members, due to the extreme thickness (see Attachment A) of these units and their understudied economic potential. For the convenience of talking about the *Cobalt Group* in different areas, the Southern Province has been subdivided into the Sault Ste. Marie, Elliot Lake, Espanola, Sudbury, and Cobalt Plain Areas (see Figure 1B). All the formations of the *Cobalt Group* tend to thicken in the areas near the Flack Lake Fault and Murray Fault (see Figure 1B).

The *Cobalt* is significant for several reasons. It contains the first "red beds" in the geologic record. The presence of red in sedimentary rocks is caused by hematite (iron) and indicates significant oxygen in the atmosphere. The fact that ancient metamorphosed glacial diamictites are preserved at the base, has lead to the potential accumulation of minerals, such as uranium and copper. The rocks of the *Cobalt Group* show drastic climatic changes in time span of about 120 million years. You have rocks deposited by glaciers, river deltas, tidal flats in a tropical environment, meandering rivers, and desert winds. All of these rocks have been tectonically metamorphosed into quartzites, argillites, and other low grade metamorphic rocks. The *Huronian Supergroup* is relatively unique in the fact that we can nail down the age of the rocks with near certainty. Thanks to the fact that there are igneous intrusions not only near the base but up through and at the top of the supergroup. The *Thessalon Formation* is near the base of the supergroup and has been dated to 2.450 Gya. The *Nippissing Diabase* cuts through the *Huronian* and overlies it. It has been dated at 2.219 Gya. Knowing this we can determine the age of the sedimentary formations by using what we know about sedimentary rates and unconformities (see Figure 2).

In general the *Cobalt Group* shows a general maturing up sequence. This means that amount of quartz relative to feldspars and lithic fragments, increases as you go up (to younger rocks) through the formations. The *Cobalt Group* is bounded by unconformities above and below but all units within are gradational with one another. There does not appear to be any unconformities within the *Cobalt Group*. The basal *Gowganda Formation*, is the most texturally immature formations in the *Cobalt Group*. It contains diamictites (commonly called glacial till) in three main layers. The diamictites (and interbedded rocks) are collectively called the *Coleman Member*, named by Thomas in 1968. It is overlain by the delta deposits of the *Firstbrook Member*, which is mostly feldspathic (arkosic) siltstones (argillites) and sandstones. The *Gowganda* grades up into the sandstones (quartzites) of the *Lorrain Formation*. The *Lorrain* is the thickest of the *Cobalt Group* formations (see Attachment A). It is extremely feldspathic near the base and almost a pure quartz arenite at the top. The *Lorrain* grades up into the *Gordon Lake Formation* which is very fine grained and contains much feldspar. It also contains much chert and some evaporates. The *Gordon Lake* grades upward into the most texturally mature formation of the *Cobalt Group*, the *Bar River Formation*. The *Bar River* is mostly white arenites with lenses of white kaolin.

Gowganda Formation

The *Gowganda Formation* is the oldest and basal formation of the *Cobalt Group*. It was named by Collins in 1917, although he designated no type section. The principle reference section (used as the type section) is the same as for the *Coleman* and *Firstbrook Members*. Other reference sections are north of Bruce Mines (Sault Ste. Marie Area), Highway 108-Dunlop Lake, and Whitefish Falls or Lake Penage (Robertson, Card, Frarey, 1969). Herein the *Gowganda* will be described in detail and not redefined. We feel that the present divisions are sufficient and no nomenclatural corrections are needed.

Overall, the *Gowganda Formation* is best described as a dark green to dark gray, brown, and red, sandy polyomitic paraconglomerates (diamictites) interbedded with fine to coarse lithic arkosic wackes to arkosic wackes. Figure 5 contains the classification used for conglomerates. The basal part, has been correlated with the *Fern Creek Formation* and the *Enchantment Lake Formation* of the *Chocolay Group* in the Upper Peninsula of Michigan, using the lithology of the diamictites (see Figures 3 and 4). It is herein suggested that the *Coleman Member* be extended into the bottom parts of the *Fern Creek* and *Enchantment Lake Formations*. According to Article 25 of the Code (2005), "A member may extend laterally from one formation to another." There are three "subcycles" of glaciation recognized in the *Gowganda* from Ontario into the *Fern Creek* of Michigan (see Figure 3), further reinforcing correlation. Lithology or paleomagnetism is the only way to correlate the *Huronian* rocks with other rocks since macro-life doesn't appear in abundance until the Cambrian (almost two billion years after the oldest *Huronian* rocks).

In 1968 R. Thomas attempted to divide the *Gowganda* into two separate formations, the *Coleman* and *Firstbrook Formation* based on a 7000 foot deep drill hole in Henwood Township. However, Fedreral-Provincial Committee on Huronian Stratigraphy in 1969 (the 1969 Committee), decided that the *Coleman* and the *Firstbrook* should be reduced to formal members. This publication reinforces the 1969 Committee's decision. The principal reference sections are the Eplett Drillhole conducted in 1966 by R. Thomson.

Figure 1A: Huronian Supergroup Location Map

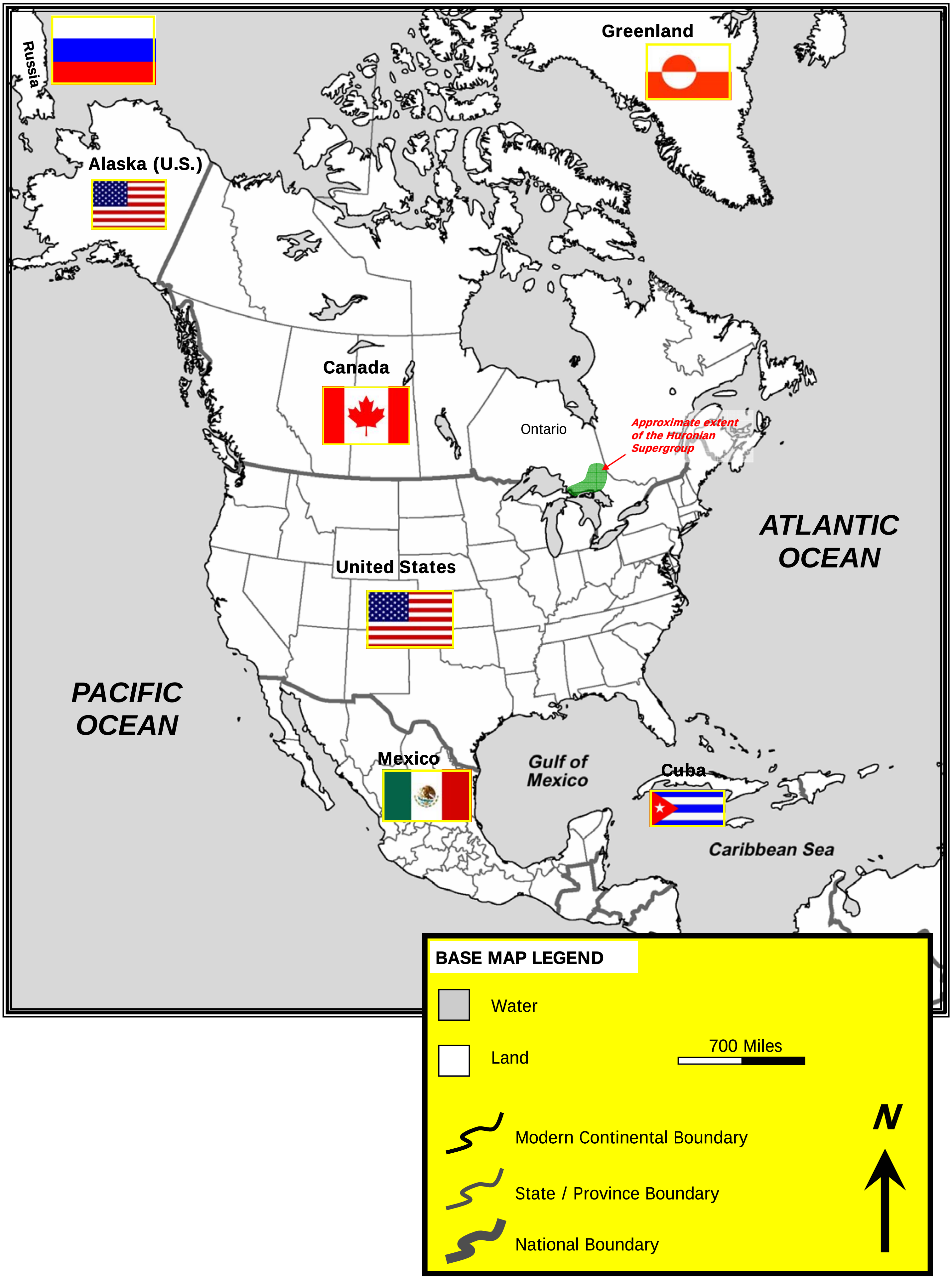
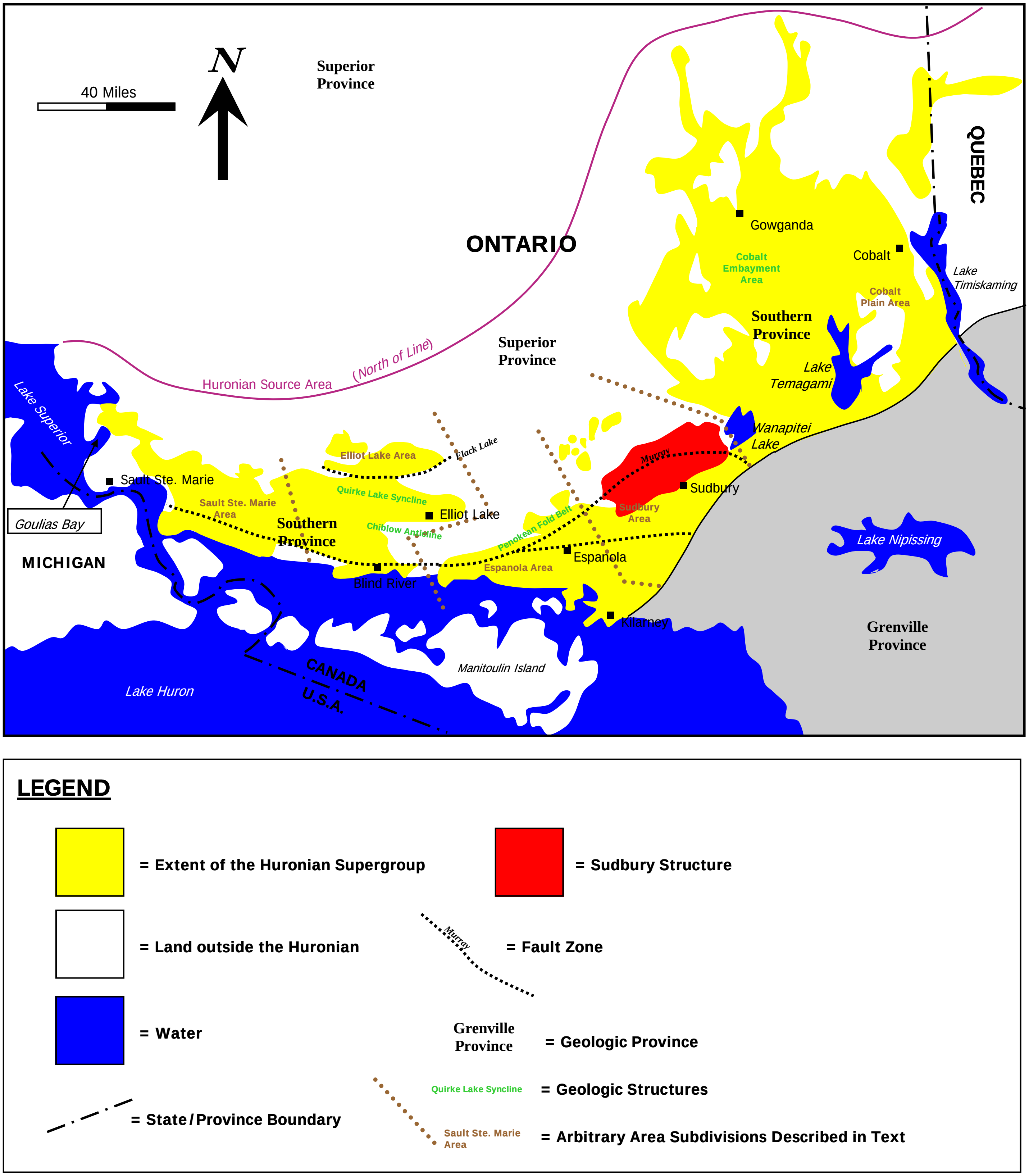
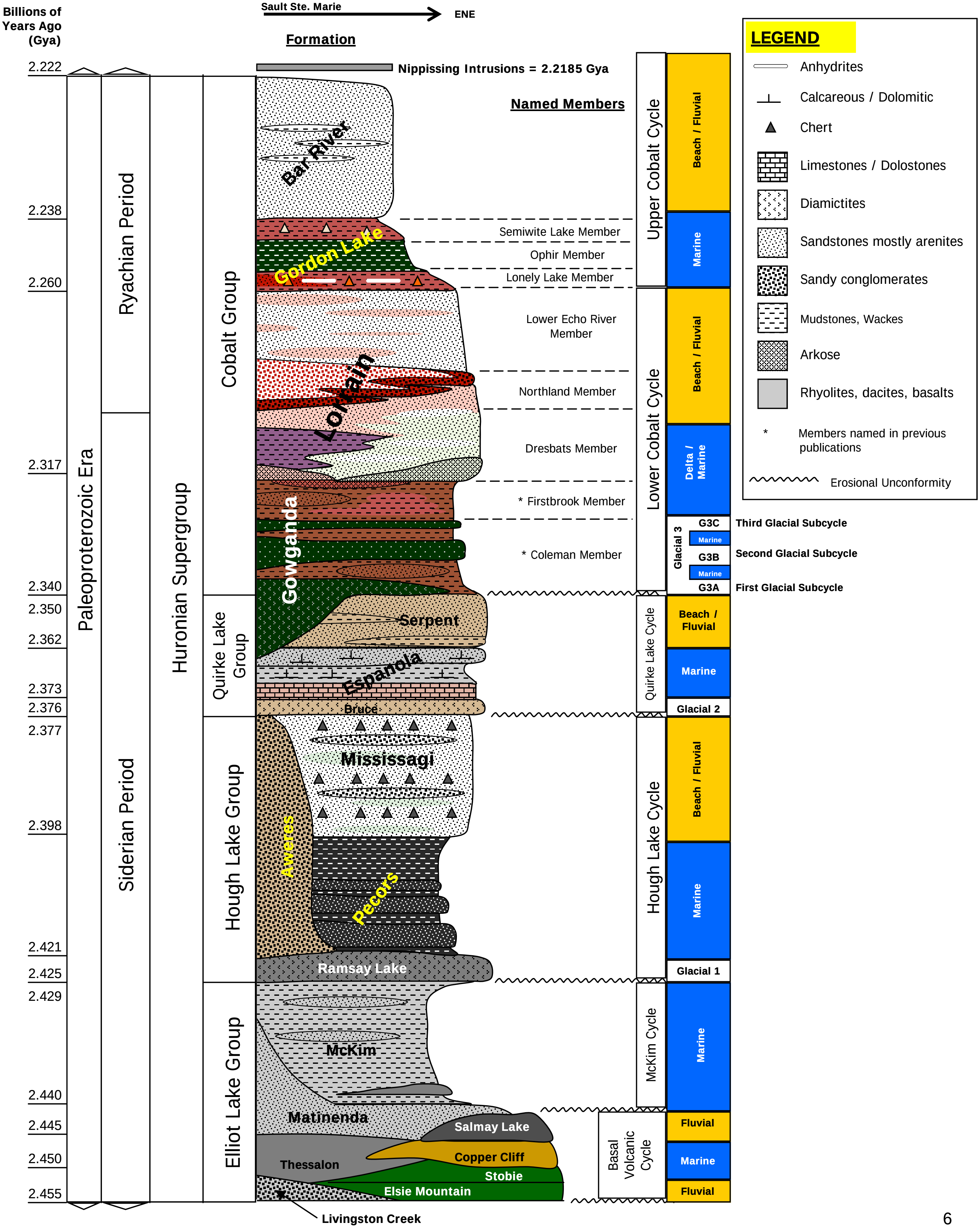


Figure 1B: Extent of Huronian Supergroup in Ontario Canada



Adapted from the "Geology of Ontario, Special Volume 4 Part 1, 1991, p.550

Figure2: General Stratigraphic Column of the Huronian in Ontario Canada



Coleman Member

The *Coleman Member* has probably been best described by Born (1989). He divided the member into two basic parts. One is the basal brecciated conglomerate, which occurs only where the *Coleman* lies directly on Archean rocks. An upper arkosic pebble wacke and conglomerate. The basal brown breccia is generally a dioconglomerate with Archean granite cobbles and boulders in a wacke matrix. The pebbles and boulders within the member are mostly quartz, granites, and lithic components of older formations. The bulk of the member is a dark green to dark gray polyomitic pebble paraconglomerate. The matrix is dominantly an arkosic wacke with local laminations to thin beds of mudstones and pebbly arkoses. The *Coleman Member* has isolated dropstones and ripple marks are common throughout the member. This basal conglomerate is not present where the *Gowganda* lies (unconformably) on the *Serpent Formation* or *Espanola Formation* of the *Quirke Lake Group*.

The *Coleman Member* has the most economic potential in the *Gowganda*. Uranium is suspected to be relatively common and in some places even mineable in the member, especially near the base and around igneous intrusions and near basal breccias. Although, the uranium potential of the *Coleman Member* has yet to be explored, base metals are known to be common as disseminated pyrite and chalcopyrite within the *Gowganda* as a whole.

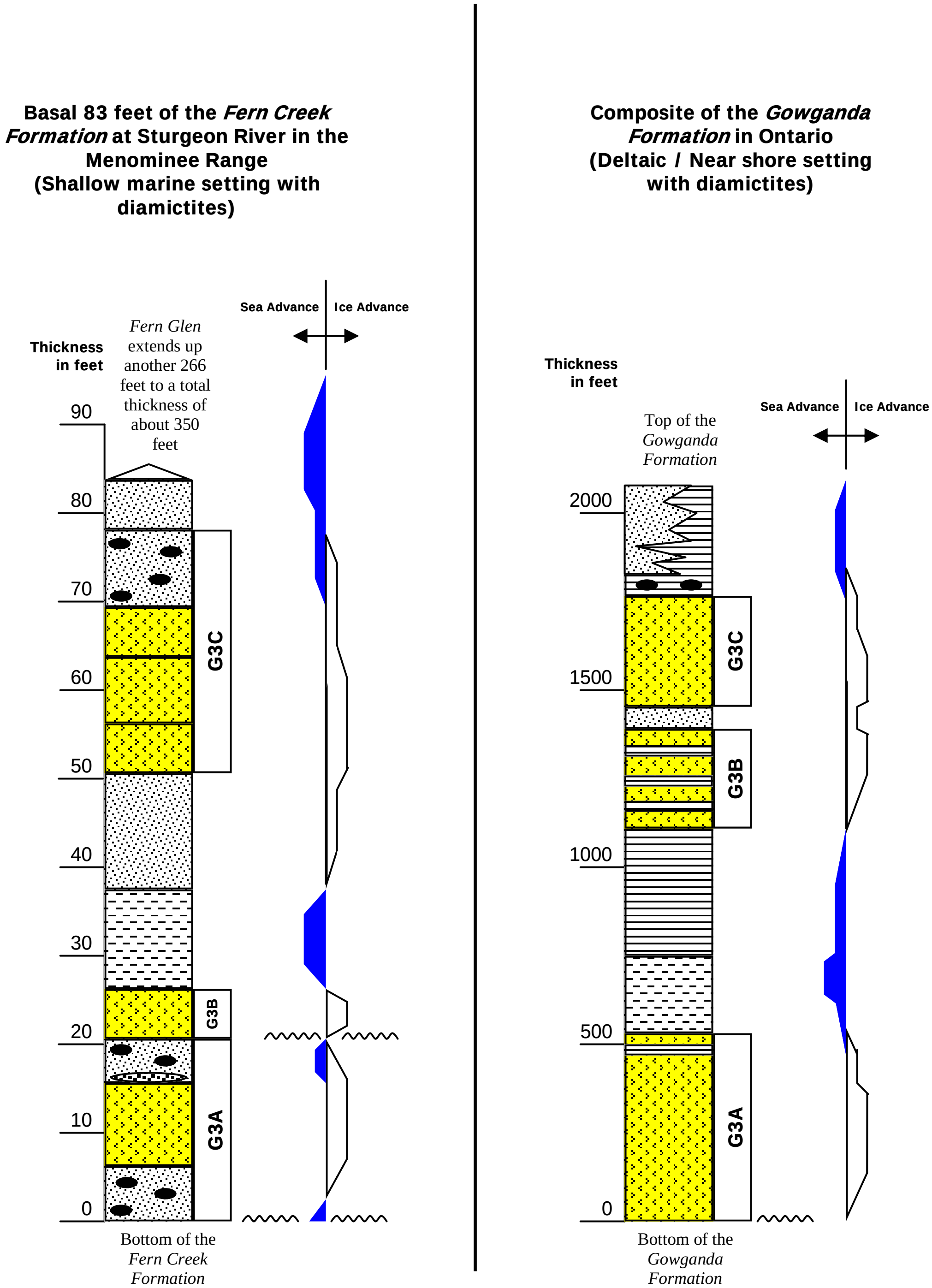
Firstbrook Member

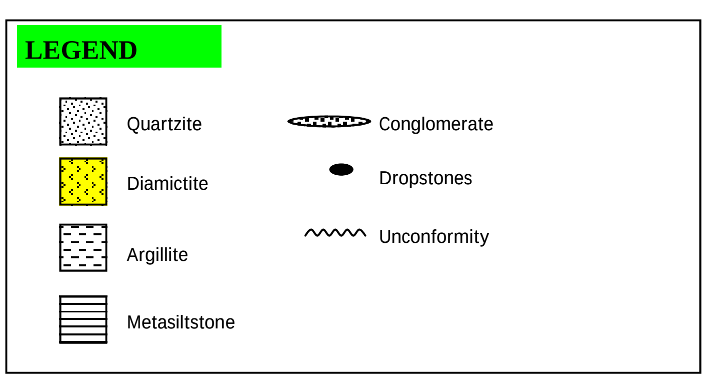
The *Firstbrook Member* was also described in detail by Born in 1989. The *Firstbrook* is the thinner of the two members (generally less than 600 feet thick) and the lower contact is placed at the top of the third diamictite unit of the *Coleman Member*. The upper contact is 60 feet in gradation with the overlying *Lorrain Formation*. Arkoses in the gradational area are included in the *Firstbrook*. Overall the *Firstbrook* is a moderately indurated, dark green to dark metallic gray or bluish gray, or deep red to brown argillites (low grade metamorphosed mudstones). It is usually laminated to wavy and cross laminated with abundant starved and symmetrical ripple marks (see Photo 3). Isolated drop stones are present in the lower part outside of the Sault Ste. Marie Area. The mudstones are feldspathic, and near the top, fine sandstones are common. The member is interpreted to be deposited in a low energy delta environment. Herein a new reference section is denoted in a northern outcrop along Route 638 at GPS coordinates north 46.46892 by west 83.8833 (see Photos 2 and 3) and is named the "East Leeburn Outcrop". The ripple marks at the East Leeburn Outcrop are typical of wind blown beach ripples right near where land meets the sea. The *Firstbrook* is not expected to have any economic use.

PHOTO 2: *Firstbrook Member* of the *Gowganda Formation* westbound along Route 638 looking east-southeast. Beds are near vertical. Ripple marks are present. GPS: 46.46892 –83.8833
Taken by: Steven D.J. Baumann on 7-2-2010

PHOTO 3: Same location as Photo 2, zoom in on the ripple marks.
GPS: 46.46892 –83.8833
Taken by: Steven D.J. Baumann on 7-2-2010
12 inch hammer for scale

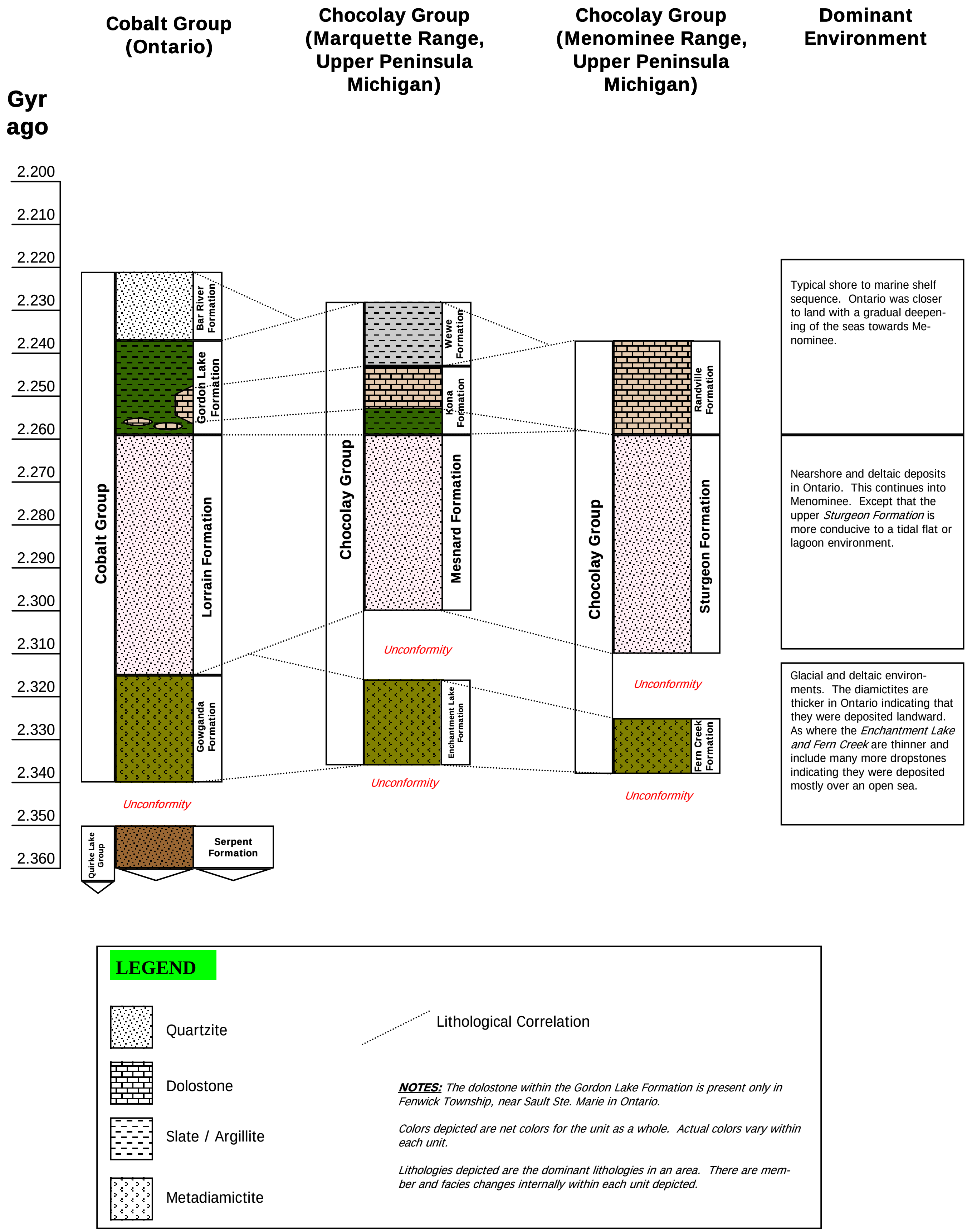
Figure 3: Glacial Subcycles within the Gowganda (Ontario) and Fern Creek Formation (Menominee Range, Michigan)





NOTES: *G = glacial. The following number is the cycle cycle during the Huronian. For example "G3" is the third glacial cycle within the Huronian. The suffix letter is the subcycle. For example "G3C" is the third subcycle to occur within the third Huronian glacial cycle. Lower numbers and letters correspond to older events. For example "G3B" occurred before "G3C".*

Figure 4: Correlation of the Cobalt Group (Ontario) with the Chocolay Group (Upper Peninsula, Michigan)



Adapted from Bekker and Bennett (2006)

Lorrain Formation:

The *Lorrain Formation* is perhaps the thickest and most extensive formation of the *Cobalt Group* (see Attachment A). Although it has been extensively mapped, its economic potential and geologic history are still poorly understood. Many authors, over the years, have attempted to divide the *Lorrain* into members, but no attempt at formal naming of members has taken place. Many authors have divided the *Lorrain* into as many as seven informal members, although about three appear to be regionally consistent (see Figure 7). Jackson divided the *Lorrain* into six members, Bennett into seven and four (depending on the area), Siemiatowska into six, Johns into four, and Card into six.

Generally the *Lorrain Formation* can be easily distinguished from other *Cobalt* formations by its white color with pink to red mottled sandstones and olgometic orthoconglomerates. Although mostly a sandstone the *Lorrain* does contain conglomerates and siltstones. The sandstones show a general maturing up sequence. The basal sandstones tend to be arkoses to subarkoses and arkosic wackes to subarkosic wackes (see Attachment C for sandstone classifications). The sandstones near the top are generally quartz arenites. There are some coarse arkoses at the base. The contact with the underlying *Gowganda Formation* is gradational by as much as 300 feet but generally less than 180 feet. Most of the arkoses in this gradational contact between the *Gowganda* and *Lorrain* are now included within the *Gowganda* (Jackson 1994).

The 1969 Committee defines the type section for the *Lorrain Formation* in Lorrain Township, in the Cobalt silver area. The type section was named by Thomson in 1964 and is no longer exposed. There are three designated reference sections. The best exposures were pointed out by Collins in 1925 and consist of exposures between Bruce Mines and Desbarats in the Sault Ste. Marie Area. Two other vague reference sections have been assigned in the Whitefish Falls and Mount Lake local areas.

The authors of this publication recommend that the *Lorrain Formation* be divided into three formal regional members (a basal, middle, and upper), with two of the three members each containing one local formal tongue and one local formal lens. Although many authors have divided the *Lorrain* further, we believe that a division of three members is ideal and much more recognizable in outcrops and subsurface drilling. This three member division will allow for future local formal beds, tongues, and lenses to be recognized without having to discard the basic three member structure proposed here.

Lower Echo River Member

We propose that the upper 990 to 3700 feet of the *Lorrain Formation* be included in the *Lower Echo River Member*. It is named for the Lower Echo River which crosses the highway about 3/4 of a mile north of the type section. In the past this member has been informally referred to as the "Upper Quartzite Member". The type section is named for a road cut along Highway 17B approximately 1 mile north of the first Echo Bay exit sign, in the Sault Ste. Marie Area. The GPS coordinates are: North 46.50626 by West 84.04568. Here the member is greater than 30 feet thick and is a very hard, white mottled red, massive bedded, fining upward sequence, from coarse quartz arenite to fine quartz arenite. There are light pink kaolin clays along fracture planes and rare red thin shale partings along bedding planes. There is a subrounded semi-transparent, quartz oligmitic sandy orthoconglomerate exposed one to two feet above the base, which may actually be the top of the middle member. This description is typical of the member at other outcrops. The member is often cut by red veins of hematite (see Attachment A for a photo). This member is not presently subdivided into any beds, lenses, or tongues and is not present in the Cobalt Plain (see Figure 7).

PHOTO 4: Coarse grained quartz arenite near the base of the *Lower Echo River Member* at the type section. Photo taken by: Steven D.J. Baumann 7-2-2010.
$2 piece for scale.

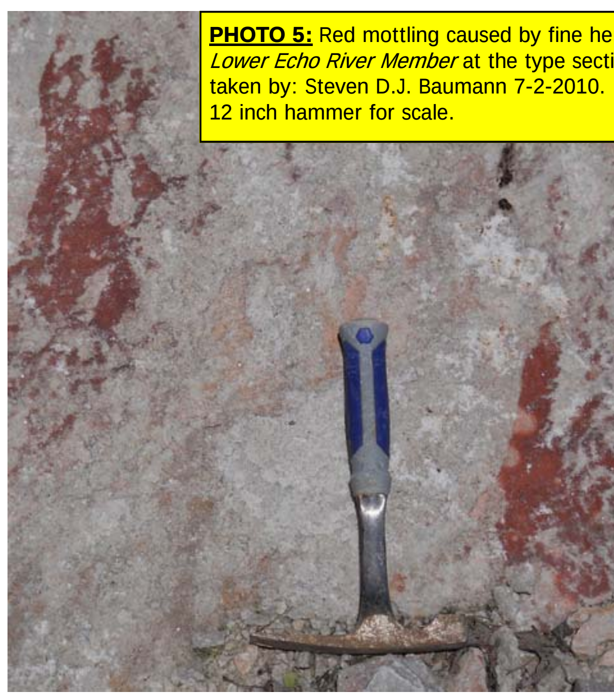


PHOTO 5: Red mottling caused by fine hematite in the *Lower Echo River Member* at the type section. Photo taken by: Steven D.J. Baumann 7-2-2010.
12 inch hammer for scale.

Figure 5: Classification of Conglomerates

3 basic types of conglomerates: Paraconglomerate: Matrix supported (Diamictites and Debris Flows)
Orthoconglomerate: Clast supported (River bars, Outwash, some Desert Pavement)
Dioconglomerate: Combination of Matrix and Clast supported (Bedded Conglomerates)

2 subtypes of conglomerates: Oligometic: Conglomerate $\geq$80% 1 rock type (i.e. silicas or feldspars)
Polyometic: Conglomerate $\leq$80% 1 rock type or multiple rock types (i.e. lithics)

Naming Procedure: Subtype (if applicable); prefix (if applicable i.e. sandy, muddy, etc.); basic type

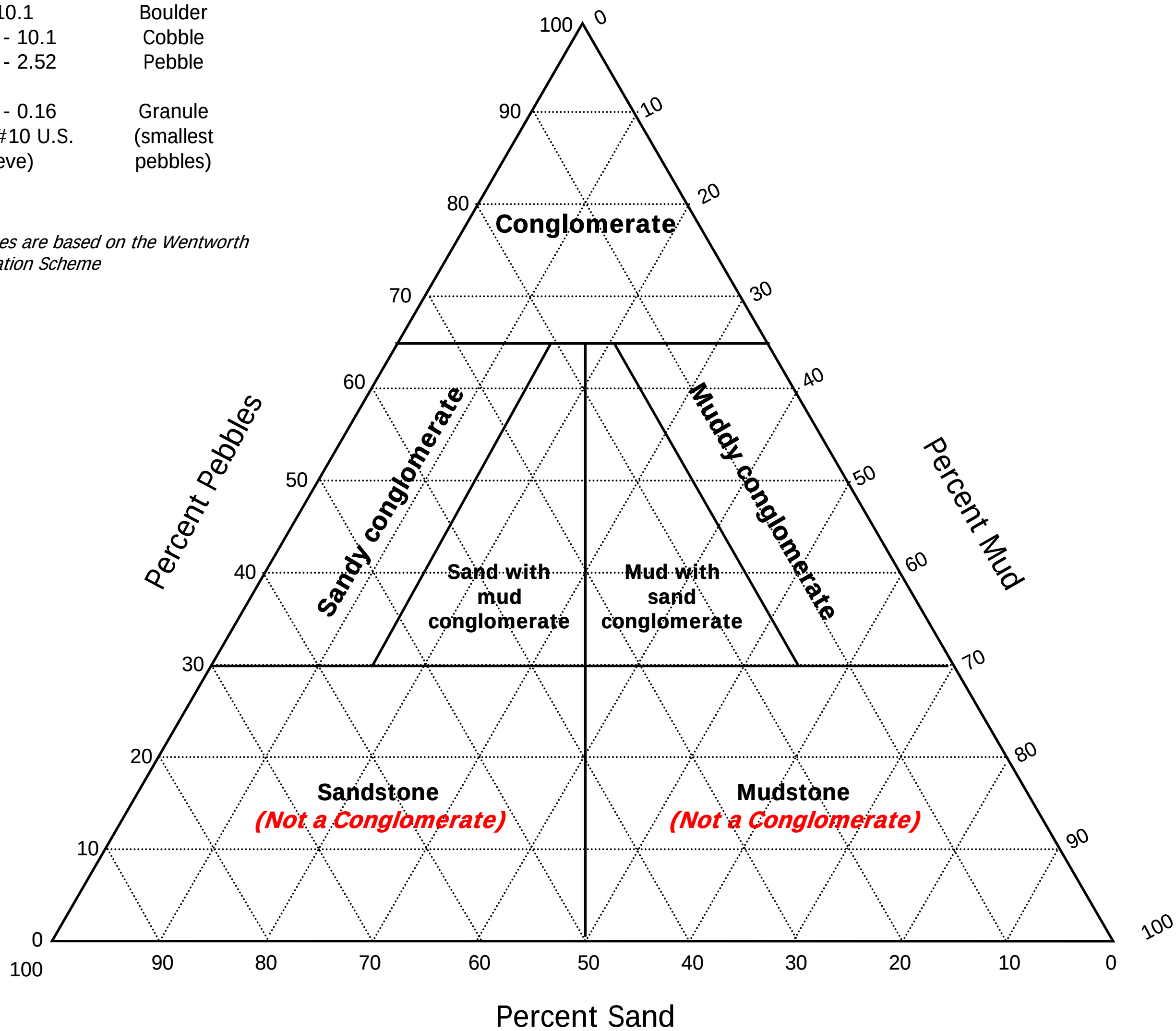
Examples: The Red Jasper Conglomerate of the *Lorrain Formation* (*Puddingstone Lake Member*) Sault Ste. Marie and Elliot Lake Areas are mostly an "Oligomitic Orthoconglomerate" to "Oligomitic Sandy Orthoconglomerate".

The *Aweres Formation* in the Sault Ste. Marie and Elliot Lake Areas is mostly a "Polyomitic Sand with Mud Paraconglomerate"" to "Polyomitic Muddy Conglomerate".

Clast size (inches)	Clast Name
>10.1	Boulder
2.52 - 10.1	Cobble
0.08 - 2.52	Pebble
0.08 - 0.16 (#5 - #10 U.S. Sieve)	Granule (smallest pebbles)

Grain sizes are based on the Wentworth Classification Scheme

CONGLOMERATES
(with matrix classification)



NOTES: *Unlike with sandstones, the matrix is an active part of the classification. It is not excluded during classification. Words like "granule", "pebble", "cobble", or "boulder" can be added to the "basic type" if the grains are large enough or added distinction is needed.*

Northland Member

The middle member is herein named the *Northland Member*, named for the town of Northland, about 1.85 miles east of the type section. This member has been informally called the "Upper Red Quartzite, Red Pebbly Arenite, Hematitic Sandstone, Buff Hematitic Sandstone with conglomerate, and the Rusty Member". The type section is an outcrop along the south side of Highway 556 in the Sault Ste. Marie Area. The *Northland Member* extends throughout most of the region. It varies from about 430 to 2950 feet thick. At the type section it is near an unnamed fault and the beds are nearly vertical. This member contains the beautiful Red Jasper Conglomerate or Puddingstone. The GPS coordinates are north 46.71742 by west 84.19462 at the type section. At the type section the *Northland* is a very hard, red, white, and pink, with rare yellow and green beds of medium to coarse grained, subarkose to quartz arenite. Ripple marks are present as are some granular to fine pebbles of white, semi-transparent, and red quartz, with thin to medium beds of pale red to pink laminated argillite. At the type section, red is not the dominant color. However, in most of the outcrop areas it is usually red or very pale yellow brown. The key to differentiating this member is the abundance of pebbles within it. Almost everywhere the member contains at least 5% to 30% subrounded to rounded pebbles and is coarse grained. It loses its red color as you head east and is absent in the Cobalt Plain. The overall depositional environment of the *Northland* is either shallow marine or fluvial streams.

Around the Dresbarats Lake in the Sault Ste. Marie Area in Johnson Township, iron and copper with minor cobalt and uranium have been found. The copper is most likely near the *Northland-Lower Echo River Member* contact. There is abundant sericite at the contact, which is a key indicator of copper. The iron is most likely in the member below the *Northland*, in veins and along contacts with the *Nippissing* intrusions. The cobalt and uranium appear to be concentrated along the contacts with the *Nippissing* intrusions.

PHOTO 6: Near vertical ripple marks in the *Northland Member* at its type section. Photo taken by: Steven D.J. Baumann 9-6-2010.
12 inch hammer for scale.

PHOTO 7: Coarse sand to granular nature of the *Northland Member* at its type section. Photo taken by: Steven D.J. Baumann 9-6-2010. $2 piece for scale.

PHOTO 8: Pink mottling in the *Northland Member* at its type section. Photo taken by: Steven D.J. Baumann 9-6-2010.
12 inch hammer for scale.

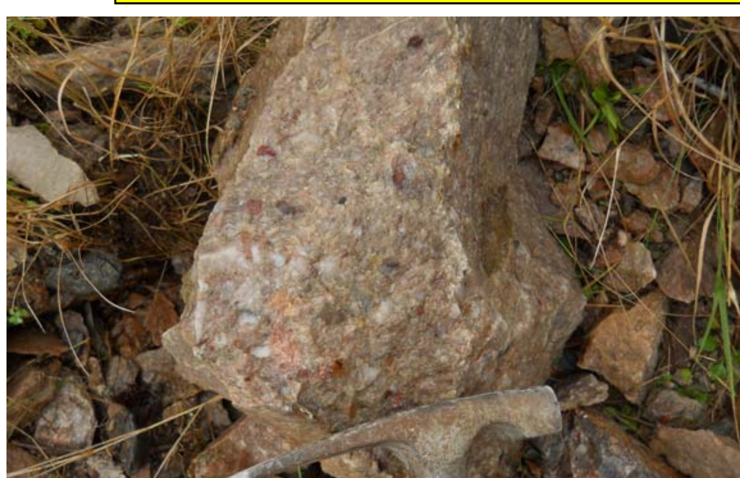


PHOTO 9: *Puddingstone Lake Tongue* at the *Northland Member's* type section. Photo taken by: Steven D.J. Baumann 9-6-2010.
6 inch hammerhead for scale.

Puddingstone Lake Tongue
The *Northland Member* contains two subordinate formal units. The most extensive is the *Puddingstone Lake Tongue* (informally called the "Red Jasper or Puddingstone Conglomerate"). The type section is exposed near McGrath Lake in Jackson Township, in the Elliot Lake Area. GPS coordinates are north 46.5572 to 46.5578 by west 83.2887 to 83.2864. It is named for Puddingstone Lake located about 1.5 miles south-southwest of McGrath Lake. The *Puddingstone Lake* is present only in the Sault Ste. Marie and Elliot Lake Areas. Further east it becomes thin intertongues or lenses within the *Northland*. It is 0 to 650 feet thick being thickest in the Sault Ste. Marie Area. It can be differentiated from the surrounding *Northland* by its pebble content. Generally the member is a olgometic sandy orthoconglomerate consisting of subrounded granular to medium pebbles of red jasper, black chert, white quartzite, and semi-transparent quartz in a coarse sand matrix. Pebble content ranges from 30% to as much as 90%. The *Puddingstone Lake* may be river bar, or migrating river mouth deposits near an ancient sea.

Blinko Lake Lens
There is an isolated yet significant "marker bed" in Grasett Township which was noted by Siemiatkowsk in 1977. He referred to it as "Unit 5d" but herein will be proposed as the *Blinko Lake Lens*. In 1978, Siemiatkowsa noted the same unit in Albanel Township and called it Unit 11d. Units 5d and 11d, connect in a roughly east-northeast trending line over an 11mile distance (althought out-crops may extend further). It's type section is 0.25 miles almost due north of Blinko Lake where it is 0 to 100 feet. It is not known to occur outside Elliot Lake Area or north of the Endikai Lake Fault (an east-west trending fault just to the north of the larger Flack Lake Fault). It is defined as a lens since it most likely pinches out on all sides laterally. It occurs just above and is gradational with the *Puddingstone Lake Tongue*. It is unique within the *Northland Member* because it contains almost no pebbles and is much finer grained. Its color varies from orange, red, pink, and white. It is a moderately well sorted, fine to medium grained, quartz arenite to subarkose. It has a sugary texture with discontinuous wedge shaped beds. The rare pebbles (<1%) that do occur are red jasper and quartz. There are black hematite laminations in the bottom 1/4 and purple leisgang rings (secondary weathering condition possibly from groundwater movement) in the upper and bottom 1/3. Due to the wedge shaped bedding and distinctive orange color of the *Blinko Lake*, it may have been deposited in a migrating dune environment near a shoreline.

Dresbarats Member
The basal member of the *Lorrain Formation* has been informally referred to as the "Purple Wacke, Purple Feldspatic Wacke, Basal Red Siltstone, Ripple Rock, Lower Red Quartzite, Purple Siltstone Member, and the Basal Arkose Member". Herein the name *Dresbarats Member* is proposed. It is named for the town of Dresbarats near where the best western outcrops are exposed. It varies from about 80 feet in the Sault Ste. Marie area to more than 4200 feet in the Cobalt Plain. It thickens at the expense of the *Northland Member*. The type section is from an outcrop noted by Bennett (2006). He referred to it as the Lower Red Quartzite/Siltstone Member. It is approximately 15.5 miles south of the intersection of Routes 17B and 638 along the north side of the road. The GPS coordinate is approximately north 46.3374 by west 83.9549 at an elevation of about 698 feet above mean sea level. At the type section it is a steeply bedded, red, siltstone with oscillating ripple marks. It is locally known as "Ripple Rock". The *Dresbarats* is also a purple siltstone with lenses of arkose along the shore of Lake Huron in the Sault Ste. Marie Area. As you head east the member becomes more of a subarkose wacke to quartz wacke and loses a lot of its deep red and purple color. The *Dresbarats* is gradational with the above *Northland Member* and the underlying *Firstbrook Member* of the *Gowganda Formation*.

McLennon Lake Tongue
The *Dresbarats* contains two traceable subunits. The largest is the *McLennon Lake Tongue*, which occurs at the top of the member from the Sudbury to Cobalt Plain Areas. The type section is located approximately 0.25 miles north and about 1.05 miles south of McLennon Lake in Kittson Township. It exists in scattered outcrops around the lake with the GPS of the center of McLennon Lake at north 47.393638 by west 79.968284. Its estimated thickness is 0 to 400 feet, although it maybe significantly thicker. In the type area it is a maroon, reddish gray, to green, arkosic wacke to subarkosic wacke. Occasionally red and green beds will interbed. It is overall thinly laminated, to cross bedded, and very rippled. It is poorly sorted and dominantly a coarse silt to fine sand. Often it is almost 50/50 quartz/feldspar. Lenses of well sorted green arkoses are common as are flakes of biotite. All of its contacts with similarly aged units and are gradational.

Malcolm Lake Lens
Although quartz arenites are not common in the *Drebarats Member*, there is one significant outcrop. Near Malcolm Lake there is a gray to orange fine grained quartz arenite that is herein named the *Malcolm Lake Lens*. The type section is at about 1090 feet above mean sea level with a GPS coordinate of north 47.4478 by west 79.8508 and is approximately 0.20 miles east-southeast of the southeast corner of Malcolm Lake. Its estimated thickness is 0 to 390 feet. It occurs at the base of the *McLennon Tongue* (see Figure 7). Contacts with the *McLennon Tongue* and *Dresbarats Members* are gradational. It may have been deposited in a terrestrial eolian dune environment. It is present only in the Cobalt Plain Area.

West of the Sudbury Area, the *Dresbarats Member* is not presently divided into any beds, lenses, or tongues, although others may be named in the future. As for economic resources the abundance of red beds indicates that iron may be abundant within the member.

Gordon Lake Formation:

The 1969 Committee authorized the subdivision of the *Gordon Lake Formation* into members. Although Bennett and others have divided it into unofficial members, no formal attempt has been made. The *Gordon Lake Formation* has the most internal variation of any formation within the *Cobalt Group*. It is also the finest grained formation of the *Cobalt Group*. It has been referred to as the "yellow chert and limestone member" in the 19th century and the "banded cherty quartzite" in the early 20th century (see Attachment B). The principle reference section for the *Gordon Lake* is located at Diamond Lake and Bruce Mines in the Sault Ste. Marie Area, defined by Collins (1925). There are two designated reference sections along the east side of Baie Fine-George Lake and in the Flack Lake local area along the Flack Lake Fault. Dolomitic argillites and chert generally define the formation. Even with the great internal variation, the *Gordon Lake Formation* is perhaps the most understudied of all the *Cobalt Group* formations. This is because it is believed not to have any economic potential and is poorly exposed throughout the Southern Province. It needs to be understood. Parts of the formation can be confused with the *Gowganda*. The carbonates have been miscorrelated with the *Espanola Formation* in the past. Easy miscorrelations can lead to confusion on the economic potential within an area. If you're are looking for copper in the *Lorrain Formation* and pass up an area because you determine an outcrop to be *Gowganda* and not the *Gordon Lake*, you could be passing up an opportunity. Miscorrelations are not due to ignorance. Miscorrelations are common not only because of lithology but because of complicated fault relationships. Because of this, we need to understand the lithological variations within the *Gordon Lake*.

Overall the *Gordon Lake* is a dolomitic feldspathic argillite (mudstone) with abundant orange, gray, and light brown chert. This general description does not encompass the entire formation. The *Gordon Lake* is extensive throughout the region but has been significantly eroded in the Sault Ste. Marie and Cobalt Plain Areas. There are thick pale cherty carbonates in the local Goulias Bay area (northwest part of the Sault Ste. Marie Area see Figure 1B) that have been recently correlated with the *Kona* and *Randville Formations* in Michigan (see Figure 4). Originally this carbonate had been correlated with the *Espanola Formation*, but Bennett (2006) and others (1987 Resident Geologist Reports) have correlated it with the base of the *Gordon Lake Formation*. There may also be miscorrelation with an outcrop along Route 638 that has traditionally been correlated with the *Gowganda*, which we will address later.

Bennett (1981 and 2006) suggested that the *Gordon Lake* can be subdivided into three basic units. Upper and lower red members with a green member in the middle. We agree with this interpretation. The overall thickness variations of the *Gordon Lake* can be seen in Attachment A. The below proposed member designations are only delineated in the Sault Ste. Marie and Elliot Lake Areas. These proposed members may not be continuous east into the Cobalt Plain Area.

Semiwite Lake Member

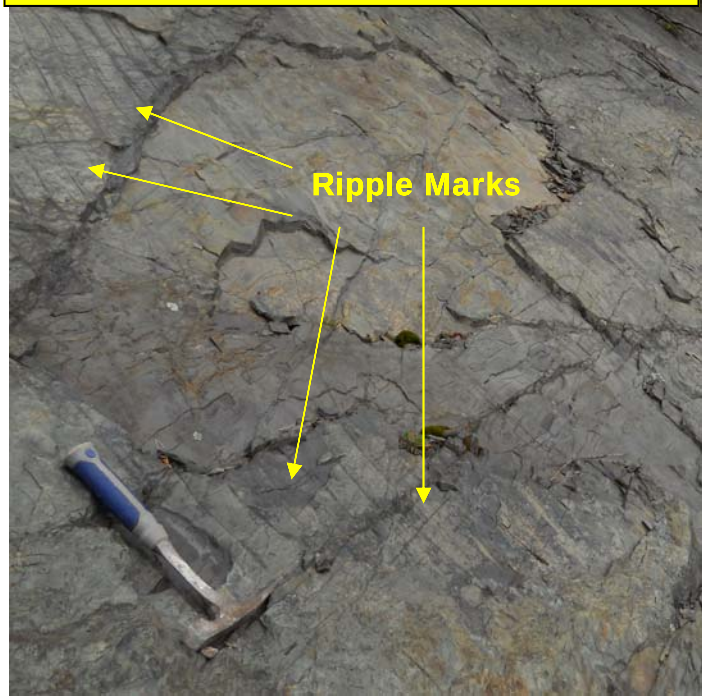
The "upper red member" is herein designated the *Semiwite Lake Member*. Overall it is a reddish gray, interbedded brown and dark green, pale brown cherty mudstone with abundant sandy siltstones. Throughout the Elliot Lake Area it is capped with a pale brown fine sandstone, which is gradational with the above *Bar River Formation*. The type section is a road cut at an unnamed creek located at GPS coordinates north 42.61118 by west 82.79331. The name is derived from Semiwite Lake located about 4.5 miles south-southeast of the outcrop. It's thickness is estimated to be at least 550 feet. At the type section it is a moderately indurated, pale reddish purple, hematitic, fine laminated to massive siltstone with pale brown chert. It is ripple marked and contains slight cross beds and mudcracks.

Ophir Member

The "middle member" is believed to form the bulk of the formation. It has often been described as a dark green argillite that is gradational with above and below units. It is also the least cherty of the three members. There is an outcrop at Route 638 and Old Mill Beach Road at GPS location north 46.43668 by west 83.72713 (described by Baumann 2010). This outcrop has been mapped as *Gowganda* in the past but is near several unnamed faults. The authors of this publication believe the outcrop to be *Gordon Lake*. This outcrop is a greenish gray, thickly laminated, siltstone to fine subarkose, which is very typical of the middle *Gordon Lake*. It contains thin laminations of metallic phyllites and has a high dip, indicating proximity to a fault. It also contains shallow marie deposited symmetrical ripple marks (smaller than the wind blown ripples found in the *Gowganda*) and mudcracks (see Photos 10-12). This location is preliminarily designated as the type section of the middle member. It is designated as the *Ophir Member* named for the town of Ophir located about 1.45 miles north of the outcrop. More work is needed to confirm this type section as indeed being the middle of the *Gordon Lake Formation*. However, we believe there is enough lithological evidence to make a good preliminary designation. Where differentiated from units above and below, the member's thickness is at least 600 feet.

PHOTO 10: *Ophir Member* at the type section. Photo taken by: Steven D.J. Baumann 9-6-2010.
Old Mill Beach Road signfor scale.

PHOTO 11: *Ophir Member* at the type section. Notice the steep dip and ripple marks.
Photo taken by: Steven D.J. Baumann 9-6-2010.
12 inch hammer for scale.



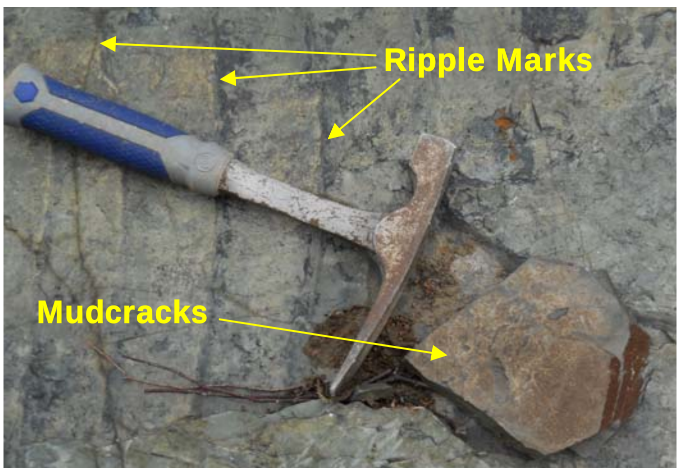


PHOTO 12: *Ophir Member* at the type section. Showing the ripple marks and mud cracks.
Photo taken by: Steven D.J. Baumann 9-6-2010.
12 inch hammer for scale.

Lonely Lake Member

The "lower member" is the gradational part with the underlying *Lower Echo River Member* of the *Lorrain Formation*. Its type section is designated herein for outcrops along Route 638 near Echo Bay and named the *Lonely Lake Member*. Lonely Lake is located almost one mile due north of the outcrop. The type section is located at GPS coordinates north 46.4678 by west 83.95171 on the north and south sides of Route 638, although there are other outcrops from this point west almost to Route 17. The contact with the underlying *Lorrain Formation* is put at the first appearance of dark purple gray laminated argillites more than six inches thick. At the type section the member is red but significantly reduced to white in places. It is mostly a feldspathic siltstone or very fine to fine subarkosic wacke (see Photos 13-15). At the type section it is cut by vertical hematite veins almost two feet wide. In other areas west of here the member is dominantly a fine red to pink mudstone with abundant multi-colored chert, with lenses of pale carbonates and arkoses. Near Flack Lake in the Elliot Lake Area, it contains thin lenses of evaporates. Throughout a large part of the member it is so fine grained that it has been mistaken for chert. Close analysis has revealed that it is fine silt possibly deposited by wind.

Goulias Bay Tongue

The *Lonely Lake Member* also contains the carbonate located just north of Goulias Bay about 12 miles northwest of the town in Sault Ste. Marie and is locally known as "Dolostone Knob". The newly designated type section is approximately 0.5 miles north and north-northeast of Goulias Mission Road, and is exposed along the east-west trending ridge. The approximate GPS location is north 46.76336 by west 84.46637. It is locally extensive and at least 100 feet thick. At one time it may have been continuous into the Upper Peninsula of Michigan connecting to the lithologically similar *Kona* and *Randville Formations*. It is herein designated as the *Goulias Bay Tongue* of the *Lonely Lake Member*. At its type section it is bounded above by red, fine to medium grained, subarkoses of the *Lonely Lake*. It is underlain by green subarkosic wacke of the *Lonely Lake*. At the type section it is a pale pink to reddish pink, internally laminated, clastic meta-dolostone with metachert that is typically pale red and gray. It also contains lenses of light gray, oolitic, clastic dolostone in the upper part of the tongue (Bennett 2006).

PHOTO 13: *Lonely Lake Member* at the type section. Showing the thick argillite beds.
Photo taken by: Steven D.J. Baumann 7-2-2010.
12 inch hammer for scale.

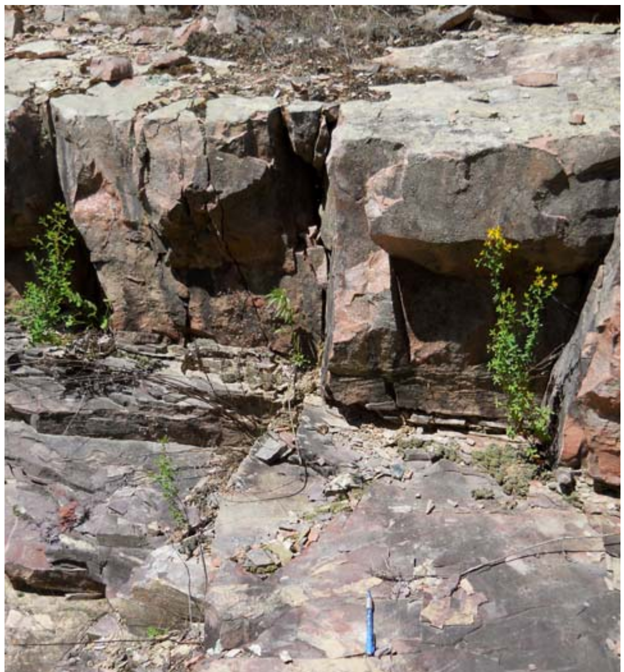
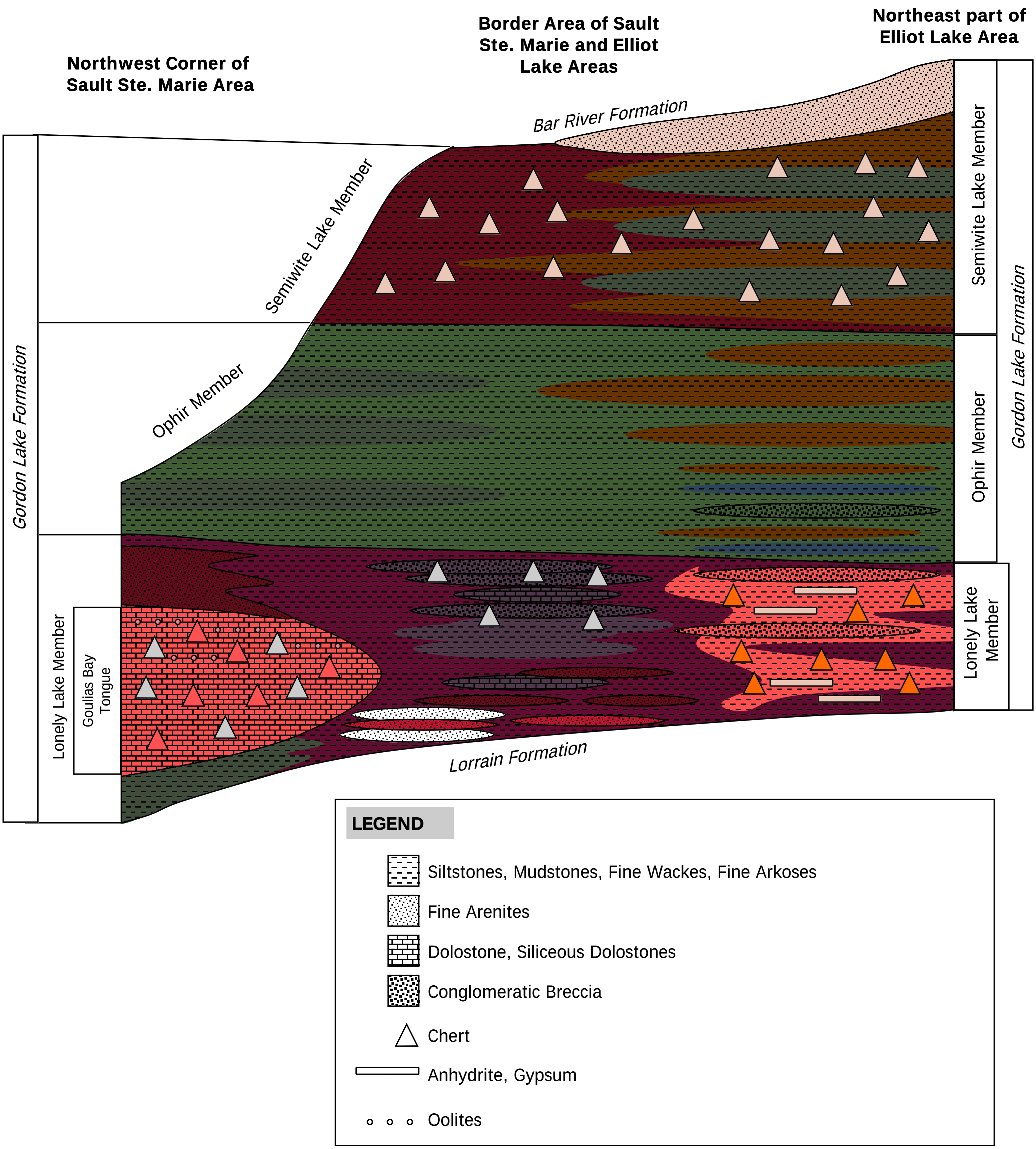


PHOTO 14: *Lonely Lake Member* at the type section. Showing the typical red subarkosic wacke beds.
Photo taken by: Steven D.J. Baumann 7-2-2010.
4 inch pencil for scale.

PHOTO 15: *Lonely Lake Member* at the type section. Showing the red subarkosic wackes and dark argillites.
Photo taken by: Steven D.J. Baumann 7-2-2010.
No scale.

Figure 8: **General Cross Section of the Gordon Lake Formation from Goulais Bay (Northwest Corner of Sault Ste. Marie Area) to Rawhide Lake (Northeast part Elliot Lake Area)**



NOTES: *At present, members of the Gordan Lake Formation, as depicted above, are traceable only in the Sault Ste. Marie and Elliot Lake Areas. More detailed work is needed to see if they delineate into the Espanola, Sudbury, and Cobalt Plain Areas.*

Bar River Formation:

The *Bar River Formation* was named by Frarey in the 1960's. Older names have included the "Upper White Quartzite, the Upper Quartzite and Siltstone." The principal reference section was described (although not named the *Bar River* at the time) by Collins in 1925 for exposures in the Sault Ste. Marie Area at Diamond Lake near Bruce Mines. Two reference sections have been designated. The first is the east side of Baie Fine-George Lake and the second is along the Flack Lake Fault at Flack Lake in the Elliot Lake Area.

The best exposures of the *Bar River Formation* are at Bay Finn (north shore of Lake Huron) and in the Flack Lake local area within the Elliot Lake Area. Bay Finn local area (within the Espanola Area) has the most complete exposed section, with the *Gordon Lake-Bar River* contact well exposed. In this area the *Bar River* has been metamorphosed (upper greenschist facies) more than in other areas due to its proximity to the Grenville Province. In this area and along the north shore of Lake Huron, the *Bar River* is structurally part of the north limb of the Frazer Point Syncline and is faulted. Outside of Bay Finn the *Bar River* is only slightly metamorphosed and extensively eroded in the western part of the Sault Ste. Marie Area. In the Elliot Lake Area mud cracks and desiccation cracks are common. In this area accurate paleocurrent measurements show a strong bimodal distribution trending south-southwest and south-southeast.

Interpretations of depositional environments within the *Bar Ri*ver have varied greatly. Roscoe, Rust, Shields, Frarey, and Pettijohn favor a shallow marine environment. Card favored a near shore coastal shelf. Wood favored a dominantly eolian environment. The authors of this paper favor near shore, beach, and fluvial environment grading up to a fluvial and eolian environment based on the textural maturity and lack of feldspar in the middle and upper part as well as argillite beds that contain sandstone. Argillite with interbedded sandstone is more typical of stream and lake deposits. Plus at this time the Huronian Sea was beginning to close (see Figure 9F). We believe that only part of the basal *Bar River* and the transition zone below are of marine origin.

Due to the overall textural maturity, lack of metamorphism, and igneous intrusions of the *Bar River Formation*, it is not believed to have much economic use other than ballast, building stone, or ornamental stone.

At first glance the *Bar River* resembles the *Lower Echo River Member* of the *Lorrain Formation*, except iron is much rarer. It is overall a white quartz arenite with light green and pink beds. In 1987, Rust and Shields divided the *Bar River* into three main informal members. In this report we will address each part but no formal members will be divided. The reason for leaving the *Bar River* undivided is one of practicality. The members are hard enough to recognize in outcrop and in the subsurface are even more difficult. Plus the extent of the informal members is not known. At this time it is not practical to divide the *Bar River* into formal members.

Gordon Lake-Bar River Transition Zone

The *Bar River* is about 100 feet gradational and conformable with the underlying *Gordon Lake Formation.* In the Espanola Area along Lake Huron, the *Bar River-Gordon Lake* transition zone appears to be a shoaling-upward sequence with a storm generated tidal flat deposit in a 12 to 20 foot thick succession. These deposits were first recognized by Chandler (1984) and based on the presence of hummocky cross beds within graded beds of sandstone. The transition zone is dominantly dark argillites interbedded with different colored subarkoses. The actual contact between the two formations should be placed where the subarkoses and quartz arenite beds are continuously thicker than the argillites.

Basal Bar River Formation

Above the transition zone lies about 250 to 270 feet of white to light green, massive, subrounded to rounded, medium grained, subarkose to quartz arenite, with minor cross beds. The quartz grains tend to be rounded and larger than the feldspar grains which make up 5%-15% of the basal part of the *Bar River*. There is a breccia present in the Espanola Area that appears to be of tectonic origin based on the proximity to the Grenville Front.

Middle Bar River Formation

The middle 1590 to 1650 feet of the *Bar River* is dominantly a white occasionally mottled pink, rounded, medium to coarse grained, quartz arenite with dominantly planar cross beds in sets 12 to 15 inches thick. It contains minor beds of argillite and ripple marks are common. This unit makes up the bulk of the formation.

Upper Bar River Formation

The top 1280 to 1340 feet of the *Bar River* is almost identical to the middle, except for argillite beds up to 66 feet thick and are mostly composed of kaolin. These argillite beds contain lenses of pale quartz arenites several feet thick. The extent of these argillite beds outside of the Espanola Area are not presently known.

Metamorphic History of the Cobalt Group

There are two major metamorphic events that occurred after the deposition of the *Huronian Super*group. The first is marked by the presence of the *Nippissing Intrusions*, which occurred at about 2.2185 (+0.0015) Gya. This is also about the same time the *Cobalt Group* stopped being deposited. The *Nippissing* cross cuts the *Cobalt Group* so we know that the *Cobalt Group* is older than the *Nippissing*. The presence of the *Nippissing* is somewhat problematic. There had to be an event taking place that is no longer recorded in the geologic record. The *Nippissing Intrusions* are too extensive and randomly distributed to be associated with "hot spot" activity. The *Nippissing Intrusions* formed after the break-up of the Kenorland Supercontinent, so that event did not create them. The best possible scenario is the merging of an island arc onto the superior craton, closing the Huronian Seaway (see Figures 9E to 9G). This island arc stimulated the initial metamorphic event of the *Cobalt Group* lasting from about 2.235Gya to 2.217Gya, a span of about 18 million years. During this time the Murray Fault Zone began to form and most *Cobalt Group* rocks were deformed to the sub-greenschist facies (see Figures 1B and 10). For about the next 400 million years the Superior Province would be tectonically quiet, with only minor movements along the young Murray Fault Zone as the area regained tectonic stability.

From about 1.90Gya to 1.75Gya, the supercontinent of Columbia (Nuna) began to form. This event merged the Superior Craton with a large continental landmass to the south and east. This formed the Grenville Province. It also reactivated the Murray Fault Zone in a major way. It also created the Sudbury Stucture (outside of the impact crater), Quirke Lake Syncline, the Chiblow Anticline, the Flack Lake Fault and most of the other minor faults and structures in the area. Only the north part of the Elliot Lake and Sault Ste. Marie Areas were left almost totally unaffected. This mountain building event lead to the *Cobalt Group* becoming metamorphosed into the greenschist facies along the Murray Fault Zone and Grenville Front, and even into the amphibolite facies within the Sudbury Structure (see Figures 1B and 10).

Structural History of the Cobalt Group

The structures that dominate the Southern Province are faults (Murray and Flack Lake), anticlines (Chiblow), synclines (Quirke Lake) and basins (Sudbury Structure). Only the major structures are depicted in Figure 1B. Hundreds of minor ones exist throughout the area. Most of these structures trend east-west or southwest-northeast. The Murray Fault Zone was initially activated around 2.2185Gya. It was reactivated around 1.850Gya, and possibly 1.450Gya (during the metamorphism of the Baraboo Area in Wisconsin). All other structures were probably formed during the formation of the Nuna Supercontinent. With the formation and eventual break-up of Nuna, erosion was dominant and the area almost eroded to sea level until the last ice age beginning about 2.2 million years ago. The area was slightly uplifted again during the formation of the Appalachian Mountains during the Acadian Orogeny (local orogeny within the larger Caledonian Orogeny), which took place in the Ordovician around 490mya to 390mya.

The formation of the complex structures of the Southern Province have lead to the concentration of many economical minerals and metals throughout the area. Uranium, copper, and iron have been found in minable concentrations throughout the area. A multitude of other minerals and metals close to minable concentrations have been discovered to include cobalt, gold, silver, lead, and silicon.

Depositional History of the Cobalt Group

The interpretations of depositional environments of the formations within the *Cobalt Group* have varied greatly. What we attempted to do in this report was to generate paleogeographic maps which represent snapshots of time throughout the history of the *Cobalt Group* (see Figures 9A to 9G). The maps generated are basic general interpretations of a poorly understood time more than two billion years ago, when the skies were yellow and the seas were green. The paleogeographic maps in Figure 9, are by no means the final word and should be taken as a general setting. They did help us interpret some of the depositional environments of the *Cobalt Group*. They are a work in progress, but we feel that they represent the best interpretation based on present evidence.

Conclusions

The depositional timeframe of the *Huronian* covers a span of time almost as long as the reign of Dinosaurs. The *Cobalt Group* is also the thickest groups of the *Huronian Supergroup*, yet it is the least understood. The four formations that make up the *Cobalt Group* represent climates ranging from extremely cold to tropical. During this time free oxygen began to appear in the atmosphere for the first time and we see the first significant "red beds" being deposited. Subsequent tectonic events metamorphosed, intruded, and faulted the *Cobalt Group* concentrating minerals along certain zones either along bedding or cutting across in veins and intrusions. We have attempted to organize the *Cobalt Group* in a way that will help future workers understand the depositional history and economic potential of the *Cobalt Group*.

The basal *Gowganda Formation* retains its present classification as does the top *Bar River Formation*. We have added members, tongues, and lenses to the middle *Gordon Lake* and *Lorrain Formations*, which was first proposed and authorized by the 1969 Committee. We have added these new units in accordance with the 2005 Stratigraphic Code and hope that future researchers will identify new units.

Even with these new additions, much work remains. We need to identify more reference sections and confirm the stratigraphic position of the *Ophir Member* of the *Gordon Lake Formation*. We need to better identify the structural relationships of the *Cobalt Group* within Sault Ste. Marie Area. This is somewhat time sensitive as the towns of Sault Ste. Marie and Echo Bay continue to expand and cover potential economic resources. Much has been done in the past century, but much more still needs to be done.

Credits

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Field work by: Steven D.J. Baumann, Adam Wolosyzn

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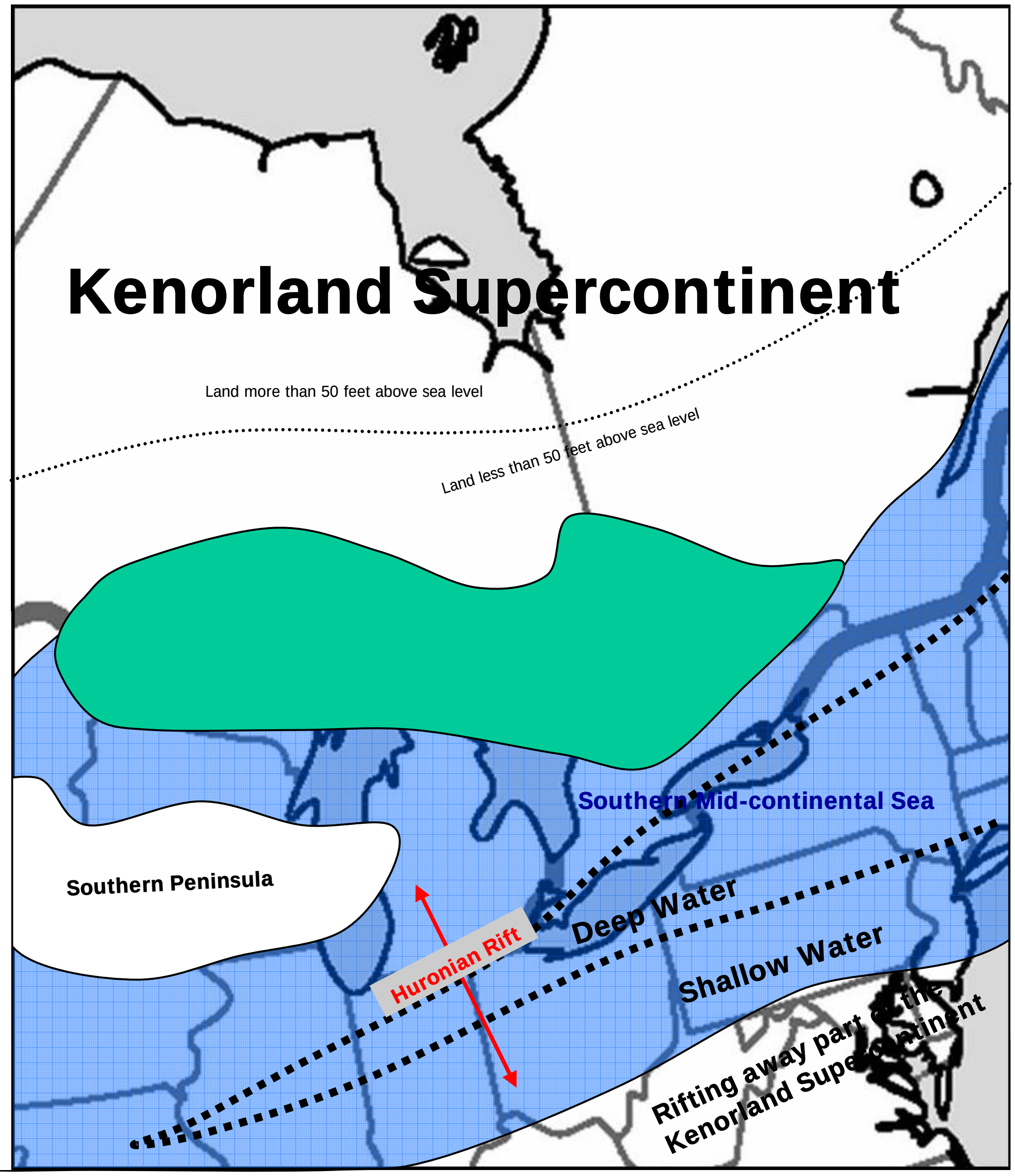
Special thanks to: Institute on Lake Superior Geology and the Ontario Geological Survey

Figure 9A: Paleomap of the Cobalt Group During Deposition

Initial Setting = 2.340 GYA

Other Events at this time:
Super continent of Kenorland had already been breaking up for about 15 million years. Kenorland is separated by the Huronian Rift at this time.

During this time and for the next 80 to 90 million years the Southern Peninsula was low enough to be covered by the growing Southern Mid-continental Sea from time to time.



HURONIAN LEGEND

- Water
- Continent
- Pre-Cobalt Group Huronian Supergroup Sediments
- Continental Margin

BASE MAP LEGEND

- Water (Where not covered by blue, areas were land during the Huronian)
- Modern Continental Boundary
- State / Province Boundary
- National Boundary

Figure 9B: Paleomap of the Cobalt Group During Mid-Gowganda Deposition

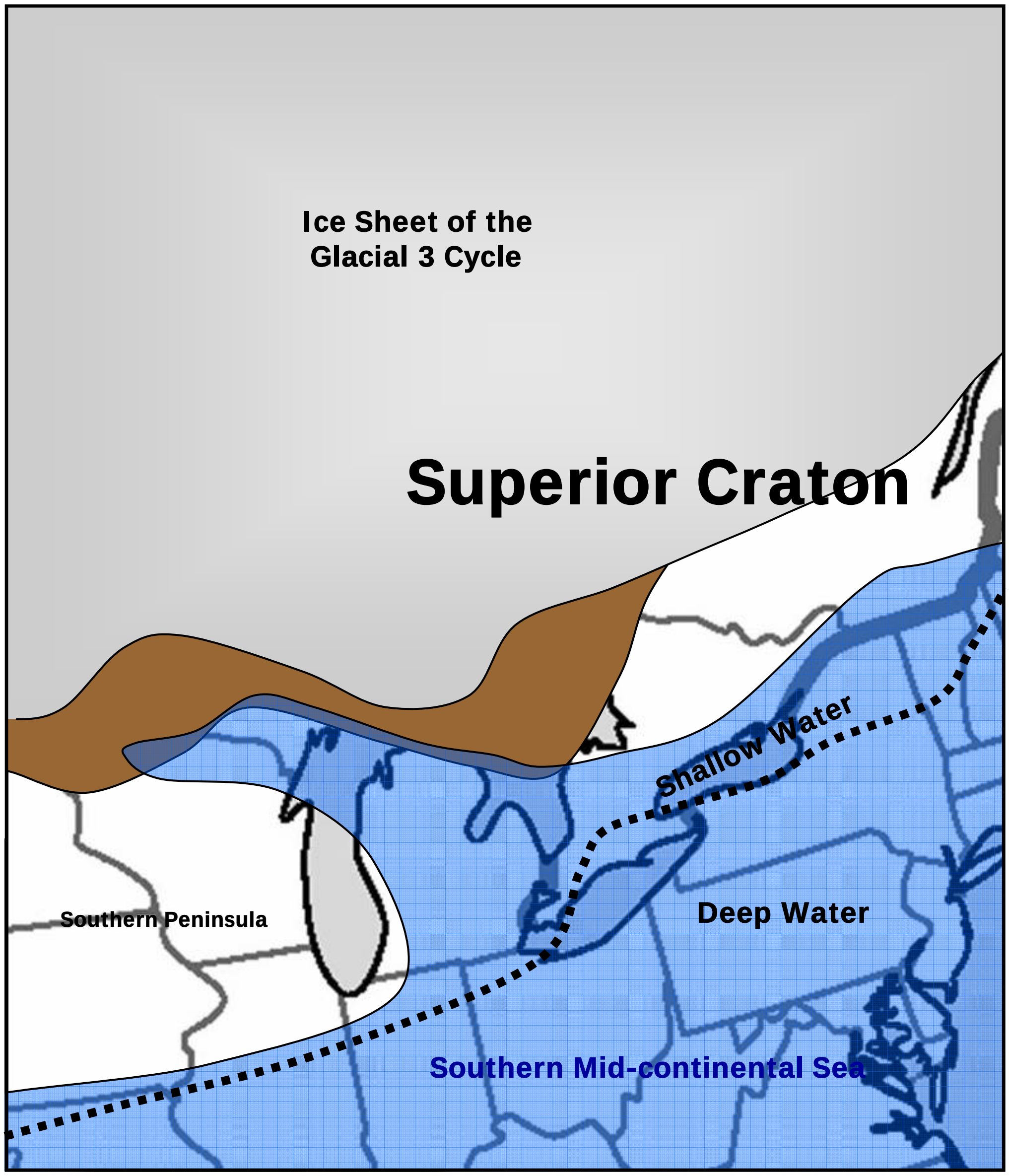
Mid-Gowganda Setting = 2.325 GYA

Other Events at this time:
Super continent of Kenorland has moved away from the Superior Craton by hundreds of miles.

The last Huronian ice age (Glacial Cycle 3) will fully retreat within one million years. This last Huronian ice sheet would periodically expose the shallow water shelf as dry low lying land.

At this time the Southern Peninsula was dry and subjected to erosion.

The ocean basin of the Southern Mid-continental Sea is established as Kenorland further breaks up.



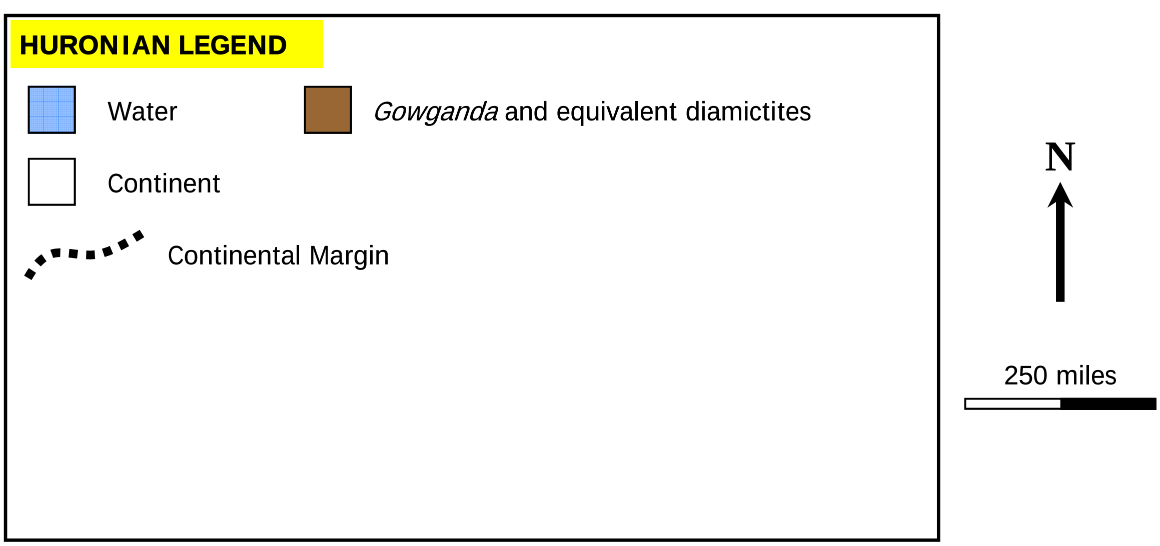
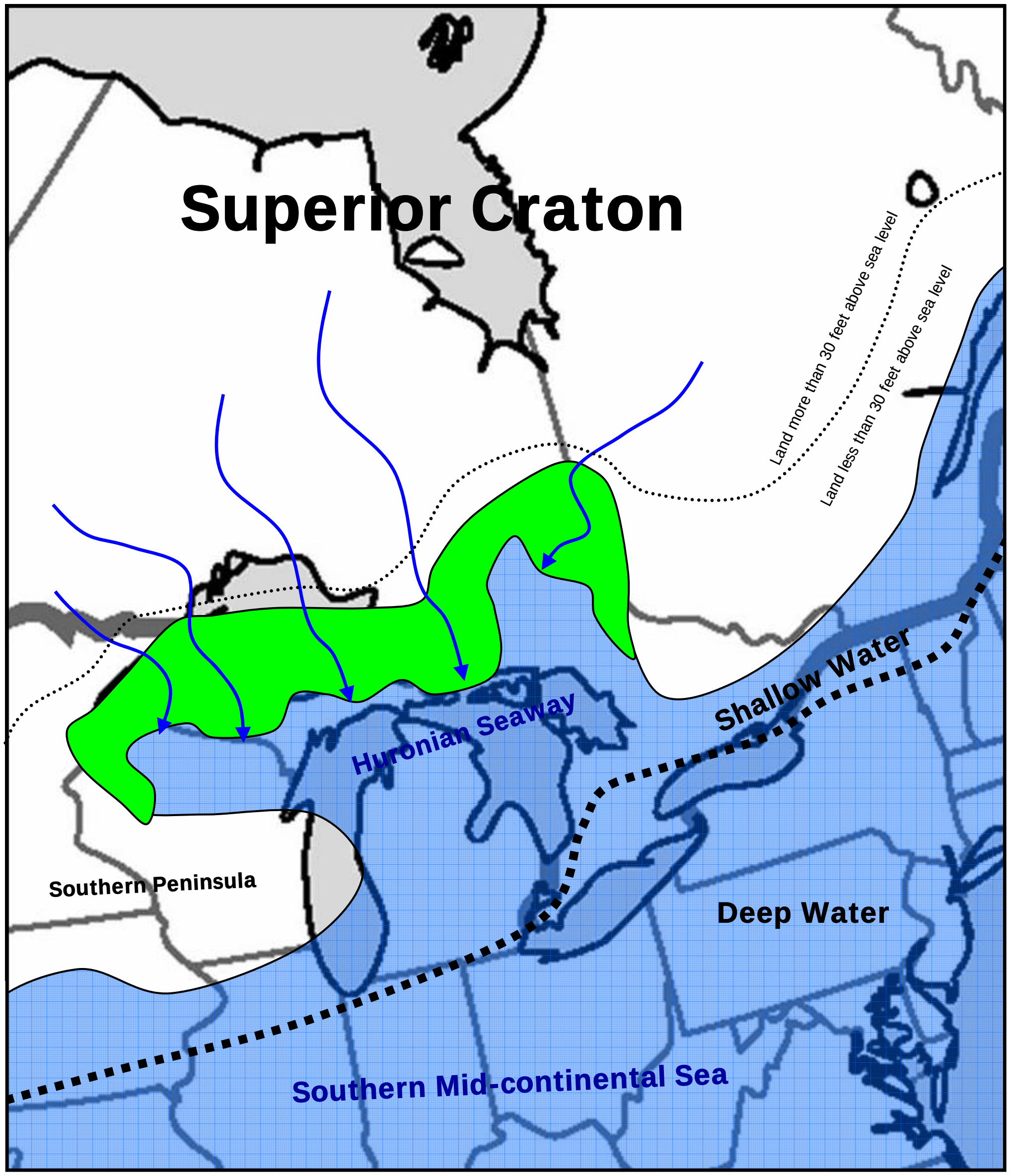


Figure 9C: Paleomap of the Cobalt Group During Late-Gowganda Deposition

Late-Gowganda Setting = 2.315 GYA

Other Events at this time:
A stable interior seaway is established from Southeastern Ontario all the way into Northwest Wisconsin (Huronian Seaway). The sea will persist for almost the next 80 million years.



HURONIAN LEGEND

- Water
- Upper-*Gowganda* and equivalent deltaic deposits
- Continent
- Continental Margin
- Paleo-Rivers

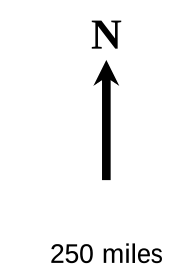
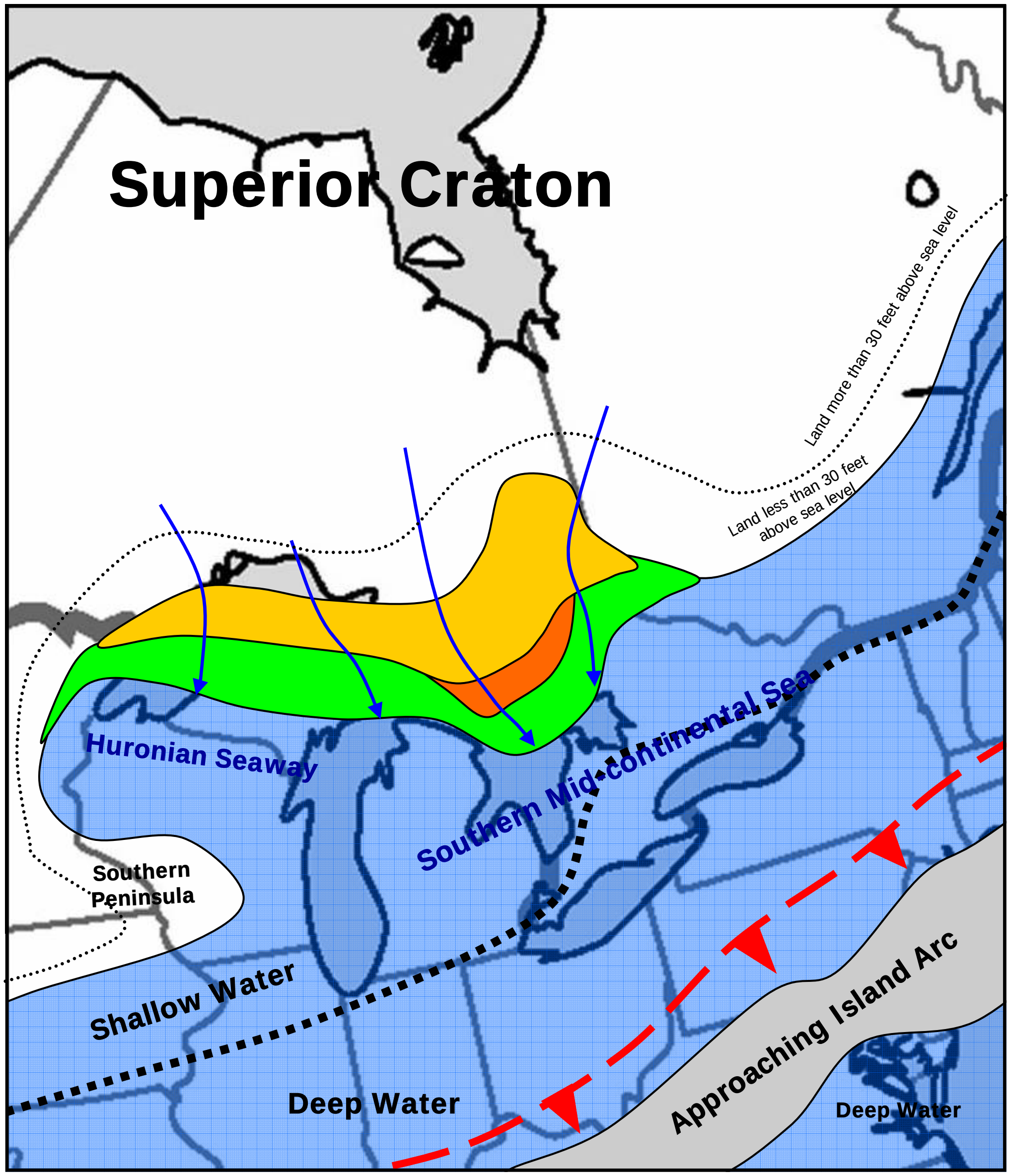


Figure 9D: Paleomap of the Cobalt Group During Lorrain Deposition

Late-Lorrain Setting = 2.275 GYA

Other Events at this time:
An island arc begins to approach the Huronian Seaway from the modern southeast as a marine subduction zone slowly approaches the Huronian Seaway.

At this time, the Huronian Seaway initially begins to shallow, leading to the mostly fluvial deposits of the *Lorrain*.



HURONIAN LEGEND

- Water
- Continent
- Early-*Lorrain* and equivalent shallow marine and deltaic deposits
- Middle-*Lorrain* and equivalent fluvial and delta conglomerate deposits
- Late-*Lorrain* and equivalent fluvial and beach deposits
- Continental Margin
- Paleo-Rivers
- Subduction Zone: arrows point to the overriding plate

N

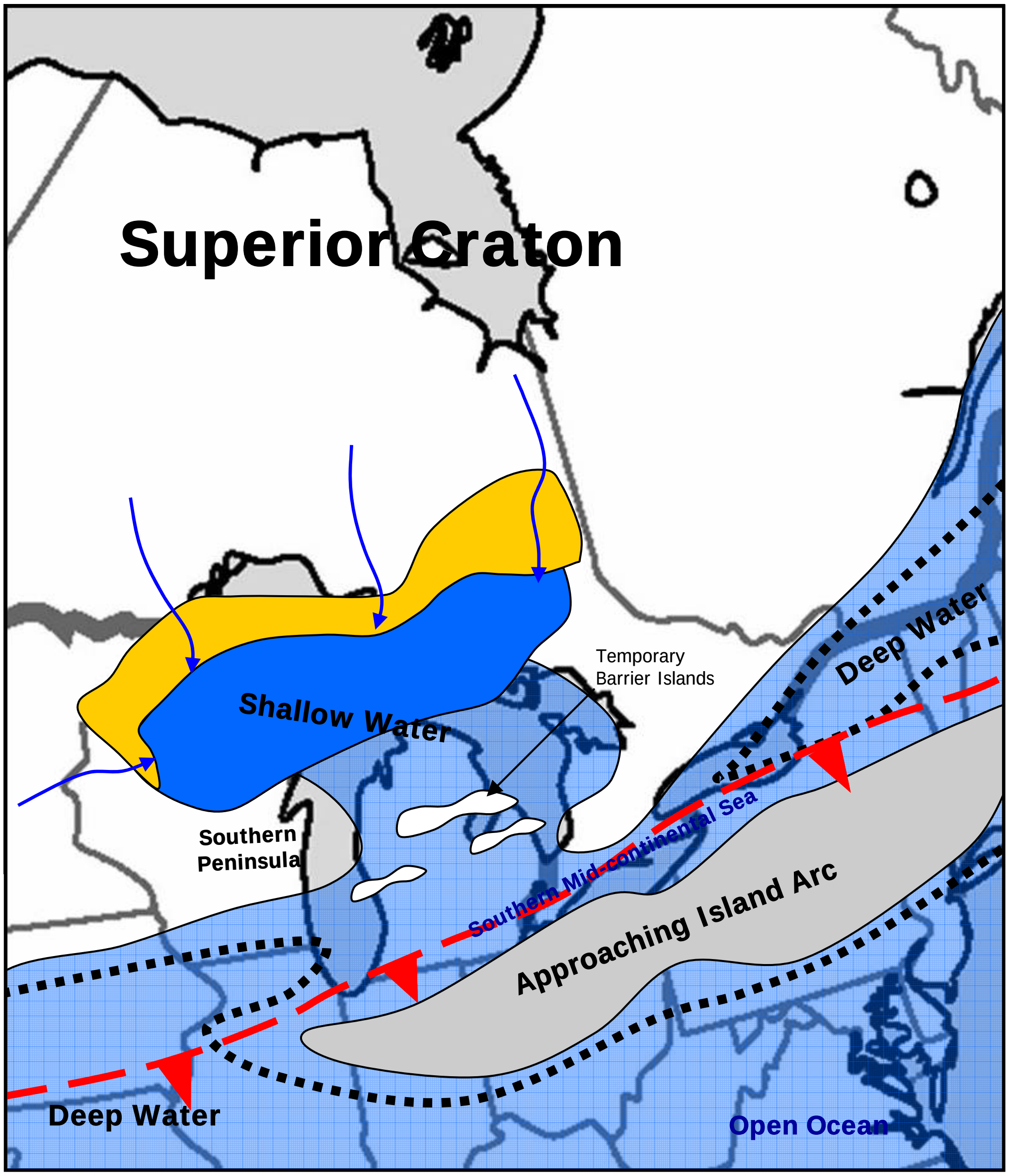
250 miles

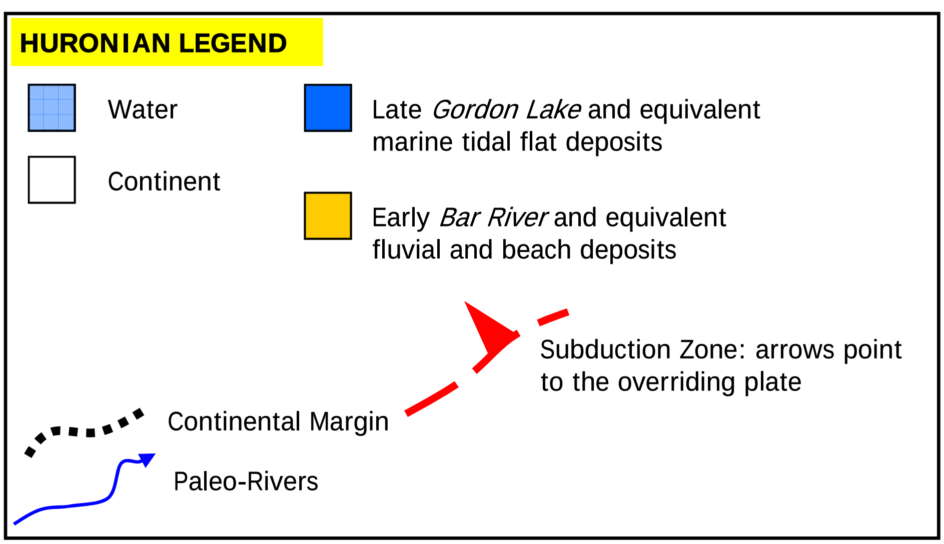
Figure 9E: Paleomap of the Cobalt Group During Late-Gordon Lake to Early Bar River Deposition

Late-Gordon Lake/Early Bar River Setting = 2.237 GYA

Other Events at this time:
The approaching island arc is almost to the Huronian Seaway. This leads to a temporary deepening of a restricted Huronian Sea. This leads to the deposition of evaporites and chert deposits in the *Gordon Lake Formation* as the Southern Mid-continental Sea closes.

Deep igneous magma intrusions begin to be emplaced deep under Northeastern Wisconsin. This resulted from the merging of the Superior Craton with the approaching island arc.





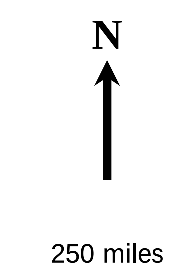
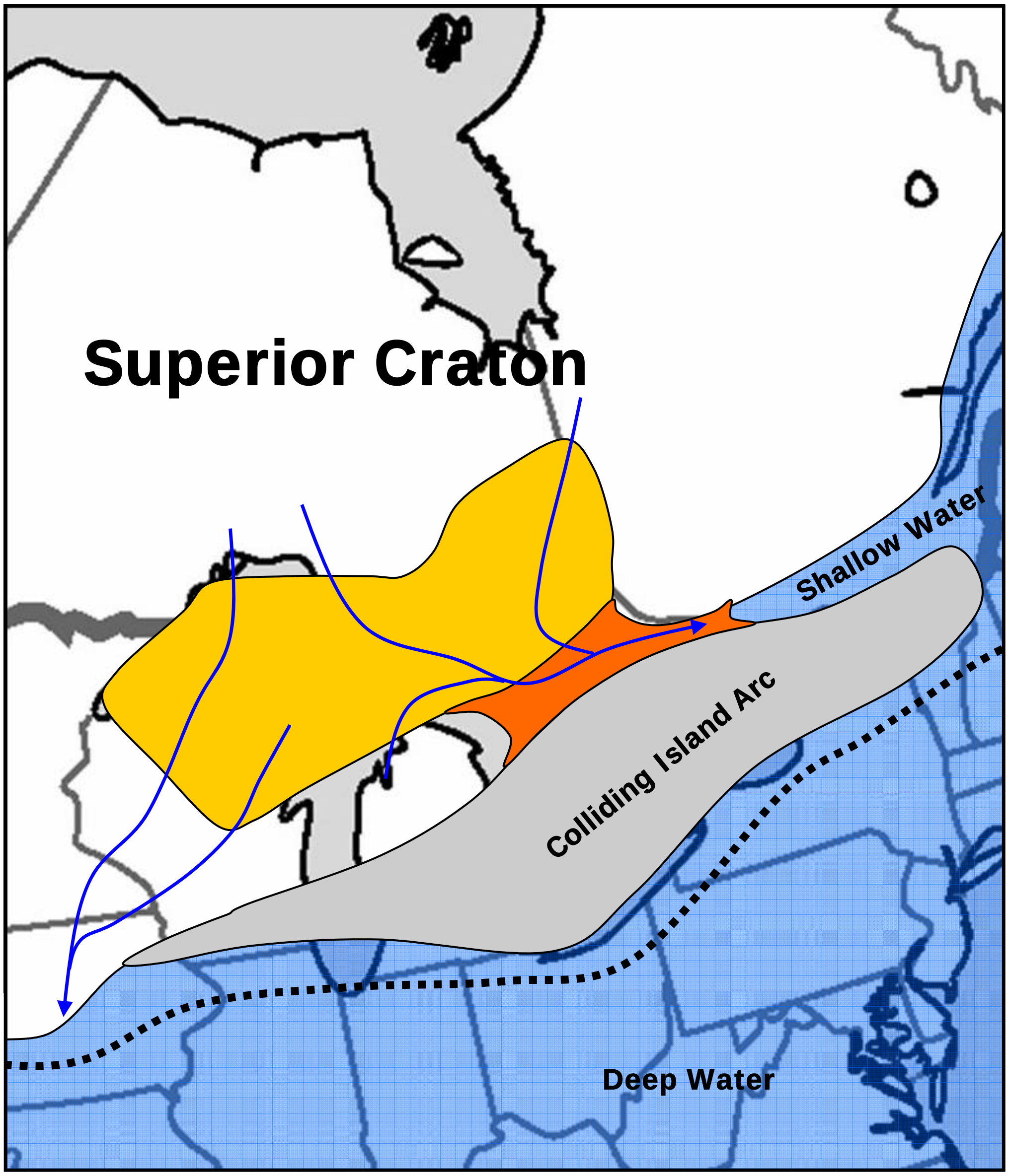


Figure 9F: Paleomap of the Cobalt Group During Late-Bar River Deposition

Late- Bar River Setting = 2.221 GYA

Other Events at this time:
The Huronian seaway closes as the island arch collides with the Superior Craton leading to fluvial deposits of the *Bar River Formation*.

Deep igneous magma intrusions continue to be emplaced deep under Northeastern Wisconsin.



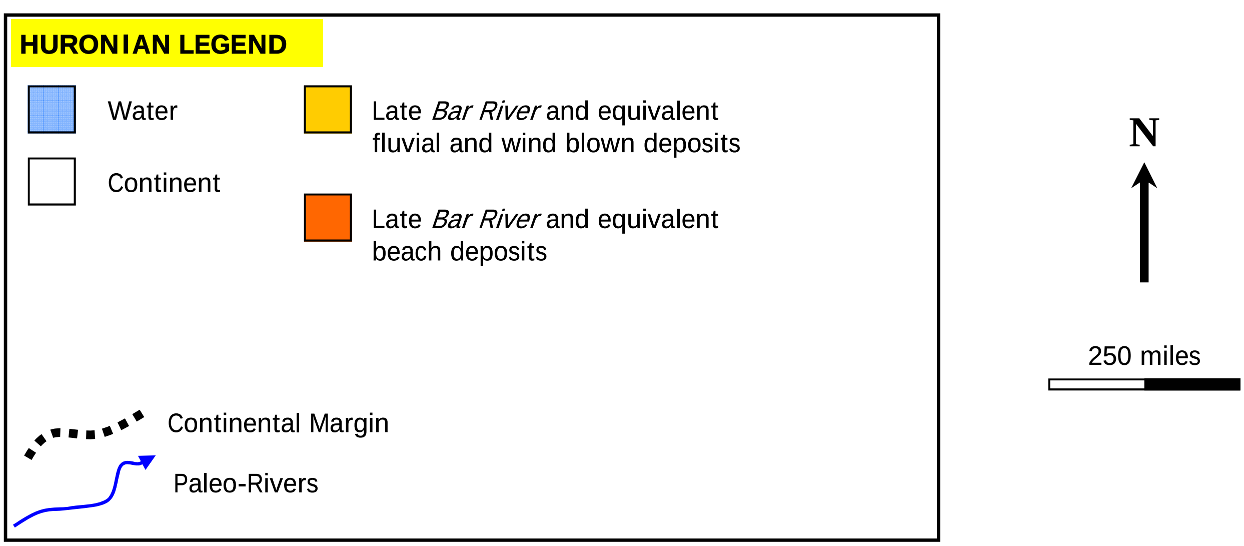


Figure 9G: Paleomap of the Post-Cobalt Group During the Closing of the Huronian Seas

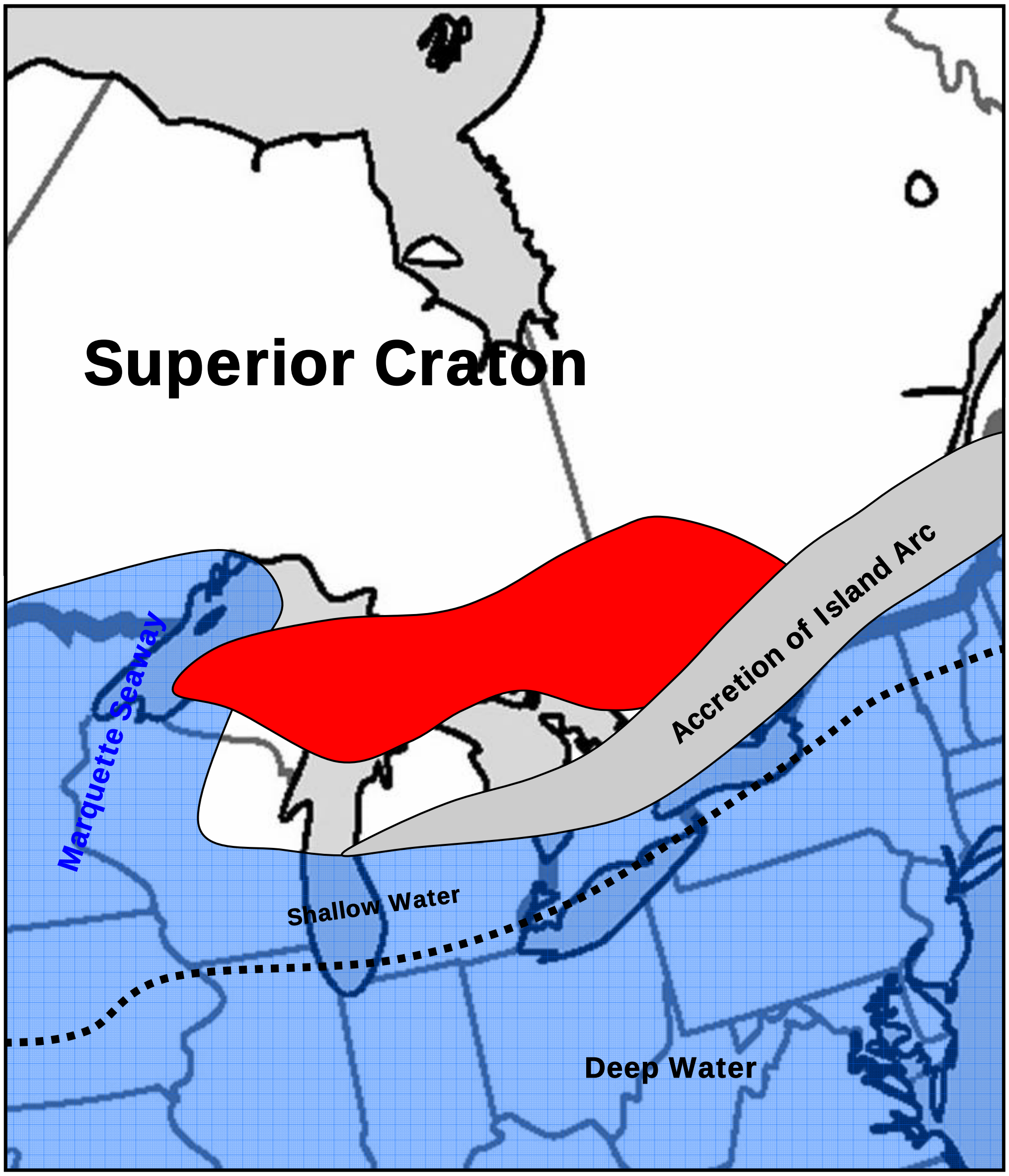
Post Huronian Setting = 2.218 GYA

Other Events at this time:
The Marquette Seaway begins to form as the accretion of the island arc is completed and *Huronian* deposition ceases. The Marquette Seaway will persist on and off for the next 500 million years. This will lead to the deposition of the *Menominee* and *Baraga Groups* in Michigan. As well as the deposition of the *Pre-Quinnesec* sediments in North-eastern Wisconsin.

The *Nippissing Intrusions* crosscut the *Huronian Super-group* as the island arc closes the Huronian Seaway and sub-duction ends.

Deep intrusions under North-east Wisconsin cease for the next 300 million years, until the Penokean Orogeny.

The island arc will be eroded to sea level within five million years.



HURONIAN LEGEND

Water

Continent

Post Huronian and equivalent deformation (initial formation of Murray Fault) and Nippissing Volcanic Intrusions and related intrusions

Continental Margin

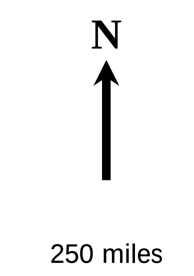


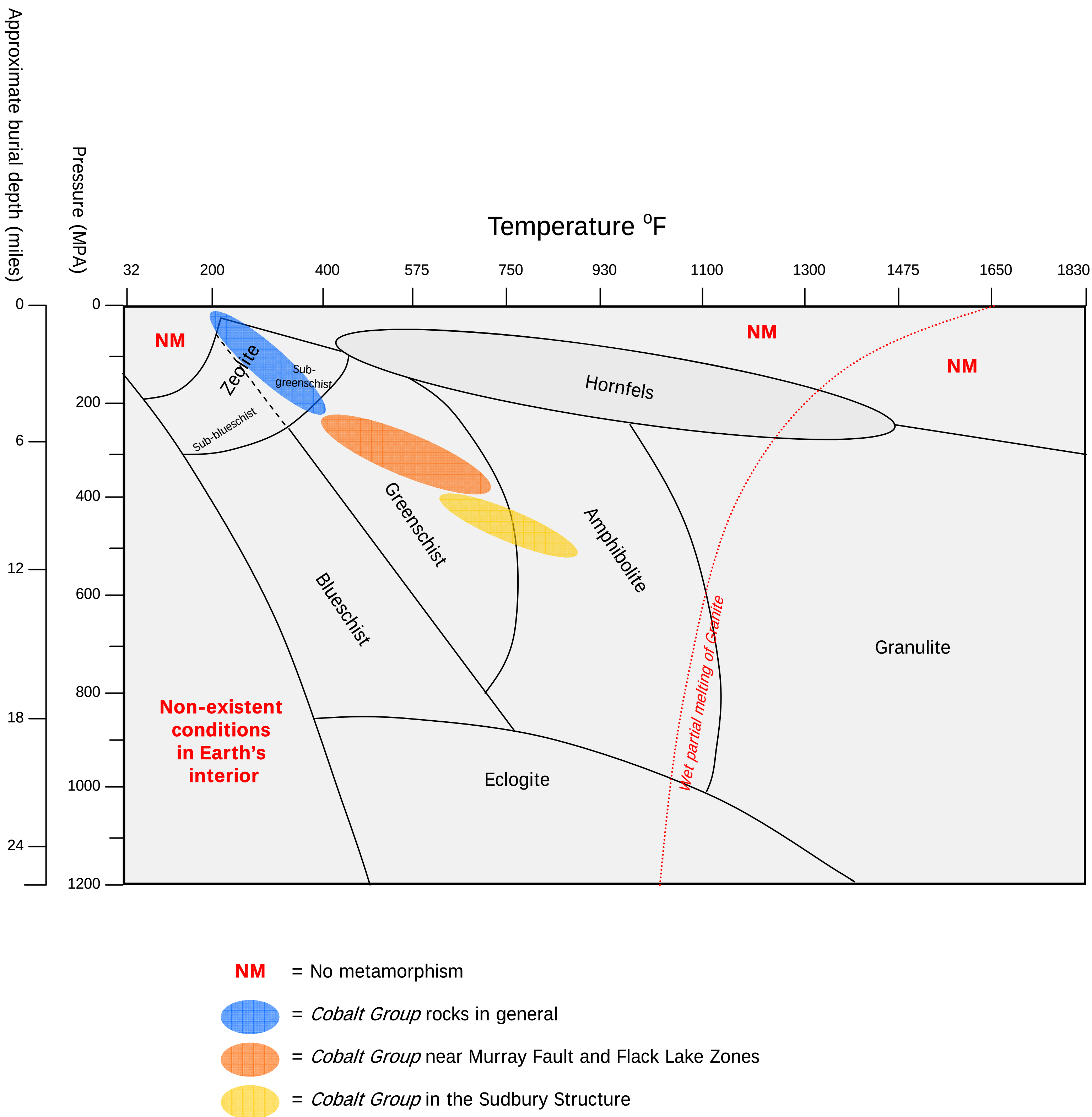
Table 3: Newly Designated Type Sections

Member Name	Associated Formation (Member)	Source of Name	Type Section Location	Description at Type Section	Other Informal Names
Semiwite Lake Member	Gordon Lake	Semiwite Lake, located 4.5 miles east-southeast of type section	Unnamed creek GPS: 46.61118 -82.7933	Pale red, hematitic fine siltstone with pale yellow chert, ripple marks, mudcracks, slight cross bedding	N/A
Ophir Member	Gordon Lake	Town of Ophir, located 1.45 miles north of type section	Road cut east side of Old Mill Beach Road and Route 638 junction GPS: 46.43668 -83.72713	Dark greenish gray, thickly laminated siltstone to very fine subarkose to arkose, symmetric ripples, mudcracks	N/A
Lonely Lake Member	Gordon Lake	Lonely Lake, located ~0.75 miles northeast of type section	Several outcrops along the north side of Route 638 ~GPS: 46.46748 -83.95171	Red to white and deep purple, feldspathic mudstone to fine to medium grained subarkose, ripple marks and hematite	Lorrain-Gordon Contact
Goulais Bay Tongue	Gordon Lake (Semiwite)	Goulais Bay, located 0.5 miles to the south and south-southwest of type section	East-west trending ridge ~3000 feet long ~1000 feet north of Goulais Mission Road ~GPS: 46.7634 -84.4664	Pale pinkish to reddish pink, dolostone, interbedded with gray to pink chert, underlain by green and maroon siltstone, overlain by deep red sandstone	Dolostone knob outcrop, Fenwick Township dolostone unit
Lower Echo River Member	Lorrain	Lower Echo River which crosses RT 17 3/4 mile north of type section	Road cut GPS: 46.5063 -84.0457	White mottled pink, quartz arenite with red hematite staining	Upper Quartzite Member
Northland Member	Lorrain	Town of Northland ~1.85 miles east of the type section	Road cuts along the south side of HWY 556 GPS: 46.7174 -84.1946	White and pink to red with green, quartz oligometic sandy orthoconglomerate to quartz pebbly coarse quartz arenite with minor yellow argillite	Upper Red Quartzite, Red Pebbly Arenite, Buff Hematitic Sandstone
Puddingstone Lake Tongue	Lorrain (Northland)	Puddingstone Lake located ~1.5 miles south-southwest of McGrath Lake near the type section	Scattered outcrops in the area of GPS: 46.5572/46.5578 -83.2887/-83.2864	White to pink, oligometic sandy orthoconglomerate, with clasts of red jasper, black chert and hematite, white and clear quartz	Red Jasper Conglomerate, Puddingstone Conglomerate
Blinko Lake Lens	Lorrain (Northland)	Blinko Lake about 0.25 miles due south of type section	Outcrop in the area of GPS: 46.5287 -83.2585	Orange mottled white and pink, well sorted medium grained, quartz arenite to subarkose	Unit 5d-1977 Unit 11d-1978
Dresbarats Member	Lorrain	Immediate area of the town of Dresbarats where the best outcrops occur	Outcrop GPS: 46.3374 -83.9549	Red to purple, feldspathic siltstone to arkosic wacke	Purple Feldspathic Wacke, Basal Red Siltstone, Ripple Rock, Lower Red Quartzite, Basal Arkose Member
McLennon Lake Tongue	Lorrain (Dresbarats)	McLennon Lake where the type sections are 0.25miles to the north and 1.05miles south of the Lake	Scattered outcrops surrounding the Lake ~GPS (center of Lake): 47.39364 -79.96828	Green, gray, red to purple, arkosic wacke to subarkosic wacke	N/A
Malcolm Lake Lens	Lorrain (Dresbarats)	Malcolm Lake where the type sections is about 0.2miles ESE of the lake	Outcrop ~GPS: 47.4478 -79.8508	Orange to gray, fine grained, quartz arenite (poorly indurated)	N/A

NOTES:
The stratigraphic position of the Ophir Member still needs to be confirmed.

The rest of the type locations were defined by either the authors of this publication or Bennett (1981, 1982, 2006), Born (1989), Card (1975), Jackson (1994), Siemiatkoska (1978), Wood (1975).

Figure 10: **Metamorphic Facies Chart of the Cobalt Group**



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Attachment A: Table 1: Thickness Variations within the Huronian Supergroup

Geologic Unit	Associated Area	Thickness Variance (Feet)
Bar River Formation	Sault Ste. Marie	0 to 1020
	Elliot Lake	1020 to 2970
	Espanola	2970 to 1975
	Sudbury	1975 to 1320
	Cobalt Plain	1320 to 1020
Gordon Lake Formation	Sault Ste. Marie	1190 to 1650
	Elliot Lake	1650 to 980
	Espanola	980 to 2310
	Sudbury	2310 to 1980
	Cobalt Plain	1980 to 950
Lorrain Formation	Sault Ste. Marie	3960 to 8250
	Elliot Lake	8250 to 5520
	Espanola	5520 to 10890
	Sudbury	10890 to 7590
	Cobalt Plain	7590 to 5250
Gowganda Formation	Sault Ste. Marie	3530 to 3200
	Elliot Lake	3200 to 3530
	Espanola	3530 to 4950
	Sudbury	4950 to 8910
	Cobalt Plain	8910 to 2310
Serpent Formation	Sault Ste. Marie	0 to 700
	Elliot Lake	700 to 825
	Espanola	825 to 4950
	Sudbury	4950 to 3300
	Cobalt Plain	3300 to 1980
Espanola Formation	Sault Ste. Marie	500 to 660
	Elliot Lake	660 to 750
	Espanola	750 to 900
	Sudbury	900 to 450
	Cobalt Plain	450 to 100
Bruce Formation	Sault Ste. Marie	15 to 150
	Elliot Lake	150 to 165
	Espanola	165 to 825
	Sudbury	825 to 990
	Cobalt Plain	990 to 1970
Mississagi Formation	Sault Ste. Marie	4950 to 1485
	Elliot Lake	1485 to 2975
	Espanola	2975 to 4950
	Sudbury	4950 to 9900
	Cobalt Plain	9900 to 1480
Aweres Formation	Sault Ste. Marie	4300 to 3630
	Elliot Lake	3630 to 0
	Espanola	0
	Sudbury	0
	Cobalt Plain	0
Pecors Formation	Sault Ste. Marie	0
	Elliot Lake	0 to 100
	Espanola	100 to 420
	Sudbury	420 to 2970
	Cobalt Plain	2970 to 0
Ramsay Lake Formation	Sault Ste. Marie	0 to 65
	Elliot Lake	65 to 100
	Espanola	100 to 1250
	Sudbury	1250 to 1815
	Cobalt Plain	1815 to 0

Geologic Unit	Associated Area	Thickness Variance (Feet)
McKim Formation	Sault Ste. Marie	0 to 265
	Elliot Lake	265 to 380
	Espanola	380 to 4150
	Sudbury	4150 to 7920
	Cobalt Plain	7920 to 0
Matinenda Formation	Sault Ste. Marie	50 to 595
	Elliot Lake	595 to 1985
	Espanola	1985 to 950
	Sudbury	950 to 350
	Cobalt Plain	350 to 90
Salmay Formation	Sault Ste. Marie	0
	Elliot Lake	0
	Espanola	0
	Sudbury	0 to 300
	Cobalt Plain	300 to 1485
Thessalon Formation	Sault Ste. Marie	100 to 330
	Elliot Lake	330 to 0
	Espanola	0
	Sudbury	0
	Cobalt Plain	0
Copper Cliff Formation	Sault Ste. Marie	0
	Elliot Lake	0
	Espanola	0
	Sudbury	0 to 2510
	Cobalt Plain	2510 to 0
Livingston Creek Formation	Sault Ste. Marie	0 to 35
	Elliot Lake	35 to 495
	Espanola	495 to 0
	Sudbury	0
	Cobalt Plain	0
Stobie Formation	Sault Ste. Marie	0
	Elliot Lake	0
	Espanola	0
	Sudbury	0 to 2800
	Cobalt Plain	2800 to 0
Elsie Formation	Sault Ste. Marie	0
	Elliot Lake	0
	Espanola	0 to 3000
	Sudbury	3000 to 0
	Cobalt Plain	0

NOTES: The thickness above are based on calculated thicknesses in outcrop by various workers (Baumann, Bennett, Card, Coleman, Collins, Debickie, Frarey, Robertson, Williams, and others). Subsurface units may vary outside of the above thick-nesses.

Where thicknesses = 0, there may be outliers within these areas. The above charts only includes units where they are continuous and greater than 10 feet in thickness.

All the above units are metasedimentary except for the volcanic meta-igneous rocks of the *Elsie Mountain*, *Stobie*, *Copper Cliff*, *Thessalon*, and *Salmay Lake Formations*.

Red Hematite in the *Lorrain Formation* along Route 638

Photo by: Steven D.J. Baumann
Taken on: 9-6-2010

Attachment B: Table 2: **Stratigraphic Evolution of the Huronian Supergroup in Ontario Canada**

Logan and Murray 1863	Coleman 1914	Collins 1914, 1925 * McConnell 1927	Coleman, Collins 1914, 1925, 1937 South of Murray Fault	Abraham 1953, 1956, 1957	Roscoe 1957, 1960, Pienaar 1963, Card 1978	Robertson 1965 North of Murray Fault	Robertson 1965 South of Murray Fault	Robertson 1968, 1969, 1977 East and NE of Manitoulin Area	THIS REPORT: Bennett 1996, 2006 Baumann 2011 West of and to include the Espanola area	THIS REPORT: Williams 1991 Baumann 2011 East of the Espanola area to include the Cobalt Plain/Embayment
White quartzite Yellow chert and limestone White quartzite Red jasper conglomerate Red quartzite Upper shale conglomerate	Upper Huronian	Cobalt Series: Upper Cobalt; Gowganda; * Lower Cobalt	Cobalt Series: Upper formations (upper white quartzite; banded cherty quartzite); Gowganda	Cobalt Series: Lorrain; Gowganda	Cobalt Group: Upper formations; Gowganda	Cobalt Group: Upper formations; Gowganda	Cobalt Group: Not Recognized	Middle Precambrian; Huronian Supergroup; Cobalt Group: Not Recognized; Gordon Lake; Lorrain; Gowganda	Paleoproterozoic Era; Rhyacian Period; Huronian Supergroup; Cobalt Group: Bar River Formation; Gordon Lake Formation; Lorrain Formation; Gowganda Formation	Paleoproterozoic Era; Rhyacian Period; Huronian Supergroup; Cobalt Group: Bar River Formation; Gordon Lake Formation; Lorrain Formation; Gowganda Formation
Limestone Lower shale conglomerate White quartzite Chloritic slates Gray quartzite	Lower Huronian McKim greywacke	Bruce Series: Serpent; Espanola; * Bruce Limestone; Bruce conglomerate; Mississagi * Soo Series: * Aweres; * Duncan greenstone; * Driving Creek	Bruce Series: Serpent; Espanola; Bruce; Mississagi; Ramsay Lake Sudbury Series: McKim; Wanapitei	Bruce Series: Serpent; Espanola; Bruce; Upper Mississagi; Middle Mississagi; Lower Mississagi	Quirke Group: Serpent; Espanola; Bruce Hough Group: Mississagi; Pecors; Whiskey Elliot Group: Nordic; Matinenda (Upper); Matinenda (Lower)	Bruce Group: Serpent; Espanola; Bruce; Upper Mississagi; Middle Mississagi; Lower Mississagi	Bruce Group: Serpent; Espanola; Bruce; Upper Mississagi; Middle Mississagi; Lower Mississagi Sprague Group: Pater Volcanics	Quirke Lake Group: Serpent; Espanola; Bruce Hough Lake Group: Mississagi; Pecors; Ramsay Lake Elliot Lake Group: McKim; Matinenda; Salmay Lake; Gabbro Anorthosite	Siderian Period; Quirke Lake Group: Serpent Formation; Espanola Formation; Bruce Formation Hough Lake Group: Mississagi Formation; Aweres Formation; Pecors Formation; Ramsay Lake Formation Elliot Lake Group: McKim Formation; Matinenda Formation; Thessalon Formation; Livingstone Creek Formation	Siderian Period; Quirke Lake Group: Serpent Formation; Espanola Formation; Bruce Formation Hough Lake Group: Mississagi Formation; Pecors Formation; Ramsay Lake Formation Elliot Lake Group: McKim Formation; Matinenda Formation; Copper Cliff Formation; Stobie Formation; Elsie Mountain Formation

NOTES: *Exact stratigraphic position of the Aweres Formation (Baumann and Bennett) is not known for sure, due to complex intertonguing, limited extent, and proximity to faults within the Hugh Lake Group.*

Several formations have been broken down into members (see text for detailed stratigraphy of the Cobalt Group).

Robertson 1977, is still used for nomenclature south of Murray Fault.

Brown names indicate rocks of volcanic origin. Prior to 1965 volcanics often were not differentiated from the sedimentary rocks that they intruded. Black names indicate sedimentary formations. Red indicates formations that were not recognized in an area. Green names indicate sedimentary formations with meta-diamictites (glacial tills). Prior to 1960 diamictites were not recognized, except Coleman (1905) who first suspected that the Gowganda may be of glacial origin. They were often referred to as paraconglomerates.

The Huronian Supergroup is bounded at the very top and very bottom by erosional unconformities.

~~~~ = Unconformity or Disconformity

Chart adapted from J.A. Robertson and K.D.Card's "Federal-Provincial Committee on Huronian Stratigraphy Progress Repot", 1969, Table 1; and J.A. Robertson's "Geology of the Cutler Area", 1977, Chart B, Table 1
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Attachment C, Figure 6: Classifications of Sandstones with Quartz-Feldspar-Lithic (QFL) Charts

TERMS:

Arenites: Sandstones with <15% matrix.

Arkose: A rock with >50% feldspar and <90% quartz.

Clastic: In sedimentary rocks, a mechanically weathered non-chemical/non-biological (i.e. chemical and biological rocks include: evaporates, carbonates, coal) rock composed of smaller rock fragments (grains) to include silica, feldspar, chemical, and biological rocks.

Feldspar: Silica minerals where some metal (potassium, sodium, barium, calcium) is bonded to a $(Si,Al)O_4$ tetrahedra. Average hardness = 6.

Fines: Unconsolidated term for matrix. Fines and matrix are interchangeable terms.

Lithic: All grains to excluded siliceous and feldspars grains.

Matrix: Grains <1/16mm in diameter. This includes all silts and clays, which collectively are referred to as mudstones.

Maturity: A sandstone with <15% fines is considered mature. 15% to 30% fines is a moderately mature sandstone. >30% but <50% (±5%) fines is an immature sandstone.

Sandstone: A sedimentary rock or unconsolidated sediments with 50% (±5%) or greater of particles between the size of 1/16mm (0.0025 inches) and 2mm(0.0787 inches) in diameter. These are particles that will pass a #10 sieve but be retained on a #230 sieve (U.S. standard sieves).

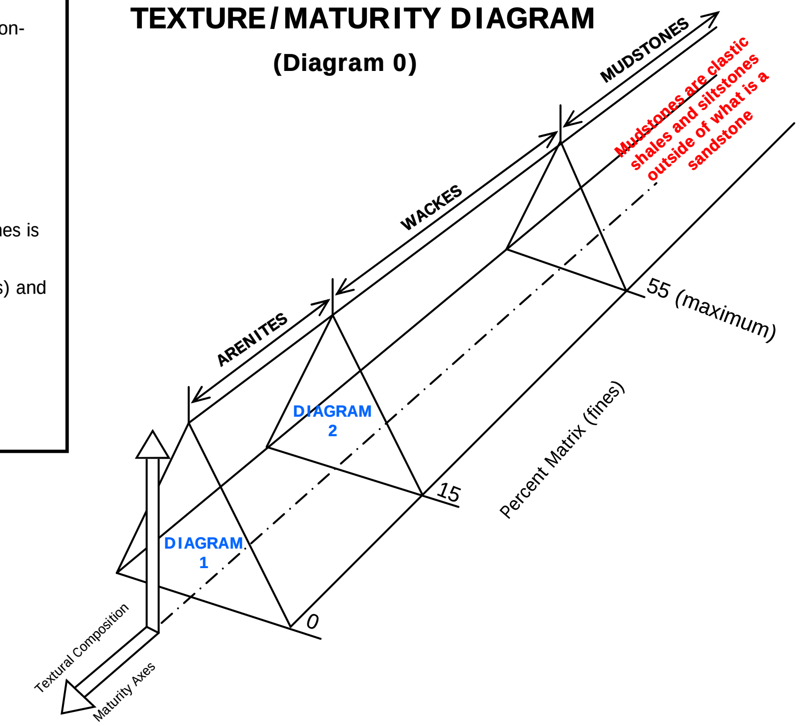
Siliceous/Silica: Grains made of SiO_2. This includes quartz and cherts. Cherts include jaspers, agates, chalcedony, onyx, etc.

Texture: Physical properties of a rock. i.e. composition, size, shape, orientation, and crystal form.

Wackes: Sandstones with >15% but <50% (±5%) matrix.

TEXTURE/MATURITY DIAGRAM

(Diagram 0)



Explanation: Identifying a sandstone requires a three dimensional approach. The first step is to determine the amount of fines (Diagram 0). The amount of fines will determine if the rock even is a sandstone and then determine if it is an arenite (Diagram 1) or a wacke (Diagram 2).

Once it is determined if the sandstone is an arenite or wacke the QFL chart can be used to classify the rock in a useful manner. The QFL charts are based on percentages, once the amount of fines (matrix) and pebbles have been excluded. Excluding the amount of fines and/or pebbles "resets" your total grain percentage to 100%.

Once the rock has been plotted on the QFL chart, the name of sandstone is dropped. i.e. if your rock plots as a "lithic subarkose sandstone", it is just a "lithic subarkose". Keeping the term "sandstone" is redundant as the terms arenite, arkose, and wacke are only used for sandstones.

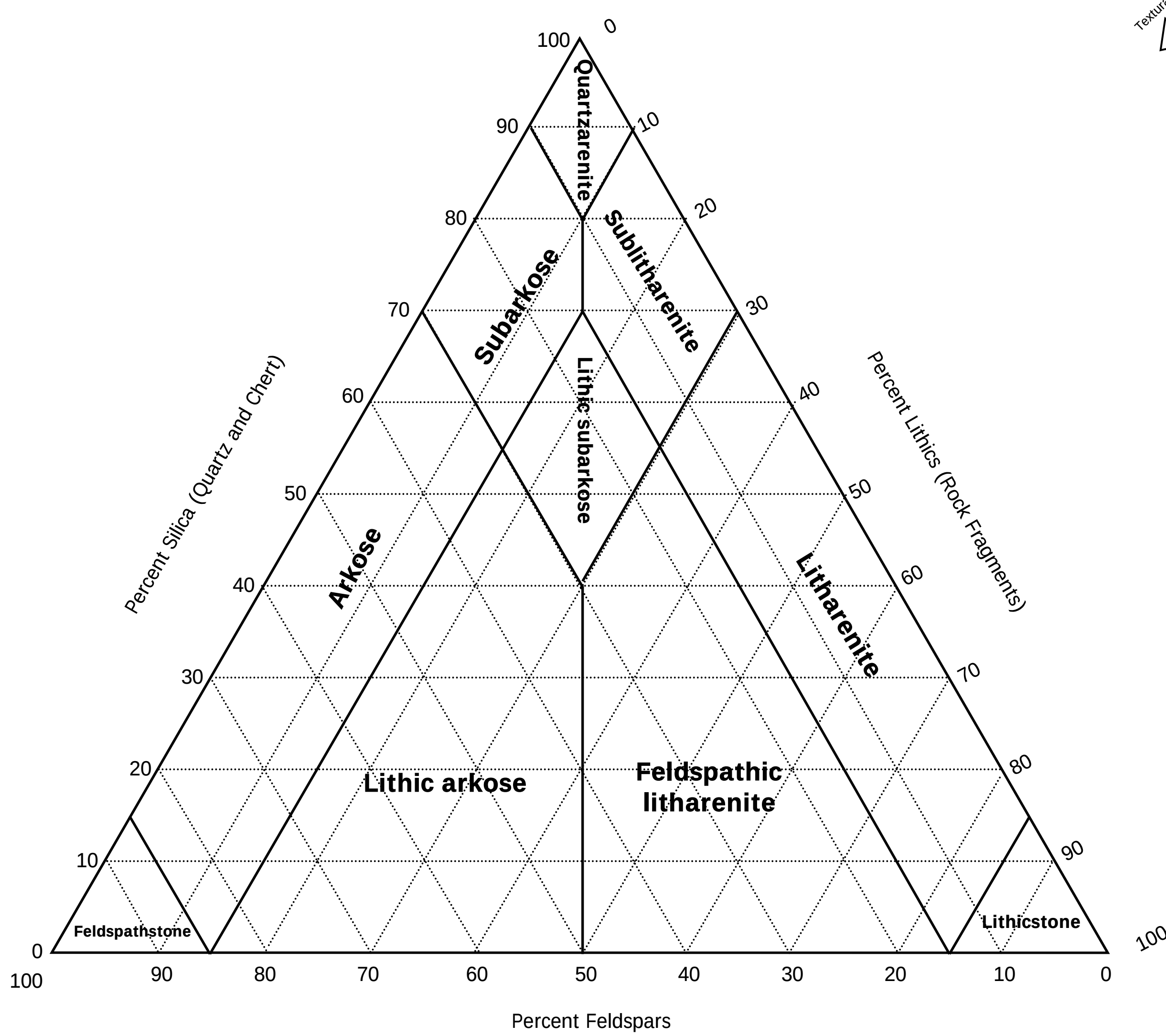
If your QFL chart plots on a line you should take the name that is just above the line (if plot is on a triple junction opening up or angled line), or to the right (if plot is on a vertical line). Move straight down if plot is on a triple junction opening down. For example if your plot is at the "Quartzarenite/Subarkose/Sublitharenite" boundary you should move up to "Quartzarenite". If your plot is on the "Subarkose/Sublitharenite" line move to the right and pick "Sublitharenite". If your plot is on the "Arkose/Lithic arkose" line move up and select the "Arkose". If your plot is on the "Subarkose/Sublitharenite/Lithic subarkose" line you should move down and select the "Lithic subarkose".

If the specimen contains >5% but less than <30% pebbles the term "pebbly" is added before the rock name. i.e. sample with 19 to 23% pebbles that classifies as a "Lithic subarkose" would be a "Pebbly lithic subarkose".

QFL

ARENITES

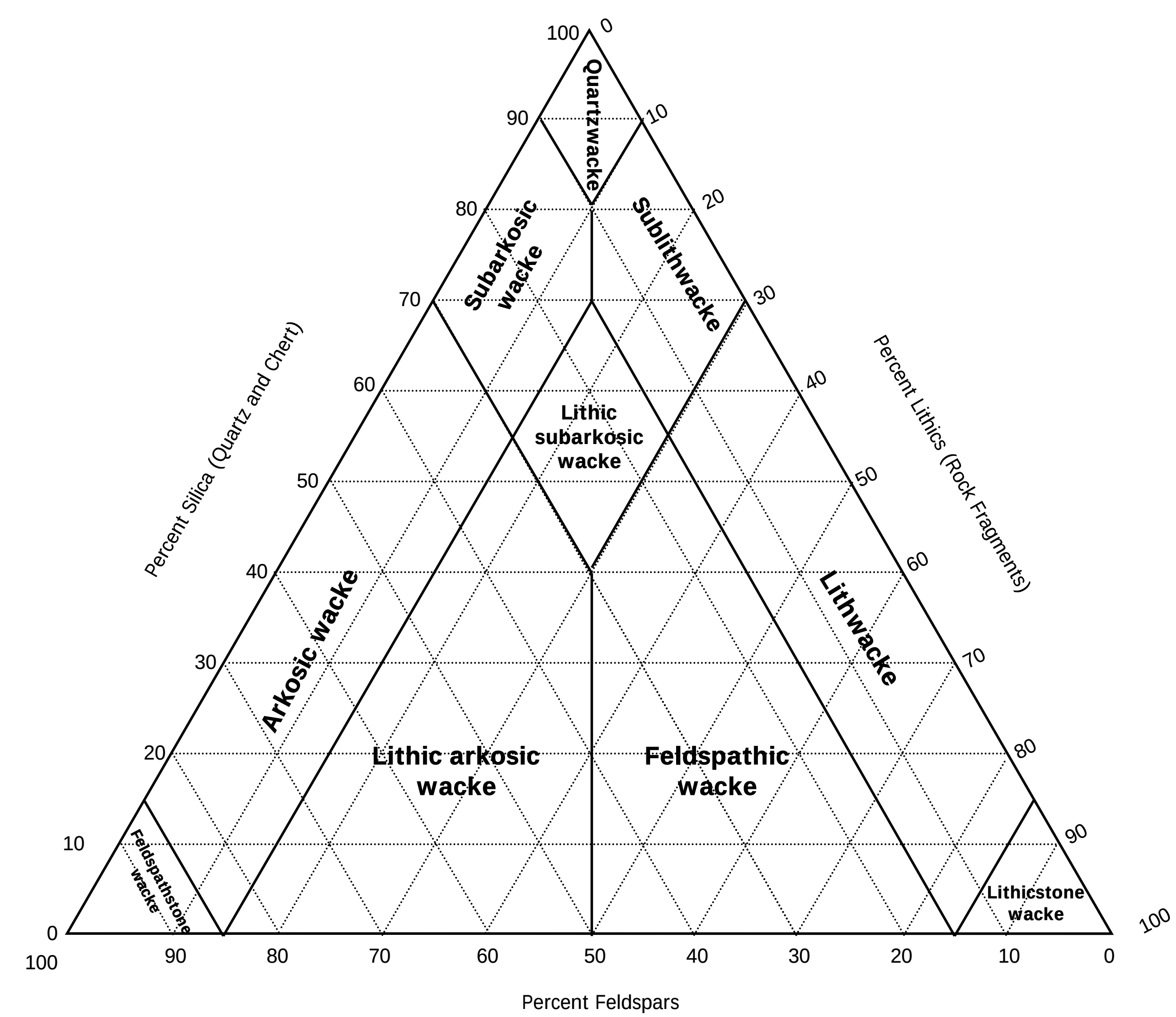
(Diagram 1)



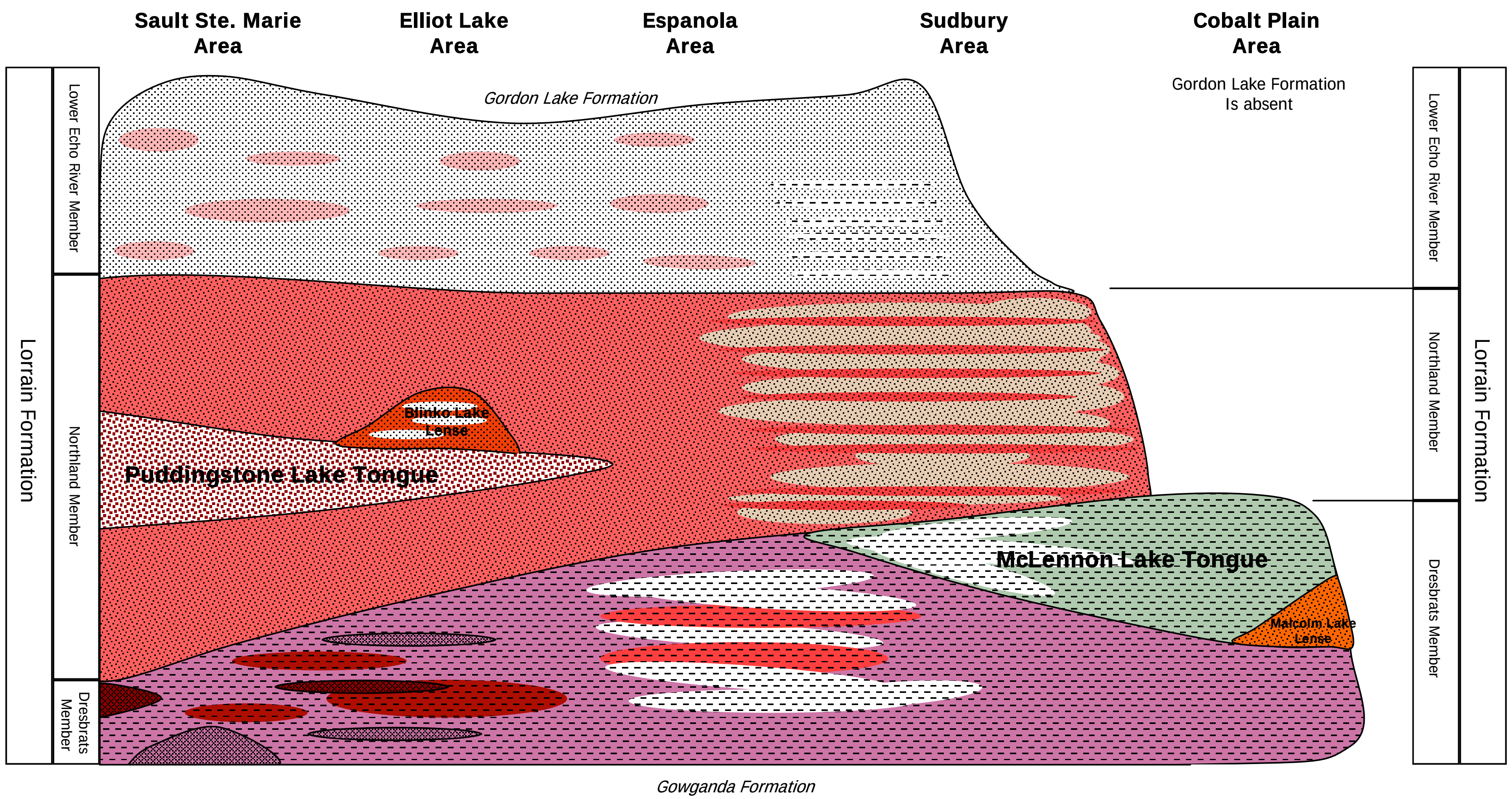
QFL

WACKES

(Diagram 2)



Attachment D: Figure 7: Correlation and Stratigraphic Units of the Lorrain Formation Ontario Canada



LEGEND

- Quartz arenites and Subarkose
- Pebbly Quartz arenites and Subarkose
- Oligometic orthoconglomerate
- Wacke and Argillite
- Arkose

NOTES:

All units are internally gradational with the above, below, and lateral units.

Lower Echo River and *Northland Members* are absent in the Cobalt Plain Area.

At present, the *Lower Echo River Member* is not sub-divided.

The *Northland Member* contains the *Puddingstone Lake Tongue* and the *Blinko Lake Lens.*

The *Dresbrats Member* contains the *McLennon Lake Tongue* and the Malcolm Lake Lens.

This three member division allows for the future naming of individual beds, lenses, and tongues.