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SEDIMENTOLOGY OF THE
HURONIAN COLEMAN AND
FIRSTBROOK FORMATIONS,
COBALT AREA, ONTARIO

by

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A thesis submitted to the Faculty of
Graduate Studies in partial fulfilment
of the requirements for the degree of
Master of Science

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ABSTRACT

Within the study area the Huronian succession is represented by the Cobalt Group sediments. This group comprises the Coleman, Firstbrook and Lorrain Formations in ascending order. This study deals with the first two formations.

The Coleman Formation comprises argillite, sandstone and conglomerate. The conglomerate is the uppermost and the most widespread lithology. It has features typical of glacial transport and structures suggesting local water action; locally there are massive sand bodies within the conglomerate.

Sandstone is present at places and underlies the conglomerate with a sharp contact. The sandstone ranges from arkose to lithic arkosic wacke. Grain size increases from the bottom to the top of the sandstone. Primary sedimentary structures also indicate an upward increase in current strength.

The argillite underlies the conglomerate and wherever present, the sandstone. The contact with the conglomerate is sharp but it is gradational with the sandstone. The argillite, made up of regular, graded laminations, probably was deposited in a glacial lake.

Structures in the siltstones of the Coleman Formation that superficially resemble worm burrows probably were formed by rolling of sediments released

from melting snow. Euhedral casts on some bedding surfaces of the Coleman argillites appear to represent early-formed carbonate crystals.

The Firstbrook Formation is made up of laminated clay- and silt- size particles. Red colour and abundant current structures distinguish it from the Coleman argillite. Large-scale soft sediment intrusions within the Firstbrook Formation suggest episodes of seismic activity.

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CHAPTER I

INTRODUCTION

Conglomerates and associated sedimentary rocks of the Cobalt Group of the Huronian Supergroup occur in a belt extending from Lake Huron to western Quebec (Fig. 1), (Stockwell et al. 1970). The origin of these Proterozoic rocks has been the subject of controversy since Coleman (1907) suggested that the Cobalt conglomerates are of glacial origin; this interpretation is supported by recent work mainly among the north shore of Lake Huron (Ovenshine, 1965; Casshyap, 1966; Lindsey, 1967; Chandler, 1969).

This thesis summarizes a study of the Cobalt Group in the type area west of Lake Temiskaming (Fig. 1). The study was carried out to obtain more detailed information on conditions of deposition than previously available, and to seek criteria useful for stratigraphic correlation of lithologic units of the Cobalt Group. Sedimentary structures and petrographic characteristics were emphasized in the study.

The results of this study are presented mainly as analyses of distinctive sedimentary structures of the Cobalt Group in the study area; several such analyses in different areas can provide a basis for a regional synthesis of conditions prevailing during deposition of the Cobalt Group.

Fig. 1 - Distribution of the Huronian Supergroup and
locations of the study areas.

CHAPTER II

GEOLOGICAL SETTING

The Huronian succession is subdivided into four groups; in ascending order these are: Elliot Lake, Hough Lake, Quirke Lake and Cobalt Groups (Table 1). All but the lowermost of these groups record cycles of deposition which begin with conglomerate; these are then overlain by fine-grained beds which are overlain by sandstone (Frarey and Roscoe, 1970). Within the study area and farther north the Huronian is represented by the Cobalt Group which rests directly on the Archean metavolcanic and metasedimentary rocks of the Superior Province. These essentially unfolded rocks overlying the folded Archean rocks belong to the Cobalt Plate (Stockwell et al., 1970)

The Cobalt sediments were subdivided into two formations by Collins (1917): the Gowganda Formation (lower) and the Lorrain Formation. Later the Gowganda Formation was further subdivided in the Cobalt area by Thomson (1957). Thomson's terminology (Table 2) will be used henceforth in this thesis.

The Nipissing diabase which intrudes the Huronian rocks has been dated by the Rb-Sr method at 2155 ± 80 m.y. by Van Schmus (1965). Coleman Formation greywackes and argillites gave a Rb-Sr age of 2288 ± 87 m.y.

Text complete; leaf 4 omitted in numbering

Table 1 - Stratigraphy of the Huronian succession (from
Stockwell et al., 1970 and Frarey and Roscoe,
1970).

	Maximum thickness (in m.)
COBALT GROUP	
Lorrain Fm.: arenite ----->	2000
Gowganda Fm.: argillite, siltstone, conglomerate ----->	1300
- Conformity, local disconformity -	
QUIRKE LAKE GROUP	
Serpent Fm.: arkose, quartzite ----->	600
Espanola Fm.: limestone, siltstone, dolomite ----->	600
Bruce Fm.: conglomeratic greywacke ----->	200
- Slight angular discordance -	
HOUGH LAKE GROUP	
Mississagi Fm.: quartzite ----->	1300
Pecors Fm.: siltstone, argillite, quartzite ----->	1200
Ramsey Lake Fm.: conglomerate ----->	200
- Local angular unconformity -	
ELLIOT LAKE GROUP	
McKim Fm.: argillite, siltstone, quartzite ----->	1000
Matinenda Fm.: quartzite, conglomerate ->	200
- Unconformity -	
ARCHEAN BASEMENT: volcanic, sedimentary.	

Thomson 1957	Collins 1917
LORRAIN FORMATION Arkose, quartzite	LORRAIN FORMATION
FIRSTBROOK FORMATION Argillite	GOWGANDA FORMATION
COLEMAN FORMATION Conglomerate, bedded greywacke, quartzite	

ARCHEAN

Table 2 Cobalt Group. Subdivision into
formations in the Cobalt area
(from Thomson, 1957).

(Fairbairn et al., 1969). It can thus be concluded that the age of the Huronian rocks is between 2600m.y. and 2160m.y. (the approximate ages of the Archean basement and the Nipissing diabase respectively).

Huronian rocks in the study area are in broad basins and domes with inclination of bedding normally less than 20 degrees. Only chlorite-grade (greenschist facies) metamorphism is recognized. Outside the study area along the north shore of Lake Huron, Huronian rocks are moderately to tightly folded (Lindsey, 1967), with local evidence of amphibolite facies metamorphism (Card, 1964).

A generalized geological map (after Thomson 1963), shows the distribution of lithologies and structural features in the study area.

CHAPTER III

STRATIGRAPHY

The formations of the Cobalt Group, like those of the lower successions of the Huronian Supergroup, thicken from west to east and from north to south, and the Cobalt Group is thicker and more extensive than the other three groups. It attains a thickness of more than 5000m south of Sudbury, but farther north it decreases to less than 1000m (Frarey and Roscoe, 1970).

Within the study area the Cobalt Group is represented by the Coleman, Firstbrook and Lorrain Formations. The Lorrain Formation was not included in the present study.

The Coleman Formation is made up of extensive conglomeratic bodies with less abundant sandstones and argillites. The lateral discontinuity of sandstones and argillites, and faulting, hamper regional correlation despite good control given by data available from numerous drill holes in the region (Thomson 1961-3, 1961-4).

The top of the formation is a widespread conglomerate which is the dominant rock type seen on the west side (footwall) of the reverse Cobalt Lake Fault. This fault extends for several miles through the area and dips steeply east-southeast. Because rocks on the hanging wall have been more extensively eroded, several

lithologies underlying the conglomerate can be observed in the scarp on the east side of the Cobalt Lake Fault.

The greatest known thickness of the Coleman formation in the study area is about 500m., west of Sasaginaga Lake (Thomson, 1961-4). Fig. 2 is a fence diagram tentatively correlating the prominent lithologies; information on subsurface details, supplementing the sections observed at the surface, is from Thomson (1961-3, -4). As mentioned by Thomson (1961-3, -4, and personal communication, 1971) the Coleman Formation has filled valleys in the Archean terrain, one of which underlies the present Cobalt Lake. These troughs were separated by topographic arches such as the Peterson Lake arch southeast of Cobalt Lake, where the Nipissing diabase rests directly on Archean rocks; probably the Coleman Formation was relatively thin in this location before the pre-Nipissing erosion (Thomson 1961-4).

In view of this topographic control, it is clear that the lower parts of the Coleman Formation cannot be easily correlated from trough to trough. The uppermost lithology of the Coleman Formation, on the other hand, covers a wide area and shows distinctive sedimentary structures common at least to the east side of the Cobalt Lake Fault, therefore offers the best basis of regional correlation.

The conglomerate contains bodies of massive siltstone and sandstone, very coarse-grained sandstone and argillite.

Fig. 2 - Fence diagram tentatively correlating the prominent lithologies of the Coleman Formation in the Cobalt area. Columns are projected down from surface locations (solid circles), and one based on both measured sections and drill-hole information.

A sandstone containing sedimentary structures indicative of water transport underlies part of the conglomerate on the east side of the Cobalt Lake Fault. A banded argillite underlies the conglomerate and the sandstone wherever the latter is present. The contact between the conglomerate and the underlying lithologies is sharp whereas the contact between the argillite and the sandstone is gradational.

Below the banded argillite, a conglomerate encountered in the drill holes (Thomson, 1961-3, -4) also contains units of banded argillite; data available at present are insufficient for correlation of individual units in this lower conglomerate. Therefore, only the upper conglomerate will be dealt with.

A second type of conglomerate characterized by distinctive texture, geometry and composition occurs in lenses at the base of the Coleman Formation. It outcrops in areas farther south of the study area (Schenk, 1965) and also farther north of the Cobalt region.

The contact between the Coleman and Firstbrook Formations is not well exposed, but the general consensus is that the latter overlies the former and that there is no marked unconformity between the two (Thomson, 1957). The greatest known thickness of the Firstbrook Formation is within Henwood township, about 30 km. northwest of the town of Cobalt, where a drill

hole penetrated a total of almost 600m. of Firstbrook without reaching the Coleman Formation (Thomson, 1966).

The contact of the Firstbrook Formation with the overlying Lorrain Formation is gradational.

The Firstbrook Formation outcrops west and northwest of the Cobalt area, but east and southeast of the study area it is absent and the Lorrain Formation, where present, rests either on the Coleman Formation or the Archean basement (Thomson 1957).

CHAPTER IV

LITHOLOGY

Huronian rocks within the study area are entirely clastic. The Coleman Formation comprises conglomerate, wacke, argillite and minor arkose whereas the Firstbrook Formation is essentially a siltstone according to Pettijohn's (1957, p. 341) definition.

Coleman Formation

Conglomerate

The conglomerate is the most widespread unit of the formation; it forms all the Coleman outcrops west of the Cobalt Lake Fault and many of those east of it. The maximum known thickness of the conglomerate is about 70m. (Thomson 1961-4). The lower contact of the conglomerate is sharp (Plate 1a) whether it overlies the sandstone or the argillite. A few isolated clasts may be observed within the upper few centimeters of the underlying lithologies, and sporadic load casts up to 50cm. wide and 40cm. deep were observed (east side of Hwy. 11B, just north of Cobalt). These load "pockets" have deformed laminations in the lithologies immediately below, and pebbles within the pockets are randomly arranged.

Where the lower contact of the conglomerate is seen, the bottom part for about 2m. is massive and structureless except for rare discontinuous and poorly defined pebble alignments which do not extend for more than a few meters horizontally.

This unit of the Coleman Formation is an inhomogeneous mixture of very poorly sorted conglomerate, moderately sorted conglomerate, and massive to faintly laminated siltstone-sandstone. The matrix of the conglomerate is massive, poorly sorted, sandy and well indurated.

Most clasts in the conglomerate are smaller than 10cm.; they show a wide range in composition, but can be classified in three main groups: plutonic ones (granite to granodiorite), which constitute roughly half of clasts, sedimentary ones derived from the Coleman itself and which constitute 5 to 10 percent of the total, and Archean metavolcanics and metasediments. Although most of the Huronian clasts are recognizable by their angularity, composition and texture, the chlorite-grade metamorphism that has affected all the rocks in the area makes it difficult to distinguish Archean sedimentary clasts from those of Huronian origin.

The striking characteristics of the conglomerate are the great size range of the framework elements, and the heterogeneity of shape and composition of the clasts. In general, there is no relation between the composition of the clasts and their shape except that granite clasts tend to be equant.

Clasts larger than 10cm. are mostly subrounded. Fig. 3 shows the distribution of roundness of clasts larger than 10cm. Most of the largest clasts are plutonic in origin. Fig. 4 shows the percentage of clast types larger than 10cm. at different localities shown in Fig. 5.

Boulders in excess of 1m. in apparent diameter are enclosed in a silt-, and sand-sized matrix. Although clasts of comparable size are not found everywhere, those in the order of tens of centimeters are extremely abundant. Of more than 300 clasts in the Cobalt area with apparent diameters greater than 10cm., at least 40 percent are larger than 20cm.

Nevertheless most clasts are smaller than 10cm. Plate 1b shows an example of poorly sorted conglomerate in which the majority of clasts are smaller than 10cm. Some parts of the conglomerate are better-sorted (Plate 1c) and have a coarse to very coarse sandy matrix with fresh pebbles similar in shape to those in the rest of the conglomerate but mostly smaller than 5cm. Lenses of very coarse sand less than 2m. in horizontal extent are present in this part of the conglomerate. The size and abundance of the clasts varies greatly within the conglomerate. Outcrops range from those with sparse and small (less than 20cm.) clasts (east shore of Sasaginaga Lake, west of Cobalt), those with sparse but large (up to 70cm.)

Fig. 3 - Distribution of roundness of clasts larger
than 10cm., Coleman conglomerate. See Fig. 5
for locations. Chart from Pettijohn, 1957.

1

2

3

4

5

6

Fig. 4 - Volumetric abundance of sedimentary(S),
plutonic(P) and volcanic(V) clasts, as
determined by megascopic point counts of
clasts larger than 10 cm., Coleman con-
glomerate. See Fig. 5 for locations.

Fig. 5 - Locations of Coleman conglomerate outcrops
referred to in Fig. 3 and 4.

1. Little Silver Vein outcrop, southeast of Cobalt Lake.
2. Outcrop on the east side of Hwy. 11B, just north of the town of Cobalt.
3. Outcrop on the west side of Hwy. 11, about 15km. north of its junction with Hwy. 66.
4. Outcrop southeast of the Cobalt Hydro Plant.
5. Outcrop on the south side of Hwy. 558, about 1.5km. east of its junction with Hwy. 11.
6. Outcrop at Kenogami Lake, along Hwy. 11 about 1km. north of its junction with Hwy. 66.
7. Outcrop on the south side of Hwy. 66, 3km. east of Virginiatown.
8. Outcrop on the east shore of the east arm of Sasaginaga Lake.

clasts (250m. northwest of the Dumphill west of Cobalt), those with abundant and dominantly large (up to 80cm.) clasts (east side of Hwy. 567 about 1km. southeast of North Cobalt), to those with abundant and mixed sized clasts (south of west arm of Peterson Lake, Fig. 6).

Southwest of Peterson Lake the conglomerate contains fractured clasts ranging from 10cm. to 60cm. (Plate 1d). Matching fragments of these clasts are separated by intruded matrix material; some of the fragments have been rotated, but most clast fragments are separated from each other by up to 15cm. without appreciable rotation.

Fracturing by alternate freezing and thawing of water absorbed in the rocks is a known phenomenon in high mountains or periglacial zones (Termier, 1963), but such fracturing is also reported from non-glacial regions (Ollier 1969). Fractured clasts are believed to be due to insolation weathering; as the rock heats and expands "dirt fragments fall into any open crack and prevent its closing as the rock cools" (Ollier, 1969). The process continues until the fragments fall apart. If the fragments are not carried away they may be buried by sediments and preserved in their parted position.

Some clasts, mostly within the 10 to 40cm. range, have rinds around them which range from a few milli-

Fig. 6 - Map of part of the outcrop south of the west
arm of Peterson Lake, southwest of Cobalt.
Position of the mapped area relative to power
line poles (a and b) that border the road south
of Peterson Lake is shown in the inset.

meters to a centimeter in thickness. These rinds are best seen on glaciated surfaces although some are visible on bedding and fracture surfaces as well. Such rinds are restricted to clasts that are more or less rounded. Clasts of different original composition exhibit slightly different types of rinds.

Some clasts of basic rocks have a concentration of dark chloritic spots around them (Plate 1e). In some cases these spots form a continuous rind. Clasts more silicic in composition do not have such spots even though they are in a matrix rich in chlorite. The formation of the chlorite rinds appears to relate more to mineralogy and metamorphism and will not be dealt with here.

Rinds on the argillaceous clasts are lighter in colour than the cores of the clasts. This light brownish colour is the typical weathering colour of the argillites in the Cobalt area and it is most probable that the rinds are the product of pre-depositional weathering. The discolouration commonly extends within the clasts along the fractures (Plate 1f). As seen on the bedding surface the rinds are non uniform in thickness. But in three dimensions they are much thinner, and more uniform in thickness (Plate 2a). It seems therefore that the appearance of the rinds depends on the depth of erosion.

Some granitic clasts have light-coloured rinds and darker, rusty red cores, but the three-dimensional aspect is quite different from that of the argillite clasts. The dark colouration at the centre of the argillite clasts is the unweathered colour of the rock as it can be seen on broken clasts. The dark colouration at the centre of the rinded granitic clasts rarely extends more than a few millimeters below the present weathered rock surface. When broken, the part underneath the central portion is seen to be fresh and unaltered compared to the rusty red surficial core (Plate 2b). One possible mechanism for the formation of these rinds is the weathering of the pebble to a certain depth prior to its deposition with resultant removal of its less resistant minerals from this outer weathered zone. After deposition and lithification, if the affected pebble is exposed to weathering on a bedding surface, joint, etc. the centre of the surface will weather to give the rusty colouration, while the periphery, where the more resistant minerals have remained, will not change appreciably in colour.

The occurrence of rind-bearing clasts adjacent to rind-free clasts demonstrates that the rinds are of pre-depositional origin. A thin section of a

rinded siltstone clast shows an abundance of chlorite and some opaque minerals in the core but none in the rind, indicating removal of less resistant minerals from the outer part of the pebbles before their deposition (Plate 2c).

Sand Fraction of the Conglomerate

There are concentrations of sand bodies within the essentially conglomeratic units. These bodies are mostly massive, less than 3m. thick and limited in lateral extent (in the order of tens of meters). They contain sparse pebbles mostly smaller than 10cm., and locally, there are isolated, faint and discontinuous laminations. Apart from these features, the sand bodies are compositionally and texturally similar to the sand fraction (matrix) of the conglomerate, and as such they are treated as part of the sand fraction. Prominent features of this fraction are an abundance of silt- and clay-size material, a predominance of poorly sorted, angular grains, a high degree of matrix corrosion and an abundance of plagioclase.

For classification of the sand fraction of the Coleman Formation the scheme proposed by Casshyap (1966) was adopted (Fig. 7); 200 to 350 points per thin section were counted. The spacing of points was arranged to cover the whole section; parts of pebbles,

Fig. 7 - Sandstone classification scheme used for the
present study (from Casshyap, 1966).

if present, were not counted. Grains down to 0.03mm. were individually identified and classified, the smaller fraction being grouped as matrix.

Eight samples selected from representative areas of the Coleman Formation, from Sasaginaga Lake in the west to Lake Timiskaming in the east have matrix contents between 45 to 65 percent; they are therefore wackes according to the adopted classification scheme. It should be pointed out that diagenetic enrichment of matrix is widespread in the Coleman Formation. The amount of primary matrix, therefore, is probably somewhat less than the figures obtained, but even then these samples fall well within the wacke class.

The major constituents of the matrix are fragments of quartz, feldspar and abundant chlorite with some sericite. Stages of alteration of grains can be observed in thin section, ranging from fresh grains to those hardly distinguishable from the matrix. Some grains remain as ghosts that are best distinguished in plane polarized light. Despite the abundance of feldspar in the rock, clay minerals are not an important part of the matrix (shown by X-ray analyses).

Chemical analyses of samples from the matrix of the Coleman Formation in the Cobalt area have revealed a high amount of sodium (average Na_2O 4.07 percent, standard deviation 0.42) for the sand fraction, and this

was interpreted as due to a lack of significant chemical weathering (Young, 1969). On the other hand, the low CaO content (average 2.15 percent, standard deviation 0.88) was interpreted to be the result of the breakdown of Ca-bearing minerals such as calcic plagioclase and clinopyroxene. These Ca-bearing minerals "being in a finely comminuted state.... would be susceptible to diagenetic and metamorphic alteration, giving rise to abundant chlorite" (Young, 1969). No clinopyroxene, amphibole or calcic plagioclase were observed in the conglomerate matrix or in the argillite. Young (1969) also found that the sand fraction of the conglomerate contains more magnesium and iron than the average analysis for the Archean Shield of northwestern Ontario (Shaw et al, 1967). Young suggested that the softer (more cleavable) mafic minerals were easily affected by mechanical breakdown during transportation, because there is little evidence for chemical breakdown.

The composition and abundance of grains within the sand fraction of the Coleman Formation show distinct variability, even within short distances (Fig. 8). The amount of matrix in these samples is shown in Fig. 9. The location of the samples is shown in Fig. 10. The largest grains are rock fragments, but besides the rock fragments there is no relation of grain size to composition. The examined samples are in general rich in

Fig. 8 - Composition of the sand fraction of the Coleman conglomerate in the Cobalt area. See Fig. 10 for locations. Q: quartz, F: feldspar, LF: lithic fragments.

Fig. 9 - Amount of matrix in the 8 samples plotted in Fig. 8.

Fig. 10 - Location of samples from the sand fraction of
the Coleman conglomerate.

11. North end of Little Silver Vein outcrop,
southeast of Cobalt Lake.
- 12b. South end of Little Silver Vein outcrop,
southeast of Cobalt Lake.
29. Outcrop at the north end of Dump hill,
west of Cobalt.
32. Outcrop on the north side of Hwy. 558,
about 1.6km. east of its junction with
Hwy. 11.
38. Outcrop on the west shore of Lake
Timiskaming, about 400m. north of the
Agaunico shaft.
42. Outcrop on the east shore of the east arm
of Sasaginaga Lake.
53. Outcrop southeast of the Cobalt Hydro
Plant.
54. Outcrop at the east end of Dump hill, west
of Cobalt.

quartz. Some quartz grains are composite but most are single grains. They are mostly angular to sub-rounded with a few rounded ones; in general they are poorly sorted. Most of the grains are corroded by the matrix to some extent; those of subhedral form have well-preserved crystal faces while their anhedral sides are corroded.

X-ray analyses have shown that the feldspar species present in decreasing order of abundance are plagioclase, orthoclase and microcline, with the latter much less in amount than the first two. The plagioclase grains, mostly irregular in form and slightly rounded, are mainly albite. The orthoclase grains typically are larger than the plagioclase grains. Feldspar sericitization is a common but variable phenomenon, the grains ranging from fresh ones to those hardly discernible from the matrix. There is no relation of size to alteration. For thin-section modal analyses, only the rock fragments less than 2mm. were counted. Different rock types were not counted separately in thin section but of note is the great scarcity of sedimentary rock fragments; there is no doubt that the angular siltstone pebbles seen within the Coleman Formation could not withstand abrasion and therefore disintegrated readily to their components.

Most clasts of volcanics are rounded and poorly preserved. Many of them have been strongly corroded and remain as ghosts within the matrix.

Plutonic fragments are irregular in form but generally are somewhat rounded. They range in composition from granite to granodiorite. They are better preserved than the volcanics; nevertheless sericitization of their feldspars is common. Clast edges are corroded, and some clasts have broken pieces adjacent to them with little rotation; matrix fills the spaces in between.

Grain-size analyses are based on the long-axis measurements of 250 grains per thin section. Grains between 2mm. and 0.03mm. were considered. Cumulative frequency curves for sieve-size distribution have been derived from thin-section data with the aid of the correlation chart of Friedman (1958). Statistical parameters of grain-size were determined from the cumulative curves thus constructed (Appendix). The methods for the determination of graphical parameters from cumulative curves are given by Folk (1968). The results for the sand fraction of the conglomerate are listed in Table 3.

The graphic mean (M_z) of the samples ranges from 2.38 to 3.0, and thus the average grain-size is in the fine-grained sand range.

The inclusive graphic standard deviations (σ_I) range from 0.97 to 1.36, and all except one are in the poorly-sorted range of 1.0 to 2.0. The exception

Table 3 - Statistical parameters for samples of the
sand fraction of the Coleman conglomerate.
Sample numbers correspond to locations shown
on Fig. 10.

Sample	M_z	σ_I	1. Mode ϕ	2. Mode ϕ	S_{KI}
11	2.82	1.15	2.1	3.8	-.26
12b	2.80	1.16	2.7	3.5	-.08
29	2.58	1.31	3.25	-	-.25
32	2.38	1.36	1.5	3.0	-.068
38	3.00	.97	2.3	3.3	+.04
42	2.70	1.01	1.9	2.6	-.12
53	2.47	1.29	3.75	-	-.59
54	3.00	1.32	3.1	-	-.17

(0.97) is close to the limit (1.0), and thus the sand lenses of the conglomerate can be classified as poorly sorted.

The modal range of the samples varies greatly between sample localities, ranging from 1.5 to 3.75, and thus the sand fractions are medium- to very-fine grained. Five samples are bimodal with the secondary modes ranging from 2.6 to 3.8.

All samples, except one, are negatively skewed (Table 1). The inclusive graphic skewness (Sk_I) ranges from 0.4 (near-symmetrical) to -0.59 (strongly coarse-skewed). Seven of the samples have near-symmetrical or coarse-skewed curves.

Sandstone

Bodies of sandstone less than 15m. thick differ from those within the dominantly conglomeratic unit by their sedimentary structures and their mineralogy (Fig. 11). The amount of matrix in these samples is shown in Fig. 12. The locations of samples are given in Fig. 13. These sandstones outcrop on the east side of the Cobalt Lake Fault. They extend for about a mile in a north-south direction. At the northern end they lens out, but the south end cannot be followed because of poor exposure.

The matrix is mainly a product of physical breakdown. The abundance of feldspar facilitates to some

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Fig. 11 - Composition of 8 samples from the Coleman
sandstone. See Fig. 13 for sample locations.
Q: quartz, F: feldspar, LF: ~~lithic frag-~~
ments.

Fig. 12 - Amount of matrix in the 8 samples plotted in
Fig. 11.

10^a 10
8 10b

20 23

21 24

15 30 45 60 75

% matrix

Fig. 13 - Location of samples from the Coleman sandstone.

- 8. Lower part of the sandstone, Little Silver Vein outcrop, southeast of Cobalt Lake.
- 10. North end of the Little Silver Vein outcrop, above the level of sample 8.
- 10a. Middle part of the Little Silver Vein outcrop, above the level of samples 8 and 10.
- 10b. South end of the Little Silver Vein outcrop, near the top of the sandstone.
- 20. Outcrop southeast of Cobalt Hydro Plant.
- 21. Outcrop southeast of Cobalt Hydro Plant, above the level of sample 20.
- 23. Outcrop east of La Rose Mine, northeast of Cobalt Lake.
- 24. Outcrop east of La Rose Mine, northeast of Cobalt Lake.

degree the present-day weathering of these sandstones which range from arkose to lithic arkosic wacke. The more extensively cross-bedded parts of the sandstones are better sorted and contain less matrix although the grains are angular and the feldspars are fresh. Feldspar grains, mostly plagioclase, are comparable in size to quartz grains.

The grains in the arenite are angular, interlocking and some are welded together. Corrosion of grains is widespread and commonly it is difficult to distinguish the boundaries.

The angularity of the grains in the wacke is very similar to those of the arenite grains. But the grains are dispersed in the matrix and thus their form is easily distinguished.

The degree of corrosion, in both types of sandstones varies from grain to grain within a sample. The differential corrosion probably derives mainly from the susceptibility of individual grains to corrosion. If this is the case, the presence of both fresh and corroded grains indicates that some grains had a different origin and/or transport history than the rest of the grains, making them more susceptible for corrosion.

One sample contains about 3 percent calcite; this was the only sample in which carbonate was found during the present study (Plate 2d).

The results of the grain-size analyses are listed in Table 4. Parameters were derived from the cumulative curves mentioned earlier. Ogive curves are shown in the Appendix.

The graphic mean (M_z) of the samples ranges from 3.41 (very fine-grained) to 0.9 (coarse-grained). Seven of the samples are medium or finer grained; this distribution reflects the grain size of the non-conglomeratic parts of the Coleman Formation.

The inclusive graphic standard deviation (σ_z) ranges from 0.39 (well-sorted) to 1.22 (poorly sorted). Two of the samples are poorly sorted; the others are moderately to well sorted.

The curves of the samples are skewed; four of them are fine- to strongly fine-skewed (0.17 to 0.6) and the four others are coarse- to strongly coarse-skewed (-0.14 to -0.48).

Argillite

Lithologies belonging to the Coleman Formation and defined as banded argillite in this study are those which show tabular laminations. They are made of alternate layers of silt- and clay-size materials.

On a fresh surface the silty layers are dark green, almost black, while the argillaceous layers are green. On weathered surfaces the silty layers are light

Table 4 - Statistical parameters for samples of the
Coleman sandstone. Sample numbers correspond
to locations shown on Fig. 13.

Sample*	$Mz\phi$	$\sigma_I\phi$	1. Mode ϕ	2. Mode ϕ	Sk_I
8	3.25	.62	3.25		-.15
10a	1.35	.92	1.25		+.21
10b	1.45	1.22	1.5		-.37
10	2.72	.56	2.6		+.29
20	1.75	.39	1.75		+.6
21	3.41	.59	3.5		-.48
23	0.90	.74	.8		+.17
24	2.66	1.18	3.5		-.14

brownish green, and the argillaceous layers are green.

The thickness of layers varies greatly. The silty layers are generally thicker; they range from a fraction of a millimeter to 2.3cm., but mostly they are less than a centimeter thick. The argillaceous layers are up to 1cm. thick but normally are less than .5cm. Both types of layers are internally laminated. Silty layers are mostly graded; their bases are sharp while the tops are sometimes not very distinct from the overlying argillite layer. Silty and argillaceous layers form couplets which are repeated throughout the laminated argillite. The grains identifiable in thin section are quartz and feldspar; although plagioclase grains are more abundant than K-feldspar, the small grain size does not permit the determination of feldspar ratios.

The grains are fresh and angular, but corroded on the outer margins. There are a few rock fragments up to 0.3mm. in diameter, mostly plutonic; this is to be expected because the non-plutonic clasts present in the coarser fraction of the Coleman Formation have a poor resistance to weathering. X-ray analyses by Young (1969), of samples of similar argillites collected from different localities in the Gowganda Formation (Bruce Mines to Virginiatown) including samples from the Cobalt area, have shown that the argillaceous layers have much

more chlorite but less quartz and feldspar than the silty ones, and thus there is a difference of both chemistry and mineralogy between the two types of layers.

Gray-white speckles in argillaceous layers of some hand specimens are seen to be clusters of sericite in thin section (Plate 2e). X-ray analyses has also confirmed the presence of sericite.

Dark green, black, spherical chlorite spots up to 1.5cm. in diameter are abundant throughout the argillites of the Coleman Formation, particularly in the silty layers. Commonly the spots are larger than the silty layers in which they occur (Plate 2f). Spots are present also in the conglomerate and to a lesser amount in the sandstone.

The fact that spots in the banded argillites occur in the silty layers which are poorer in mafic minerals suggests that ~~permeability of the rock is a prime factor in the formation of these spots.~~

Granite Conglomerate

This conglomerate is quite distinct from the other conglomerates in that it has very abundant clasts, mostly granitic and syenitic, ranging from sand size up to 70cm. The clasts are generally rounded but they show a wide range in shape.

The clasts represent several types of granite. Although most of them are pink and leucocratic, their textures show a great diversity. The matrix is a green-grey arkosic wacke rich in pink feldspar.

One good example of this conglomerate outcrops along Hwy. 11 at Kenogami Lake, about 20km. west of Kirkland Lake. In this outcrop 96% by volume of the clasts larger than 10cm. are felsic plutonic. Because of their texture these clasts tend to be equant, but fracturing has resulted in other forms as well. The outcrop on the northeast side of Hwy. 11 interfingers at its southeastern end with a fine- to medium-grained subarkosic wacke which has very few pebbles in it, none of them larger than 5cm.

The subarkosic wacke has 40 percent matrix, about 10 percent feldspar, 50 percent quartz and less than 1 percent rock fragments and mica. The grains are angular to sub-rounded and poorly sorted. Feldspars are comparable in size to quartz grains but most of them are weathered. Plagioclase is slightly more abundant than the orthoclase and microcline is appreciably less than the other two. The quartz grains although fresh inside are corroded by the matrix on the outside. The corroded sides of the grains have a chlorite coating usually less than .01mm. thick. Mica grains are both muscovite and biotite. The larger ones are deformed by the adjacent grains. Some muscovite grains are fresh and easily

recognizable but most micas are altered and some are hard to distinguish within the matrix.

The graphic mean grain size is 2.42 and the mode is 2.3; both fall in the fine-grained sand size. The inclusive graphic standard deviation is 0.73 (moderately sorted) and the inclusive graphic skewness is 0.14 (fine skewed).

The arkosic wacke has more than 45 percent matrix, about 20 percent quartz, slightly more than 20 percent feldspar and about 10 percent rock fragments. The largest grains, mostly angular, are plutonic rock fragments. Quartz grains are fresh but feldspars (especially the orthoclase) are mostly altered. Mica grains, mostly muscovite, form less than 3 percent of the rock; some, up to 0.4mm. in diameter, are deformed or disrupted by the framework grains. The rock fragments are differentially altered, the feldspars being cloudy in contrast to the fresh grains of quartz. The few mafic volcanic rock fragments are more strongly altered than the plutonic ones. There is extensive corrosion of all framework grains by the matrix.

The graphic mean is 1.35, and the mode is 1.3, both parameters thus indicating the medium-grained sand size. The inclusive graphic standard deviation is 1.18 (poorly sorted) and the inclusive graphic skewness is -0.23 (coarse skewed).

Firstbrook Formation

This formation is almost entirely made up of clay- and silt-size particles. Its pale red colour contrasting with the dark green colour of the Coleman, the Firstbrook Formation consists essentially of laminated claystone-siltstone intercalations. Laminations range from 0.1mm. to 6mm. in thickness. On fresh surfaces silty layers are dark green, generally thinner than the claystone layers, rarely exceeding 5mm., and lensoid.

They are made of silt and very fine-grained sand in a sericitic and chloritic matrix. The largest grains are quartz, up to 0.2mm., but most are about 0.06mm. in apparent diameter. They typically are angular and somewhat corroded on the outside.

Identifiable feldspars are mostly plagioclase, forming about 10 percent of the silty fraction. They are somewhat fresh and angular like the quartz grains.

Mica fragments (mainly muscovite and lesser biotite) are ubiquitous in the Firstbrook Formation, although they form at the most only 3 to 5 percent of the silty layers (Plate 3a). The average size of the discernible micas is about 0.02mm. They are essentially within the silty fraction, and give a shiny appearance to the bedding surfaces of rippled silty layers. One such outcrop is on the east side of Hwy. 11, about 4km. south of the junction with Hwy. 558.

Grains of opaque minerals smaller than .1mm. form less than 1 percent of the rock. Elongate grains are parallel to bedding. They are mainly specularite.

The argillaceous layers are much too fine-grained to be identified in thin section, although the abundance of chlorite is indicated by some green colouration in the essentially red-coloured layers. X-ray analyses have shown the presence of quartz, mica, chlorite and albite. Mica grains, attaining 0.3mm. in the argillite layers, are commonly chloritized.

The red colouration of the Firstbrook Formation disappears near its contact with diabase intrusions. Along Hwy. 11, about a mile north of its junction with Cobalt Road, the argillite is very dark grey within 3m. of a diabase dike. Such alteration also exists along Hwy. 11B south of Cobalt.

Sericitization is quite common in both fractions although it is more easily seen in the coarser layers.

The Firstbrook Formation also contains a few massive sandstone bodies. Two distinct types outcrop along Hwy. 11. One type outcrops about a mile north of the West Cobalt Road junction; it is a fine- to very fine-grained subarkosic wacke. The average matrix content is 44 percent. The framework is made of over 80 percent quartz, over 10 percent feldspar and about 5 percent rock fragments and mica. The grains are

mostly subrounded and have low sphericity. Elongate grains are mostly parallel to bedding. Grains are corroded by the matrix rich in chlorite.

The graphic mean grain size is 3.2mm (very fine-grained), the mode as determined from the cumulative curve (Appendix) is 3.25mm. The inclusive graphic standard deviation is 0.57 (moderately well sorted).

The subarkosic wacke has scarce cross-beds less than 10cm. long and 5cm. thick. The pink colour of the Firstbrook Formation disappears within 3m. of the intruded diabase. The dike is less than 10m. thick. From about 7m. away from the dike, chlorite spots up to 1mm. in diameter appear in the Firstbrook Formation. The spots are much more abundant in the sandstone. There is some concentration of spots along cross-bed surfaces, but apart from this, the distribution of the spots within the sandstone is random. The spots in the banded wacke are restricted to the coarser-grained layers.

A second type of sandstone outcrops on the east side of Hwy. 11, within 1.5km. of its junction with Hwy. 558. This is a massive, white-grey subarkose with slightly less than 10 percent matrix. Quartz grains make up about 80 percent of the rock, feldspars amount to 15 percent, and the rest consists of rock fragments. The grains are interlocking and cemented, and this

renders difficult the distinction of rock fragments from the other grains. The grains are sub-rounded to rounded and relatively fresh. The feldspars, mainly plagioclase, are comparable in size and freshness to the quartz grains. Chlorite is present between the grains, it amounts to about 3 percent.

The maximum grain size is 0.4mm., the graphic mean is 2.55 (fine grained), the inclusive graphic standard deviation is 0.59 (moderately well sorted) and the inclusive graphic skewness is 0.01 (near-symmetrical). The subarkose is unimodal with a mode of 2.65 (fine-grained) (Appendix).

CHAPTER V
SEDIMENTARY STRUCTURES

Coleman Formation

Conglomerate

In addition to the well-known massive, poorly sorted parts of the Gowganda conglomerate that have been described since the days of Coleman, there are relatively well-sorted parts with evidence of water transport.

Channels, although not widespread, are recognizable in several outcrops (Plate 3b, c, d). The depths of the channels range from 20cm. to 50cm. It should be noted that surfaces of the outcrops seen in Plate 3b, c, d, are at low angles to the bedding and so depths of the channels appear greatly exaggerated. As channels are observed on outcrops cutting the bedding surfaces, their extent cannot be determined, but considering that they are neither thick nor widespread and that the relatively well-sorted conglomerate in which they occur has a limited extent, the channels might not extend beyond a few tens of meters. They trend roughly east-west.

Pebbles in the channels rarely exceed 10cm. in apparent diameter and are generally rounded to well rounded. Where numerous pebbles occupy the channels, the pebbles are randomly distributed (Plate 3c), but where sand is abundant, there tends to be some stratification (Plate 3d), and even horizontal alignment of elongate pebbles (Plate 3c).

The channels are cut into very coarse sand lenses which extend laterally for a few meters and then grade into the conglomerate. The thicknesses of these sand lenses is less than 50cm. Where there is abundant sand in the channels, cross-bedding typically occurs near the top (Plate 3c).

In addition to the channels, the well-sorted part of the conglomerate contains isolated cross-beds of very coarse to conglomeratic sand. These cross-beds are up to 50cm. thick but rather poorly formed. Beds are up to 10cm. thick and almost invariably contain abundant angular clasts smaller than 2cm. which in some cases are concentrated on bedding surfaces. The apparent dip of the crossbeds is less than 20 degrees. There is no consistent pattern of transport direction. The best examples of these cross-beds are on the western ridge of the hill north of Cobalt Lake, and west of the northeastern part of the town of Cobalt.

Along the east shore of the easternmost arm of Sasaginaga Lake, 1km. west of the town of Cobalt, the conglomerate contains sporadic clasts, none larger than 20cm., and most smaller than 7cm. The clasts are distributed mainly in conglomeratic sandstone beds ranging from 2 to 15cm. thick. Some beds contain pebbles that are larger than the bed itself. The conglomeratic beds are interbedded with essentially pebble-free, fine-grained, sandstone beds up to 40cm., but mostly less

than 10cm. These beds have faint, discontinuous laminations. Both types of beds grade into each other and their boundaries are difficult to trace.

The clast-free sandstone beds show rare ripple-marks less than 3cm. thick. The beds are essentially horizontal with very slight and small-scale (in the order of a few centimeters) undulations. Some of the beds continue for a few meters horizontally and lens out.

The faintly laminated sandstone beds are locally disrupted by scattered clasts. Most clasts are in the 2-3cm. range but some are up to 20cm. in diameter. Some clasts have bent the laminations below them, but laminations on top of them also are deformed, indicating that there has been some compaction. Some beds or laminations are thinner on top of large clasts, and there is no accumulation of material on either side of these buried clasts, suggesting that the sediments were deposited mainly from above with little or no lateral drag.

Other clasts interrupt the laminations without deformation; their relationship indicates that the pebbles were deposited with the laminated sandstone. Near the top of the outcrop southeast of the Cobalt Hydro Plant, the same type of relationship exists

between lenses of laminated, very fine-grained sand, in beds 3 to 30cm. thick and a few meters long, and clasts up to 25cm. that intersect these beds.

At the bottom of the ridge facing the Cobalt Arena from the east, a conglomeratic bed extends for a few meters in laminated argillite (Plate 3e). Its thickness is within the 10cm. range, but it varies greatly over a short distance; for example, within 30cm. it thins from 8 to 4cm. The largest clasts have diameters similar to the thickness of the bed in which they occur. Large clasts have bent the laminations of the argillite below, and there is no evidence that the clasts were dragged along the bottom during the deposition.

Bodies of siltstone and very fine-grained sandstone up to a few meters thick occur within the conglomerate. They grade laterally into the conglomerate with their lateral extent nowhere exceeding a few tens of meters. These bodies are massive or faintly laminated with very few clasts in them.

One such unit north of the Hydro Plant at Cobalt has conglomeratic beds up to 30cm. thick with pebbles less than 2cm., in the lower 1.5 meters; upwards it contains some asymmetric ripples (average index 1:9) and cross-beds less than 8cm. thick. Both structures indicate northeastward transport. A conglomeratic bed about 50cm. thick overlies this unit. Another sandy

unit occurs on top of the conglomerate. This second sandy unit contains more matrix (70 versus 30 percent) and more lithic fragments (20 versus 5 percent) than the lower sandy unit.

Another such fine-grained unit within the Conglomerate is exposed on top of the Little Silver Vein, south-east of Cobalt Lake. It is a very fine-grained sandstone-siltstone which has darker coloured laminations less than 1cm. thick. The laminations are rather faint and horizontal. There is some scarce cross-lamination as well. The laminations do not extend along the whole surface of the outcrop but they exist within the finer grained parts of the unit. There are sparse pebbles, mostly smaller than 4cm., which are in great contrast to the fine-grained nature of the unit. Some of the larger clasts have bent the laminations below them (Plate 3f).

The Coleman Formation contains clasts of argillite-siltstone which are similar in texture and composition to beds of the same lithologies that occur within the formation. A distinction should be made between such clasts and those derived from the Archean terrain. Although in some cases it is difficult to distinguish one type from the other, Archean clasts generally are darker in colour, somewhat more rounded and commonly are foliated. Most intraclasts in the Coleman Formation are angular to subrounded indicating

some degree of rolling and abrasion (Plate 4a). However, sporadic intraformational clasts have shapes indicative of little or no significant water transport. Some clasts, although rare, can be seen on the east side of Hwy. 11B, just north of Cobalt.

Moran (1971) gives a possible explanation for the formation of the angular clasts. Glaciers overriding unfrozen cohesive sediments could consolidate the sediments by their weight. The sediments thus compacted would consolidate if they expel their water into the lower, more permeable beds. Water in these lower beds would flow toward points of lower hydraulic head. Where the pervious beds were confined, the pore water pressure might become high enough to lift blocks of the consolidated sediments (Fig. 14).

The angular intraformational clasts are incorporated in the lowermost parts of the Coleman conglomerate and are of the same lithology as the beds underlying the conglomerate; these observations would favour a mechanism similar to that proposed by Moran. The intraformational clasts in the Coleman Formation are relatively rare, and therefore if the mechanism proposed by Moran is valid for their formation, it must have been rather restricted in its effect.

Because elongate clasts in a glacial deposit tend to be aligned parallel to the direction of ice movement

Fig. 14 - Large-scale block inclusion resulting from
elevated pore water pressure (from Moran,
1971).

(Holmes, 1941), Huronian conglomerates have been subject to several studies for pebble orientation (Pettijohn, 1962; Ovenshine, 1965; Lindsey, 1967).

At present it is well established that there is a general north-south transport direction as expressed by pebble fabrics. During the course of the present study, the orientations of clasts with a long to short axial ratio of 2:1 or greater were plotted at three localities within the Cobalt area (Fig. 15). The main transport directions are parallel to the pre-Coleman trough, which branches at the south end of the present-day Cobalt Lake. A second, less important, orientation of clasts is roughly perpendicular to the main direction, a common relationship in glacial deposits that was first recognized by Holmes (1941).

Sandstone

The sandstone underlying the conglomerate is exposed on the east side of the Cobalt Fault. It extends from the Hydro Plant southward to the west shore of Cart Lake (Fig. 16). The contact is gradational with the underlying laminated argillite. As the amount of sandstone increases upwards, so does the grain size.

Primary sedimentary structures are plentiful in this unit; the more delicate ones are in the intercalated argillite-sandstone zone whereas near the top there are only large cross-beds. By far the most

Fig. 15 - Orientation of clasts with a long to short
axis ratio of 2:1 or greater. Coleman con-
glomerate. Numbers in brackets indicate
the sample size.

Fig. 16 - Geological map showing the different lithologies of the Coleman Formation. Because of the near-horizontal attitude of the beds, thicknesses of argillite and sandstone have been exaggerated, so that these units show on the map.

common structure is ripple-lamination; other structures are: convolute lamination, ball-and-pillow, cross-bedding and graded-bedding.

Ripple Lamination

These structures begin from a few meters below the lower limit of sandstone within the argillite, where silty layers alternate with argillaceous ones.

McKee (1965) has conducted a series of experiments to determine the factors that form different types of ripples resulting from changing conditions of deposition. To develop ripple-laminations, sediment must be fed continuously to the currents or waves so that the ripples are built upwards rather than simply migrating forward (McKee, 1965).

In the argillite the ripples are mostly in isolated lenses, fading into horizontal laminations beyond the limit of individual ripples. One very common form is the delta-foreset type (Plate 4b); these are in lenses about 10cm. long and 1 to 2cm. thick, formed by overlapping laminations (foresets) with partly eroded top-sets. The extensions of these lenses, in both upcurrent and downcurrent directions are horizontal beds less than a centimeter thick. The lenses occur on the lee sides of irregularities on the underlying beds. These irregularities are either caused by other lenses (Plate 4b) or by slight folds in the underlying beds (Plate 4c).

Because of the lee-side accumulations on some of these folds it appears that this folding, which extends laterally for no more than 30 meters, was contemporaneous with deposition.

Also associated with these slightly folded beds are sparse lenses of climbing laminations (Plate 4d). These are mostly less than 1.5cm. thick and are isolated in horizontal beds of even thickness.

To form isolated, fading, delta-foreset type ripples, the current (or wave with a forward motion) must be slow and carry only a fraction of its maximum load capacity. The rather steep foresets in Plate 4b also indicate a slow current. That the current lacked abundant particles is also suggested by the isolated ripple lenses (an abundance of particles would form extensive, consecutive, climbing ripples). A stronger current with the load remaining constant could deposit ripples as well, but undisturbed, thin laminations that underly the lenses renders sediment shortage a more probable cause.

That there was erosion on some climbing ripples after their formation is evident in the same unit (Plate 4e). Truncated laminations record the removal of ripple tops, but since the remaining ripples are not deformed, the currents that eroded the ripples probably were not strong. A shortage of sediments in the

currents on the other hand, can cause the removal of previously deposited sediments without deforming the thin layering.

Within the same unit there are thin elongate sand lenses that have accumulated on the lee sides of bottom irregularities (Plate 4f). These lenses are less than a centimeter thick and laminated. The laminations on the lee sides are tangent to the bottom while on the stoss sides they are truncated. Only a small part of the lenses are on the stoss sides of ripples and irregularities below, while the greater part is on the lee side. The lenses are also thicker on the lee sides. These isolated lenses with truncated laminations on the stoss sides suggest also that the sediments were removed after deposition. Apart from the truncation the laminations are undisturbed suggesting that a shortage of sediment is the probable cause of the removal of material.

Transport direction is variable; even within a few meters, there is no dominant direction at the level where silty layers are intercalated with argillaceous ones.

Thinly laminated beds of even thickness covering the ripples indicate that the periods of flow were followed by periods of quiet deposition.

In summary, sporadic currents charged below their load capacity formed isolated ripples, some of which

were subsequently eroded when the sediment load dropped. Although in general the currents were not enough to deform the deposited layers, local increases in the erosive strength are shown by the presence of a few channels less than 6cm. wide and 3.5cm. deep and by a sandstone bed 2cm. thick that contains fragments of angular argillite (outcrop southeast of the Cobalt Hydro Plant).

That the laminated beds of even thickness were formed by sediments carried in pulses is shown by the graded nature of many silty laminations.

Upwards in the formation, the amount of silt and then sand-size materials increases progressively, and there is a change in the nature of the ripples. In the outcrop southeast of the Hydro Plant, climbing ripple sequences attain thicknesses up to 15cm. and are separated by laminated beds 4-5cm. thick (Plate 5a). These ripples, although fitting in general the model of climbing ripple formed by strong current (or directed waves) of McKee (1965), have nevertheless features that somewhat differ from the ideal model.

Compared to the ripples at lower levels, sediment grain size, thickness and amplitude of the ripples are larger, as would be expected to result from stronger current action. The foresets flatten downward and are tangent at their base (Plate 5a, 5b); this could result

from poor sorting, strong current or both (McKee 1965) but as the sediments are well sorted, a strong current is the more likely cause of these tangential foresets.

On the other hand, instead of a superposition of climbing ripples as in an ideal model, rippled lenses are covered by thinly laminated beds less than 1cm. thick which form an undulose surface on top of the ripples. In addition to this, there are laminated but non-undulose beds that separate such rippled, undulose surfaces (Plate 5a). The presence of these thinly laminated, horizontal beds most probably is due to a change in the current strength.

Convolute Laminations

Where the sandy beds are dominant over the argillaceous ones upward in the argillite-sandstone sequence, the finer-grained layers commonly are deformed in convolute laminations. The deformation is most pronounced where the fine-grained beds are less than 3cm. thick and are intercalated with sandstone (Plate 5c). On the other hand, fine- to medium-grained beds in sequences about 20cm. thick show broad folds (Plate 5d).

Beds showing strong deformation have thinned crests and thickened troughs. The overlying sandstone has laminations that parallel the deformed beds. In both types of deformation (Plate 5c, 5d) the folding is restricted to the upper few centimeters, and the beds below them remain undisturbed.

In the strongly deformed beds, some large convolutions have deformed the overlying sandstone laminations; although the latter are pushed upwards, no piercing was observed. Broadly folded beds which become coarser-grained near the top of each sequence contain small (less than 3cm. thick) cross-beds in the troughs. These cross-beds are tilted along with the folded laminations.

Where the folds are overturned, all are inclined in the same direction within a given horizon. All convoluted beds observed during the present study persist laterally no more than 30m.

The convolutions are not due to slumping because there is no pile-up of disrupted beds typical of slumping. The most probable mode of formation is that suggested by Sanders (1960):

Silty layers are deposited in thin laminations by currents neither strong nor rich in sediments (recorded by thin, continuous laminations devoid of ripples). An increased current strength increases the shearing stress on the bottom and forms irregularities on the sediment surface (ripples), but if the cohesion between grains is strong, ripples cannot form. Thus the bottom, unable to form ripples, responds by forming folds which fulfill the same purpose. Erosion of the crests and filling of the troughs tends to restore a smooth sediment surface. The shearing intensity of the current, on the other

hand, tends to maintain the bottom irregularities. The preservation of the relief depends on the cohesiveness of the sediments, the rate of burial and the current strength.

In the present case, laminated, continuous and undisturbed beds at the bottom of the folded sequences indicate the prevalence of a current moderate in strength and sediment load. The folding of the upper layers, without disruption of the bottom ones, indicates that a shearing force applied to the sediment surface produced the irregularities. The folds that are overturned dip in the same direction within a given horizon, recording a consistent current direction during the formation of these folds. The deformation continued after deposition of more sediments on the cohesive layers as is shown by the tilted cross-beds in the troughs.

The tightly-folded beds are not eroded, but the broadly-folded beds are truncated at the top. The latter also become medium-grained near their top. One reason for this truncation seems to be the gradual decrease of cohesiveness with increasing grain size. That the currents truncating the laminations were not very strong is indicated by the absence of brecciation and channelling. A decrease in the sediment load and probably a slight increase in the current velocity are the most likely reasons for the removal of the particles that had become less cohesive with increasing size.

A return to quiet depositional conditions is indicated by the undisturbed beds that cover the folded ones.

Repetition of the sequences of folded beds overlying undisturbed ones indicate that quiet periods were followed by increased current activity and sediment transport, then by a decrease in the amount of sediments, causing the removal of some of the particles already deposited, and finally by a waning of the current so that there was a return to the quiet conditions.

Ball-and-pillow Structures

That the silty-argillaceous beds in the argillite-sandstone sequence of the Coleman Formation retained their hydroplastic nature sometime after their deposition is indicated by rare ball-and-pillow structures (Plate 5e). The form of these fine- to medium-grained sand structures indicates that they have sunk into the underlying silty material. Some argillaceous beds are incorporated within the structures (Plate Vd).

Ball-and-pillow structures are common in the rock record (Pepper et al., 1954; van Straaten, 1954), and in recent deposits (Kaye and Power, 1954). These structures have also been reproduced experimentally (Kuenen, 1958). They form by the foundering of sand layers in the finer sediment below, and as the sand sinks, it separates in isolated units. The sediments

below are displaced, and may in part be incorporated within the sand (Kaye and Power, 1954). The experimental work of Kuenen (1958) showed that shock provides an effective mechanism for initiating such structures.

Cross-bedding

Above the convoluted beds there are no silty laminations and as the grain size of the sand increases, the beds become conglomeratic. At this level there are sparse, fine-grained undisturbed thin laminations, but most of the sandstone is cross-bedded. The cross-beds are less than 10cm. thick near the convoluted beds, but upwards as the sand becomes conglomeratic, cross-beds increase in thickness from a minimum of 3cm. to a maximum of 60cm. (Plate Vf). In the fine- to medium-grained sandstone the cross-beds are festooned but in the conglomeratic sand (near the top) the cross-beds form isolated units thicker than 25cm., have truncated top-sets and foresets commonly marked by pebbles (Plate 6a).

Thin undisturbed beds of pebbles, though scarce, indicate that although the flow was strong enough to transport conglomeratic sand and to form large cross-beds, it had a highly variable discharge rate with times of relative calm.

Cross-beds are oriented in different directions at different levels in the Coleman Formation. At the Little Silver Vein the lower parts of the sandstone,

where cross-beds are small and the sand fine- to medium-grained, yield transport directions towards the west and southwest (Fig. 17,1). Upwards in the sequence where the sandstone is conglomeratic and the cross-beds are thicker, the main transport direction is towards the south (Fig. 17,2). Some cross-beds nevertheless indicate much different directions, showing that the currents were not consistent although they had several general trends.

At the outcrop southeast of the Hydro Plant, ripples in the lower argillaceous beds indicate transport towards the west and northwest (Fig. 17,3), but upwards in the sandstone (where cross-beds are larger), south-eastward transport predominates.

From these limited measurements it appears that in periods of relatively weak currents (represented by the lower parts of the sandstone) sediments were carried toward the Cobalt Lake trough. Following this relatively quiet period, coarser material was brought into the trough from the north, and currents flowed south and southeastward through the trough and its outlets.

Argillite

The argillaceous-silty components of the Coleman Formation comprise two distinct types: the massive fraction incorporated within the conglomerate and the much more extensive laminated variety. The massive

Fig. 17 - Paleocurrent directions in the Coleman
sandstone.

1. fine to medium grained sand
2. conglomeratic sand above the fine
grained sandstone
3. argillaceous sandstone
4. sandstone above the argillaceous
sandstone

wacke which contains sparse, faint laminations is treated in the section on the conglomerate.

The laminated fraction is made up of alternating argillaceous and silty-argillaceous layers. The laminations are very regular, continuous and uniform in thickness. Where the argillite contains material only up to silt size, deformations in the laminations are rare and of small scale (Plate 6b). The coarser grained layers are graded (Plate 6c), and have sharp, planar bottom contacts. Elongate grains commonly are parallel to bedding.

Silty laminations contain in places coarse- to very coarse-grained sand size material and scarce clasts up to 4cm. Where coarser material is present, the laminations are slightly folded, disrupted, the thicker (1cm. or more) coarse layers have load pockets in the underlying layers and there are rare, isolated slump structures near the top of the argillite.

The laminations on top of coarse silty layers and pebbles are deformed indicating that the sediments were compacted while they were still soft. The irregular thickness of some layers, especially the less cohesive sandy silty ones, are probably due to this compaction. That such graded laminations can be formed in glacial lakes by seasonal meltwater outwash was advocated by Kuenen (1951). During the hot season the meltwater

flowing out of the ice sheets is sediment-laden and as such is heavier than the fresh water of the lake. Therefore the meltwater follows the bottom of glacial lakes in the form of a turbidity current which deposits the graded laminations. Unlike the surge induced by ordinary turbidity currents, meltwater supply is continuous for the entire melting season and therefore the sediments spread slowly over a very large area within the waterbody.

The absence of other structures characteristic of gravity-induced turbidity currents in the Coleman Formation, the very large extent of the virtually undisturbed argillite and the presence of large clasts makes a glacial origin probable.

Dropstones

One extensively studied aspect of the Huronian laminated argillites is the occurrence of sporadic large clasts (Plate 6d). Interpreted for the first time by Coleman (1907) as being clasts rafted by floating ice, they have been subject to several detailed studies (Lindsey, 1967; Schenk, 1965; Ovenshine, 1965).

The clasts were trapped in ice and then rafted away during the melting season. Because there is no indication of bottom drag, transport by turbidity currents was ruled out by all those studying the

Huronian. The fact that they occur alone, without an accumulation of clasts as would be expected in a turbidite, and also the deformation of laminations below them substantiate the ice-rafting interpretation.

Rafted clasts range from 20cm. to sand size in apparent diameter. They are mostly rounded to well-rounded. Several clasts have pierced the laminations below them (Plate 6e), but in most cases the clasts have only bent the laminations below, and the laminations above the clasts are bent indicating that there was compaction after the deposition.

It has been suggested (Rice, 1940) that when the ice carrying a clast was melting, a time would be reached when the ice could no longer keep the clast afloat, but the buoyancy of the ice attached to the clast would be sufficient to slow down the descent so that impact on the bottom would be reduced. So far there has been no other acceptable suggestions on this point. Dropstones in laminated, very fine-grained sandstones are abundant in the outcrop east of the Cobalt Arena (Plate 6f). Here there also are discontinuous conglomeratic beds described previously. The presence of these two parent structures within tens of centimeters of each other, vertically, is another indication of the role of ice rafting.

The problem of rafted stones is discussed in detail by Owenshine (1965, p. 165-180).

Mud-balls in the Coleman Formation

A particularly interesting outcrop of the Coleman Formation was drawn to the writer's attention by H.L. Lovell, Ontario Department of Mines. This outcrop, on the west side of Hwy. 11 18km. north of its junction with Hwy. 66, consists of two strikingly different siltstone-argillites (Plate 7a).

The northern part of the outcrop is a greenish red, massive siltstone that contains well rounded fragments of granite less than 2mm. in size, and abundant silt-size fragments of pink orthoclase. The southern part of the outcrop is green to a thickness of 35-40cm. and contains "mud-balls" in the upper 20-25cm. (Plate 7b). This part overlies the red siltstone and forms only a blanket on the southwestern side of the outcrop.

The appearance of the "mud-balls" on the bedding surface resembles Phanerozoic worm burrows (Plate 7c), but vertical sections show that they are composed of soft sediment which rolled from northeast to southwest (from right to left in Plate 7b). Having a maximum diameter of 3cm., some are perfectly circular in section, but most were deformed while still soft. Many are flattened, as seen to the left of the ruler in Plate 7b, and the matrix has intruded most of the deformed "mud-balls". The larger balls have squeezed the smaller ones below, but there is no indication that these large ones were dragged along the bottom. Elon-

gate balls were deposited with a tilt towards the south-east.

On the fresh surface these "mud-balls" are yellowish green; on weathered surfaces they are white. In thin section they are seen to be made of silt-sized grains with a maximum size of less than .02mm., plus scattered mica flakes. The matrix is rich in dark argillaceous material (mostly chlorite), but silty grains and mica flakes are also abundant.

Two hand specimens from this outcrops were serially sectioned (one in 7 and the other in 11 slabs less than 3mm. thick), etched with concentrated hydrochloric acid to remove the chlorite in order to see the internal structure of the mud-balls, and the three-dimensional configuration of these balls was reconstructed by orderly spacing of the slabs. Many of the "mud-balls", especially the larger ones, are not spherical as their two-dimensional aspect might suggest. In fact they are elongated perpendicular to the direction of movement and the two ends are commonly tapered. Although their overall forms are quite irregular because of the soft-sediment deformation (Plate 7d), the rod shapes and the tapering aspect is noted even for some small balls, and this indicates clearly that these structures were rolled before being deposited. The balls are closed at each end and do not connect with each other.

The "mud-balls" are laminated. These laminations are uneven in thickness and mostly are bent upward at the margins. The internal structures are usually trough shaped but in some cases the laminations are folded. In general the trough shapes of different "mud-balls" are roughly parallel to each other with concave sides upward where the "mud-balls" are not tilted. The upward bend at the margins may have resulted from the sinking of "mud-balls" through the matrix.

The tilted "mud-balls" are mostly deformed, stretched probably because they were less cohesive and less resistant than the others. The deformation of the structures is directional (from right to left in Plate 7b) suggesting a sliding of the sediments containing the "mud-balls". That the soft sediments were compacted is indicated by the bent laminations in the matrix on top of the "mud-balls".

Nodules of clastic material often displaying soft sediment deformation and found embedded in sand and/or silt size material are common in rock record and in Recent sediments. These structures range from a few centimeters to more than a meter. Depending on their shape, internal structure and the geological environment, they were given different names. They are regarded as formed from the horizontal and/or vertical movement of unconsolidated sediments (Sorauf, 1965). Smith (1916) suggested they originated from subaqueous

sliding and designated them as "ball- or pillow-form structure". Others suggested they formed from load deformation and called them flow rolls (Pepper et al., 1954), or from vertical foundering and called them pseudo-nodules (Macar, 1951). Sorauf (1965) gives a summary of the names and origins attributed to such structures. The trough shape of the laminations, the upward curved margins, and the usually flat top of the structures suggest that foundering of a bed into the underlying sediments is the main mechanism for the formation of these structures. Generally there is no evidence that the sediments were involved in horizontal movement (Sorauf, 1965).

Most "mud-balls" of the Coleman Formation have trough shaped laminations with curved margins suggesting foundering, but the rod-shape of most structures indicate that they were rolled before being deposited. It appears that the "mud-balls" were formed before being incorporated in the matrix, and were subject to compression after sinking or being buried in the matrix material.

Because these structures were soft when they were deposited, they obviously could not have been derived from a distant source. In fact the delicate nature of some of them indicates they were formed in the immediate vicinity.

Observations from studies of a modern beach, along Lake St-Jean, Quebec (Dionne and Laverdière, 1972) may

help to explain the formation of these features. In their study the two authors observed that along the beach during the late fall or early spring, sediments are brought over the icefoot (that part of the beach ice that rests on the ridge of the upper beach), or they may be introduced through icefoot-fissures during winter. When the ice melts these sediments flow slowly, rolling over the beach and drying rapidly during the warmer spring days.

In the present case the rolling of the "mud-balls" is suggested by their form. Their occurrence in clusters can best be explained by the mechanism reviewed in the previous paragraph. The fine-grained sediments in which the "mud-balls" are found and the absence of any evidence of turbulence are factors that would favor the preservation of such delicate structures.

On the other hand the "mud-balls" are scattered throughout the rock rather than being on definite horizons as they would be if deposited by melting ice. The matrix material, although argillaceous, contains up to 20 percent of silt-size grains similar to those in the "mud-balls". Since there is indication that the latter were rolled, it is possible that a number of them disintegrated during the process and the material thus available plus finer material from the meltwater buried the "mud-balls" as they rolled away from the icefoot.

Rhombic Casts in the Coleman Bedded Argillite

In the bedded argillite of the Little Silver Vein outcrop, about 1.5m. from the bottom, there are two bedding surfaces about 35cm. apart which display distinctive rhombic casts.

The long axes of rhombs on the upper surface are less than 2cm., and lie mostly in the 1 to 1.5cm. range. These rhombs are better formed than those on the lower bed and are euhedral with straight sides.

Some rhombs touch each other, but most are randomly dispersed on the bedding surfaces. The rhombs, despite their size on the horizontal plane are less than 2mm. thick, so that they are surface impressions rather than distinct casts. All are zoned with black rims (up to 1mm. thick) followed inwards by a lighter zone up to 1cm. thick, and finally there is another black zone around the core. The core on the upper bedding surface stands higher than the zones and is much lighter in colour. On the lower surface the cores do not form any prominence. There is no doubt that the mineralogy of the core was different from that of the outer zones which were eroded more easily.

Not all of the casts are rhombic. Many are nearly square or hexagonal with unequal sides. There is no apparent alignment of elongate casts (Plate 7e). At the core of some rhombs, rhombic cleavage is preserved

(Plate 7f), so that these impressions are probably relics of carbonate crystals.

Zonation of dolomite crystals is well known in nature. Katz (1971) describes ferroan dolomite and polycrystalline hematite zones in dolomite crystals of Jurassic age, and like other occurrences of zoned dolomite, they occur in marine, carbonate strata.

The only carbonates encountered in the Coleman Formation during this study are those in the arkose which is about 6m. above the mentioned horizons, at the same outcrop. Here calcite crystals are scattered and do not form more than 3 percent of the rock.

At the roadcut along Hwy. 11, about .8km. south of Timagami (about 45km. south of Cobalt), Huronian sandstone beds contain ferruginous carbonate. At the same outcrop conglomerates contain large boulders of rusty-weathering dolomite which were derived locally from the Archean basement (Church and Young, 1972).

X-ray analysis of both the outer zones and cores of the rhombs has not revealed any carbonate; only chlorite, albite and quartz were detected.

As the casts are only surface impressions on some bedding planes and there is no evidence of infiltration they are probably of penecontemporaneous origin.

If the casts in the Coleman Formation are relics of zoned dolomite crystals, they show an unusual association with distinctly varved beds of probable freshwater origin.

Granite Conglomerate

The clasts in the granite conglomerate are better rounded than those in the other parts of the Coleman conglomerate. A second feature is the lensing nature of the granite conglomerate. At the outcrop northwest of Kirkland Lake, the granite conglomerate interfingers with subarkosic wacke. Where the arkosic wacke matrix of the conglomerate interfingers with the adjacent lithology (Plate 8a), there are fragments of laminated argillite less than 15cm. large (mostly between 1 to 10cm.) and less than 2cm. thick. These fragments are slightly deformed or compacted but there is no strong deformation and they are mostly parallel to bedding (Plate 8b). Some of the fragments are rounded indicating a short transport. Small-scale injections of the arkosic wacke through the argillite are suggested by the orientation of the fragments (Plate 8c); also some fragments are imbricated. There are three zones of brecciated argillite at the southeastern end of the conglomerate outcrop. These zones are about 10cm. thick, separated vertically by about 40cm. of conglomeratic subarkosic wacke.

The absence of appreciable deformation or rotation of fragments suggests that brecciation was not due to mass movement. Fragmentation by desiccation of the argillaceous beds is a more likely process.

Another granite conglomerate outcrop occurs on the northwest side of Hwy. 66 about 10km. northeast of Matachewan.

These lithologies were previously attributed a fluvial or outwash origin (Schenk 1965, Lovell 1971). Although both origins seem valid in view of the present study, it is difficult to explain the almost exclusively granitic-syenitic nature of the clasts if the conglomerate is an outwash product of the paraconglomerate (tillite).

Firstbrook Formation

The bedded siltstone-argillite, apart from its distinctive colour, differs greatly from the Coleman bedded argillite in the abundance and types of its sedimentary structures.

Some sequences of silty and argillaceous layers are undisturbed and internally laminated, but these zones are rarely thicker than 1m. in any vertical sequence.

Silty beds which are thinner than the argillaceous ones (in the order of 0.8-1.0cm.) are extensively rippled outside the "quiet" zones. The nature of

ripples is different from those of the Coleman bedded wacke. Whereas ripples in the Coleman Formation are mostly in continuous beds, ripples in the Firstbrook Formation form discontinuous trains.

Thinly laminated argillaceous beds less than 2cm. thick are intercalated with beds and lenses of silt and very fine grained sand. Some argillaceous beds are also rippled, but these are rather faint and limited in extent (Plate 8d).

Silty lenses are mostly less than 4cm. thick and depending on their form they may be up to 10cm. long. They often fill scours in the argillaceous layers, and commonly their lower contact interfingers with the finer grained material (Plate 8e), forming wisps that extend in the current direction. Such flame structures are widespread in the Firstbrook Formation. Most, but not all, the lenses show ripples, but the ripple-laminations are mostly truncated. Silty layers have abundant load pockets less than 1.5cm. deep and 2.5cm. wide in the argillaceous ones.

On Hwy. 11, along the Tritown bypass, the first outcrop north of the West Cobalt road junction shows the stages of formation of the discontinuous lenses (Fig. 18).

Irregularities on the argillite surface form in response to the shearing effect of the current (Fig. 18a).

As the current velocity maintains the shearing effect on these irregularities they will be gradually eroded and the material will be carried away if there is not enough material brought in to bury them (Sanders, 1960). Laminations deformed by these convolutions will be truncated, and the silt deposited on the resulting irregular surface will be in irregular lenses (Fig. 18b). The finer fraction will be carried over the stoss side and accumulate in the lee side, and as the ripples move down-current the finer material accumulating on the lee side will interfinger with the advancing silt (Fig. 18c). This type of interfingering is very common in the Firstbrook Formation wherever there are ripples.

At the outcrops along the Tritown bypass, there are trough-shaped cross-beds seen on the bedding surface of silty layers. They are less than 10cm. wide (7cm. on the average), and 15cm. long, and their thickness is less than 0.5cm. Their axes are parallel to each other. Overlapping laminations are concave downstream and are continuous from one trough to the other over the ridges separating the troughs. The surface of silty laminations is often shiny from the abundant mica fragments.

From these structures it can be deduced that the Firstbrook Formation was deposited in a rather quiet body of water where calm periods alternated with periods of current action in which the currents were never strong enough to disturb the thin laminations to a depth of more than 2-3cm. from the depositional interface.

Fig. 18 - Stages of formation of discontinuous silty lenses in the Firstbrook Formation. Along Hwy. 11, at the first outcrop north of the West Cobalt road junction. Arg: argillite, silts: siltstone. Arrows indicate current directions.

- a) Convolutions on the argillite surface form in response to the shearing effect of the current.
- b) Convolutions are truncated and the silt deposited on the resulting irregular surface is in irregular lenses.
- c) The finer fraction is carried over the stoss side and accumulate in the lee side, as the ripples move downcurrent the finer material accumulating on the lee side interfingers with the advancing silt.

The lack of evidence of strong current action, the total absence of climbing ripples and the discontinuous nature of the silt lenses (some of which are rippled), indicate that sediment was in short supply.

Sedimentary Intrusions in the Firstbrook Formation

Along the east side of Hwy. 11, about 1km. south of the junction with Hwy. 558, subarkose forms large intrusions in the Firstbrook Formation. One such intrusion (Plate 8f), essentially vertical, has upturned the argillite laminations at its contact, displays evidence of forceful injection into the latter and contains chunks of argillite up to 30cm. These chunks have been deformed without breaking; they probably were coherent but not lithified when they were incorporated in the sand body. All these features leave little doubt that the latter is a dyke which forced its way up through the argillite.

About 200m. north of this intrusion there is a second sand body, stratigraphically lower than the first one. The sandy outcrop is about 40m. long and 3m. thick near the road. It is a massive subarkose. This sand body is conformable with the siltstone. It continues along the ridge at the east of the main outcrop where its thickness is slightly less than 1m. (Fig. 19). At the south end of the outcrop the contact between the subarkose and the argillite is almost vertical and sharp, and the laminations in the latter are

Fig. 19 - Sketch of the subarkose intrusion in the Firstbrook Formation, along the east side of Hwy. 11, about 1km. south of its junction with Hwy. 558. Arrows indicate the relative direction of movement.

0 5 10 m.

warped upwards. On top of the outcrop at this end, sand injections in the order of tens of centimeters, form sills parallel to the laminations.

On top of the sand body chunks of deformed argillite (Plate 9a, 9b) are contorted randomly. These chunks attain 50cm. in length and occur only on top of the subarkose. Seen in vertical section the sandstone is devoid of such inclusions, but on the northern face of the subarkose outcrop, there is a breccia zone (Plate 9c) about 2m. long. The thickness of the zone attains 15cm. near the road (west end of the subarkose outcrop) and tapers away from it. This general decrease in thickness is not regular; the zone thickens or thins at places. The bottom of the zone is rather straight, many elongate clasts along the bottom delineate the lower limit of the zone. The top of the zone is irregular with clasts trapped at different levels in the subarkose (Plate 9d). Near the road, the distance from the bottom of this zone to the top of the siltstone is 90cm. but decreases to 60cm. where it tapers.

The clasts in this zone are argillite and subarkose; all of them are angular with mostly thin extremities. They are less than 15cm. in length. Most have been deformed without breaking. Imbrication of elongate clasts suggests westward sliding of the soft sediments.

The deformed chunks on top of the subarkose do not show a distinct direction of movement, but their shape suggests that most were deformed in an east-west direction (Plate 9b).

The upper contact between the subarkose and the banded argillite is exposed at the south end of the outcrop (Plate 9d). Laminations are deformed and disrupted within about 1m. of the subarkose, but above this level, the argillite is undisturbed. The deformation of the laminations suggests forceful emplacement for the subarkose.

Along the roadcut on both sides of the subarkose body the laminations in the argillite show slumping, folding and small-scale faulting, but all these structures are soft-sediment deformations which occurred prior to lithification (Plate 9e, 9f).

Deformation in the argillite extends for several tens of meters on both sides of the subarkose body. Deformational structures on the north side appear roughly in two zones: the upper zone shows mainly a northward displacement whereas about 1.5m. below, another zone shows evidence of southward movement. On the south side beds stratigraphically lower than the subarkose are exposed only for a few meters; the deformational structures continue for about 100m. in beds at the same level or slightly above the subarkose.

The lower contact of the subarkose shows load casts, and at places the laminations in the argillite are disrupted.

The subarkose continues eastward but it is only 50cm. thick at about 75m. from the road. At this level there are small dykes a few centimeters thick in the argillite. The subarkose is eroded at this point but it outcrops along the ridge, a few meters to the east. Here it is about 1m. thick and mainly in the lower and upper parts, contains deformed chunks of banded argillite which are mostly less than 15cm. long. The subarkose exhibits load casts into the banded argillite and sporadic folded laminations in the argillite indicate that the subarkose had some basal shearing effect.

From these observations it appears that the subarkose was injected as a sill-like body. The movement was essentially parallel to bedding, but some disruption and deformation of the enclosing beds occurred.

The presence of the dyke suggests that there were several episodes of soft-sediment intrusion or that, other than the large sill flowing downdip, there were smaller forceful vertical injections. All these intrusions are probably connected to one another.

Such large-scale movement of soft sediment was reported in relation to earthquakes (Waller, 1968), where large bodies of water-laden sediment were extruded

through fissures, eroding areas of overlying sediments. Such extrusions can be either sudden, where caused by seismic waves, or gradual, as a result of the slow sinking of overlying sediments into waterladen sediments below them. The features described by Waller are in the form of dykes, but in the Firstbrook Formation, the sedimentary injections apparently did not produce large-scale dykes other than the one described above.

Dykes and sills connected to the source beds were observed in flysch sequences (Dzulynski and Walton, 1965). Liquefaction and subsequent intrusion of sand into overlying sediments were ascribed to earthquake shocks, but in the case of short dykes associated with slumped beds the passage of the slumps was seen as a possible cause of the liquefaction.

An accumulation of coarser material, as for example in a channel, can create local weight differences that may cause slumping or foundering. When the sand is buried by more cohesive sediments, as in this case by silty-argillaceous material, the weight of the overlying beds can mobilize the less cohesive sand which then may intrude the surrounding sediments.

At present, the consensus is that such large scale soft sediment intrusions are triggered by shock, mainly earthquakes. On the other hand, small dikes can be initiated by the impact of large masses of moving sediments such as in a slump, but deformations that would

result from such mass movement are lacking in the Firstbrook Formation.

It appears that, although the weight of the overlying beds was the driving mechanism of the intrusions in the Firstbrook Formation, the movement was triggered by shock, perhaps by an earthquake.

CHAPTER VI

SUMMARY OF DATA

Coleman Formation

The great lateral extent and uniform thickness of couplets of argillaceous and graded silty laminations suggests that the banded argillite was deposited in a large and quiet water body, probably a lake. The repetitive graded nature of the silty laminations indicates that sediments were transported in pulses. The presence of large clasts and discontinuous conglomeratic beds is best explained by ice rafting. Accepting the presence of a cold climate at the time of deposition, the pulses may be attributed to the seasonal melting that resulted in flow of sediment- charged water along the bottom of the basin of deposition. Large rhombic casts which appear to represent penecontemporaneous crystallization, represent an unusual association with sediments of fresh water origin, if they are relics of dolomite, as suggested by zoning and crystallization.

Upward increase in the clast size in the Coleman is indicative of increasing current strength. Isolated ripples indicate currents which were not strong enough to erode the thin laminations below the ripples, and the delta-foreset type ripples indicate a low supply of sediment at this stage.

Climbing ripples higher in the formation indicate a more generous sediment supply; the size of the ripples

and the presence of convolute laminations confirm the greater strength of the currents.

The currents however were not consistent: quiet periods, indicated by undisturbed laminations, were followed by increasing current strength, and sediment supply dropped without concurrent drop in velocity, resulting in erosion of the tops of sandy layers. Return to quiet conditions is indicated by horizontal undisturbed laminations overlying the sands. Repetition of these cycles is probably another indication of the pulsational nature of the transporting agent.

Transport within the sandstone was towards the Cobalt Lake trough during early periods of relative quiet, but later stronger currents and coarser material came mainly from the north. Current indicators show great variability in scale and direction, even within individual outcrops, indicating frequent changes in current strength and direction of flow.

The absence of large-scale scouring and channelling at the base of the conglomerate is noteworthy. The fractured clasts in the conglomerate can be explained either by frost action or by insolation, but in view of the probable glacial origin of the conglomerate, the first mechanism is the more likely cause of the fracturing. That some clasts were carried by water during some time of their transport history is suggested

by their roundness. The rinds around some clasts possibly originate from pre-depositional weathering. The "mud-balls" are formed by a mechanism different from that of ball and pillow structures, and are more evidence for suggesting the presence of ice.

The orientation of elongate clasts and the very poor sorting of the conglomerate suggest a glacial transport for the sediments. The angularity of the matrix implies a lack of appreciable water transport and weathering, supporting the glacial model. Furthermore, the clast orientation near the Cobalt trough shows a dominant direction and a secondary one at a high angle to it, a commonly observed phenomenon in glacial till.

Fine-grained sandstone lenses with dropstones, and laminations in the conglomerate, indicate the presence of quiet water bodies of small extent across which ice floes dispersed clasts. Channels and cross-beds in the conglomerate indicate small-scale runoff. The rounding of large clasts and the lensoid nature suggest a water transport for the granite conglomerate. Sorting is poor and weathering was mainly physical.

The presence of mud-balls can best be explained by melting of sediment-laden snow and ice, with accumulation and burial of sediments near the ice front.

Fig. 20 is the stratigraphic column of a type outcrop of the Coleman Formation in the Cobalt area.

Fig. 20 - Stratigraphic column showing the three main
lithologies of the Coleman Formation.
Little Silver Vein outcrop, southeast of
Cobalt Lake.

Firstbrook Formation

The thin undisturbed banded argillite and the absence of coarse material indicate quiet conditions of deposition. Isolated, small ripples in the silty beds are the product of weak currents with low sediment load.

Sandstones intruded the banded wacke when the latter was still unconsolidated. Probably a seismic shock liquefied the unconsolidated sand overlain by finer sediments. The weight of the overlying sediments was probably the driving force for the intrusion of the sand thus liquefied.

CHAPTER VII

CONCLUSIONS

1) The banded argillite of the Coleman Formation was deposited in a quiet water body, probably a lake. Ice rafting is suggested by the large clasts and the discontinuous conglomeratic beds. The graded nature of the laminations can be explained by seasonal melting of sediment laden ice. Thus, these standing bodies of water were probably glacial lakes.

2) A probable warming of the climate, resulting in increased melting is suggested by an increase in the amount of coarse sediment and the nature of the current structures in the sandstone. These currents alternated with periods of relative calm.

3) A return to colder conditions near the top of the formation is indicated by the conglomerate which has features characteristic of glacial transport. Sedimentary structures within the conglomerate indicate that there was local water transport during the deposition of the conglomerate.

4) Glacial features associated with features indicative of water action, as observed in the Coleman conglomerate, closely correspond to the wet based glacier model of Carey and Ahmad (1961).

5) The granite conglomerate is probably the product of fluvial, perhaps glacio-fluvial action.

6) The Coleman Formation fills the troughs in the basement. Only the conglomerate extends between the troughs, therefore correlation between troughs depends on accurate correlation of the conglomerate outcrops.

7) The sandstone underlying the conglomerate also offers a basis for correlation in that at least for the Cobalt area, changes in current regimes for sand deposition can be traced between outcrops.

8) The Firstbrook argillite was deposited in a quiet waterbody. The absence of coarse material probably indicates a low-lying source area.

9) Deformations in the Firstbrook argillite are due to soft sediment intrusions. Large-scale sand intrusions may have been triggered by seismic shock and intruded the confining sediments under the pressure of overlying material.

BIBLIOGRAPHY

- Card, K.D., 1964 Metamorphism in the Agnew Lake area, Sudbury District, Ontario, Canada: Geol. Soc. America Bull. v. 75, p. 1011-1030.
- Carey, S.W., and Ahmad, N., 1961, Glacial marine sedimentation in Raasch, G.O., ed., Geology of the Arctic: University of Toronto Press, v. 2, p. 865-894.
- Casshyap, S.M., 1966, Sedimentary petrology and stratigraphy of the Huronian rocks, south of Espanola, Ontario: [Ph.D. thesis]; London, Ontario, Univ. Western Ontario.
- Chandler, F.W., 1969, Geology of the Huronian rocks, Horrow Township area, Ontario: [Ph.D. thesis]; London, Ontario, Univ. Western Ontario.
- Church, W.R., and Young, G.M., 1972, Precambrian Geology of the southern Canadian Shield with emphasis on the Lower Proterozoic (Huronian) of the north shore of Lake Huron: 24 Int. Geol. Congress Field Excursion Guidebook 36.
- Coleman, A.P., 1907, A Lower Huronian ice age: Am. Jour. Sci., v. 23, p. 187-192.
- Collins, W.H., 1917, Onaping map area: Canada Geol. Survey Mem. 95.
- Dionne, J.C., and Laverdière, C., 1972, Ice formed beach features from Lake St. Jean, Quebec: Canadian Jour. Earth Sci., v. 9, p. 979-990.
- Dzulynski, S., and Walton, E.K., 1965, Sedimentary features of flysch and greywackes: Amsterdam, Elsevier.
- Fairbarn, H.W., Hurley, P.M., Card, K.D., and Knight, C.J., 1969, Correlation of radiometric ages of Nippising diabase and Huronian metasediments with Proterozoic orogenic events in Ontario: Canadian Jour. Earth Sci., v. 6, p. 489-497.
- Folk, R.L., 1968, Petrology of Sedimentary rocks: Hemphill's, Austin, Texas.
- Frarey, M.J., and Roscoe, S.M., 1970, The Huronian Supergroup north of Lake Huron in Baer, A.J., ed., Symposium on basins and geosynclines of the Canadian Shield: Canada Geol. Survey Paper 70-40, p. 143-169.

- Friedman, G.M., 1958, Determination of sieve-size distribution from thin section data for sedimentary petrological studies: Jour. Geology v. 66, p. 394-416.
- Holmes, C.D., 1941, Till fabric: Geol. Soc. America Bull. v. 52, p. 1299-1354.
- Katz, A., 1971, Zones dolomite crystals: Jour. Geology, v. 79, p. 38-51.
- Kaye, C.A., and Power, W.R., 1954, A flow cast of very recent date from northwestern Washington: Am. Jour. Sci., v. 252, p. 309-310.
- Kuenen, PH.H., 1951, Turbidity currents as the cause of glacial varves: Jour. Geology, v. 59, p. 507-508.
- 1958, Experiments in geology: Geol. Soc. Glasgow Trans. v. 23, p. 1-28.
- Lindsey, D.A., 1967, The sedimentology of the Huronian Gowganda Formation, Ontario, Canada: [Ph.D. thesis], Baltimore, Johns Hopkins Univ.
- Lovell, H.L., 1972, Geology of Eby and Otto area, district of Timiscaming: Ontario Dept. Mines Geol. Report 92.
- Macar, P., 1951, Pseudo-nodules en terrains meubles: Ann. Soc. Géol. Belgique, v. 75, p. 111-115.
- McKee, E.D., 1965, Experiments in ripple lamination, in Middleton, G.V., ed., Primary sedimentary structures and their hydrodynamic interpretation: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 12, p. 66-83.
- Moran, S.R., 1971, Glaciotectonic structures in drift, in Goldthwait, R.P., ed., Till: Ohio State University Press, p. 127-148.
- Ollier, C., 1969, Weathering: Edinburgh, Oliver and Boyd Ltd.
- Ovenshine, A.T., 1965, Sedimentary structures in portions of the Gowganda Formation, north shore of Lake Huron, Canada: [Ph.D. thesis], Los Angeles, Univ. California.

- Pepper, J.F., DeWitt Jr., W., and Demarest, D.F., 1954, Geology of the Bedford Shale and Berea Sandstone in the Appalachian Basin: U.S. Geol. Survey Prof. Paper 259.
- Pettijohn, F.J., 1957, Sedimentary rocks: New York, Harper and Row.
- 1962, Dimensional fabric and ice flow, Precambrian (Huronian) Glaciation: Science, v. 135, p. 442.
- Rice, W.A., 1940, Geology of the Blind River - Spragge area, north shore of Lake Huron: [Ph.D. thesis], New Haven, Yale Univ.
- Sanders, J.E., 1960, Origin of convoluted laminae: Geol. Magazine, v. 97, p. 409-421.
- Schenk, P.E., 1965, Depositional environment of the Gowganda Formation (Precambrian) at the south end of Lake Timagami, Ontario: Jour. Sed. Petrology, v. 35, p. 309-318.
- Schmus, R. van, 1965, The geochronology of the Blind River-Bruce Mines area, Ontario, Canada: Jour. Geology, v. 73, p. 755-780.
- Shaw, D.M., Reilly, G.A., Muysson, J.R., Pattenden, G.E., and Campbell, F.E., 1967, An estimate of the chemical composition of the Canadian Precambrian Shield: Canadian Jour. Earth Sci., v. 4, p. 829-853.
- Smith, B., 1916, Ball- or pillow-form structure in sandstone: Geol. Magazine, v. 3, p. 146-156.
- Sorauf, J.E., 1965, Flow rolls of Upper Devonian rocks of south-central New York State: Jour. Sed. Petrology, v. 35, p. 553-563.
- Stockwell, C.H., McGlynn, J.C., Emslie, R.F., Sanford, B.V., Norris, A.W., Donaldson, J.A., Fahrig, W.F., and Currie, K.L., 1970, Geology of the Canadian Shield, in Douglas, R.J.W., ed., Geology and economic minerals of Canada: Canada Geol. Survey Econ. Geology Report 1, p. 43-150.
- Straaten, L.M.J.U. van, 1954, Sedimentology of Recent tidal flat deposits and the Psammites du Condroz (Devonian): Geol. Mijnbouw, v. 33, p. 25-47.

- Termier, H., and Termier, G., 1963, Erosion and sedimentation: London, D. Van Nostrand Co. Ltd.
- Thomson, R., 1957, The Proterozoic of the Cobalt area, in Gill, J.E., ed., The Proterozoic in Canada: Roy. Soc. Canada Spec. Pub. 2 p. 40-45.
- 1961, Preliminary report on part of Coleman township, concession VI, lots 1 to 6, District of Timiskaming: Ontario Dept. Mines Preliminary Rept. 1961-3.
- 1961, Preliminary report on part of Coleman township, concession V, lots 1 to 6, District of Timiskaming: Ontario Dept. Mines Preliminary Rept. 1961-4.
- 1966, Geology of Henwood township, District of Timiskaming: Ontario Dept. Mines Misc. Paper 5.
- Waller, M.R., 1968, Water sediment ejection, in The great Alaska earthquake of 1964, Hydrology: Nat. Acad. Sci. Pub. 1603, p. 97-116.
- Young, G.M., 1969, Geochemistry of early Proterozoic tillites and argillites of the Gowganda Formation, Ontario, Canada: Geochim. et Cosmochim. Acta, v. 33, p. 483-492.

APPENDIX

Cumulative curves of sandstones from
the Coleman Formation

In the determination of size analyses, apparent long axes of 200 to 350 grains per thin section were counted using a petrographic microscope*. The measurements were converted to true sizes by the method outlined by Friedman (1958). The 5th, 16th, 25th, 50th, 75th, 84th and 95th percentiles were converted to true grain size and plotted on normal graph paper. The resultant cumulative curves are presented here.

Sand fraction of the Coleman conglomerate	Coleman Sandstone	Granite conglomerate, Coleman Formation
11	8	34c
12b	10	34d
29	10a	
32	10b	Massive sandstones
38	20	of the Firstbrook
42	21	Formation
53	23	
54	24	56
		64

* Measurements were made at 0.3mm. grid intersections.

PLATE 1

- a) Lower contact of the conglomerate. Little Silver Vein outcrop southeast of Cobalt Lake.
- b) Poorly sorted conglomerate, with most clasts smaller than 10cm. in apparent diameter, seen on a surface parallel to bedding. Ruler is 15cm. long. White line is string used as baseline for megascopic modal analysis. Outcrop south of the west arm of Peterson Lake.
- c) Moderately sorted part of the Coleman conglomerate. 200m. north of the Dumphill, west of Cobalt.
- d) Conglomerate infilling between matching parts of a fractured clast. Outcrop south of the west arm of Peterson Lake.
- e) Chlorite spots concentrated around a basic volcanic pebble. Same outcrop as d.
- f) Argillite pebble with rind of non-uniform thickness seen on a surface parallel to bedding. Same outcrop as d.

PLATE 1

PLATE 1

PLATE 2

- a) Argillite pebble with rind of non-uniform thickness seen on bedding surface. The broken part of the pebble shows the rind's three dimensional extent. Outcrop south of the west arm of Peterson Lake.
- b) Rind on a granitic clast. Broken part shows the fresh appearance of the granite. Same outcrop as a.
- c) Photomicrograph of pebble with a rind devoid of chlorite and dark minerals. Arrows indicate the inner boundary of the rind. Plain polarized light, x35.
- d) Photomicrograph of the Coleman subarkose. Arrows indicate the Carbonate. Sample from the Little Silver Vein outcrop, southeast of Cobalt. Crossed nicols, x35.
- e) Sericite speckles in banded wacke of the Coleman Formation. Sample from the same outcrop as a. Crossed nicols, x35.
- f) Chlorite spots larger than the silty layers along which they occur. Same outcrop as a.

PLATE 2

PLATE 2

PLATE 3

- a) Biotite and muscovite fragments in the silty fraction of the Firstbrook Formation. Small arrows point the muscovites, the large arrow point the biotite. Crossed nicols, x80.
- b) Channel in the very coarse-grained sandstone of the Coleman conglomerate. Crude stratification of pebbles. Northwest of Cobalt, 150m. southwest of Chambers-Ferland shaft 4.
- c) Channel in very coarse-grained sandstone of the Coleman conglomerate. Elongate pebbles roughly horizontal in the channel. Outcrop north of the Little Silver Vein outcrop, southeast of Cobalt Lake.
- d) Channel in conglomeratic sandstone. Northwest of Cobalt, 150m. southwest of Chambers-Ferland shaft 4.
- e) Conglomeratic bed in the Coleman banded argillite. Outcrop east of the Cobalt Arena.
- f) Large clast in very fine grained sandstone within the conglomerate. Little Silver Vein outcrop, southeast of Cobalt Lake.

PLATE 3

PLATE 3

PLATE 4

- a) Argillite intraclast in the Coleman Formation. Outcrop south of the west arm of Peterson Lake.
- b) Delta-foreset type ripple in argillite-fine-grained sandstone intercalation. Outcrop southeast of Cobalt Hydro Plant.
- c) Rippled lens formed on a fold. Near the top of the banded argillite unit. Little Silver Vein outcrop, southeast of Cobalt Lake.
- d) Isolated lens of climbing ripple in the argillite-fine-grained sandstone intercalation. Same outcrop as c.
- e) Truncated climbing ripple. Near the top of the banded argillite unit. ~~Same~~ outcrop as c.
- f) Sand lens on the lee side of underlying fold; the current that deposited the lens moved from right to left. Same outcrop as c.

PLATE 4

PLATE 4

PLATE 5

- a) Climbing ripples in the argillite-sandstone intercalation. Outcrop southeast of Cobalt Hydro Plant.
- b) Ripples in the sandstone. Same outcrop as a.
- c) Convolute lamination in the argillite-sandstone intercalation. Same outcrop as a.
- d) Broadly folded siltstone grading into sandstone. Folds attenuate upward in the sandstone. Little Silver Vein outcrop, southeast of Cobalt Lake.
- e) Ball-and-pillow structure in the argillite. Outcrop southeast of the Hydro Plant.
- f) Large cross-bed in the conglomeratic sandstone. Little Silver Vein outcrop, southeast of Cobalt Lake.

PLATE 5

PLATE 5

PLATE 6

- a) Cross-bed in the conglomeratic sandstone. The foreset is marked by pebbles. Little Silver Vein outcrop, southeast of Cobalt Lake.
- b) Primary deformation of argillaceous layers. Outcrop west of the west arm of Peterson Lake.
- c) Graded beds in banded argillite. Crossed nicols, x35.
- d) Large clast in unstable position. Outcrop east of LaRose mine, northeast of Cobalt Lake.
- e) Dropstone piercing laminations in the substrate. The laminations on top show compaction. Outcrop east of Cobalt Arena.
- f) Dropstone bending the underlying laminations. Same outcrop as e.

PLATE 6

PLATE 6

PLATE 7

- a) Siltstone outcrop along Hwy. 11. The left side of the outcrop (lighter coloured) contains mud-balls.
- b) Mud-balls in the siltstone.
- c) Appearance of mud-balls on surface parallel to bedding.
- d) Appearance of mud-balls on etched slab, cut normal to bedding.
- e) Randomly dispersed casts on a surface parallel to bedding. Sample from Little Silver Vein outcrop, southeast of Cobalt.
- f) Rhombic cleavage preserved at the core of the rhomb.

PLATE 7

PLATE 7

b

d

f

PLATE 8

- a) Granite conglomerate interfingering with arkosic wacke. Outcrop at Kenogami Lake, along Hwy. 11.
- b) Fragments of shale on the bedding surface of the arkosic wacke. Same outcrop as a.
- c) Injection of arkosic wacke into the shale seen on a section normal to bedding. Sample from the same outcrop as a.
- d) Faintly rippled argillaceous bed, Firstbrook Formation. Sample from the first outcrop north of West Cobalt Road-Hwy. 11 Junction, along the Hwy.
- e) Silty lens interfingering with finer grained material. Same outcrop as d.
- f) Subarkose dyke cutting the banded argillite of the Firstbrook Formation. Outcrop along Hwy. 11, about 1.5km. south of the Hwy. 11 - Hwy. 558 junction.

PLATE 8

PLATE 8

PLATE 9

- a) Deformed banded argillite chunks in the subarkose. Outcrop along Hwy. 11, about 1km. south of the Hwy. 11 - Hwy. 558 junction.
- b) Deformed banded argillite chunks in the subarkose. Top of the picture is east. Same outcrop as a.
- c) Part of the brecciated zone on the north face of the major subarkose intrusion. Left of the photograph is east. Same outcrop as a.
- d) Upper contact of the major subarkose intrusion near its southern end. Same outcrop as a.
- e) Slumping and folding in the banded argillite, south of the major subarkose intrusion. Same outcrop as a.
- f) Slumping in banded argillite, north of the major subarkose intrusion. Same outcrop as a.

PLATE 9

PLATE 9

- Nipissing Diabase
- Lorrain Formation
- Firstbrook Formation
- Coleman Formation
- ARCHEAN

0 ——— 1 Km

Sample number and location

GEOLOGICAL MAP

Nipissing Diabase

Lorrain Formation

Firstbrook Formation

Coleman Formation

ARCHEAN

Sample number and location

GEOLOGICAL MAP

2 of 2

0 1 Km