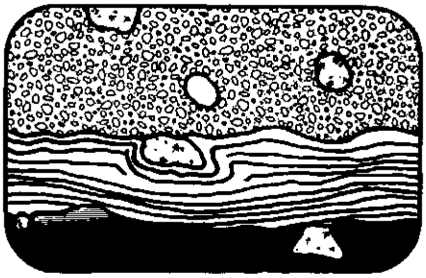
# Conference Reports



## The Gowganda Formation: Revisited to Ponder Resedimentation

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### Introduction

A field group brought together informally to evaluate the glacial origin of the Gowganda Formation (Proterozoic Age) came away with one point of consensus about the Formation: it is, in part, a glaciogenic deposit that may be no more resedimented than most other sedimentary rocks. More than twenty geologists, hosted by Grant Young and Randy Junnilla (University of Western Ontario) and Al Donaldson, Peter Mustard and Rob Rainbird (Carleton University), travelled to the Whitefish Falls and Cobalt areas, 14–17 October 1984, to assess the glaciogenic interpretation of the Gowganda Formation. The weather and the exposure were spectacular, as were some of the interpretations.

Miall (1983, 1985) has argued that, although the glacial origin of the lower part of the Gowganda has never been seriously questioned (Coleman, 1907; Lindsey, 1969, 1971; Young, 1982; Donaldson and Munro, 1982), only a minor part of the Gowganda Formation may have been deposited by grounded ice. One objective of the trip was to assess the field evidence for Miall's contention.

The major discussion centred around the direct evidence of a glaciogenic origin for the Gowganda Formation in the Whitefish Falls and Cobalt areas (separate discussion of each area follows below). The second level of debate concentrated on the specific environment of deposition of these complex sequences of rocks. The trip attempted to decide what proportion of Gowganda sediments were deposited: (1) directly by glacial ice or meltwater; (2) secondarily from drift accumulations by sediment gravity flow; (3) periglacially by mass movement; (4) interglacially by nonglacial agents.

The direct evidence of glaciogenic influence is the occurrence of rhythmic sediments (argillites) with dropstones and the occurrence of poorly-sorted diamictites (rocks comprising matrix and mixed grain sizes of unknown origin) in association with the rhythmic sequence. Additional supporting data that are not diagnostic themselves include fabric, local and regional depositional setting and facies associations, and these infer a glaciogenic origin.

### Whitefish Falls Area

In the Whitefish Falls area, lower Gowganda rocks comprise (1) massive to stratified diamictites, boulder and cobble orthoconglomerates and thin sandstone units. The next unit (2) is a thick laminated argillite, with dropstones at the base and the top. This is followed by (3) a complex of diamictite (massive and stratified), boulder conglomerate, argillite (with and without dropstones) and sandstone. The conglomerate is transitional to thick sandstones including coarsening-upward sequences of stratified diamicton. Next, thick stratified diamictites, separated by an argillite, mark a major set of strata (4). These units are overlain by a series of coarsening-upward (deltaic) sequences (5) forming the upper Gowganda. The Gowganda Formation is bounded by sandstone strata (Serpent Formation, below and Lorrain Formation, above) that are both interpreted as fluvial in origin. The lower Gowganda is interpreted as mainly resedimented material formerly of glaciomarine origin (Young, 1984, unpublished).

The diamictite sequence (1) is considered to be resedimented from glaciomarine deposits. Graded-bedding, massive sands and channels with erosional bases point to turbidity current activity. The occurence of angular boulders in sandstones (sandy grain flow deposits) prompted discussion of a glaciogenic origin for this sequence of sediments. The above sedimentary assemblage is to be expected in ice-proximal subaqueous environments, but the association is not diagnostic of a glaciogenic origin. Young and others suggested that the above sediment gravity flow deposition took place on a continental slope. Subaqueous fan deposition could account for the sedimentary association as well.

The occurrence of dropstones in the rhythmically-bedded argillites was viewed as the first unequivocal evidence of a glaciogenic origin. At the same time, the corollary, that argillites without dropstones are interglacial deposits (of deep-water origin, formed when sea level was high), was not fully accepted. For example, rhythmites without common dropstones are presently being deposited at the rate of 4 m $\text{yr}^{-1}$ by tidewater glaciers in Glacier Bay, Alaska (Powell, 1983). Dropstones are uncommon to rare in the Champlain Sea and many glaciolacustrine rhythmic deposits. Ice-marginal tidewater currents apparently remove icebergs from the area of rhythmic sedimentation without frequent rain-out of clasts. In addition, it was discussed that terrestrially-based ice could produce frequent high discharges of turbid meltwater to produce rhythmic sedimentation without icebergs.

On the other hand, chemical data apparently suggest long periods of chemical weathering that support the interglacial interpretation (Nesbitt and Young, 1982; Young and Nesbitt, in press). This same relationship has been observed for the Gowganda Formation at Cobalt. It was argued on the trip, however, that chemically distinct rock suites can be produced by mineral dispersion related to glaciation. In addition, Colman (1982) has shown convincingly from weathering rind studies that interglacial weathering of primary minerals to clay minerals in glaciated terrain is not probable in Quaternary time-scales. The weathering rinds observed in Gowganda conglomerate near Cobalt (Donaldson and Munro, 1982) are comparable to those of Colman (1982), but there may have been more time for weathering in the Gowganda Formation than in late Quaternary weathering intervals (>100,000 years).

The diamictite-bearing complexes (3) also display the other (1, 2, 4, 5) facies and facies associations and these (especially dropstones) are consistent with a subaqueous (glaciogenic) deposition. No clear evidence of deep-water (deep-sea fan) deposition was established even if the succession was determined to be glaciogenic. This is because all the observed facies and facies associations could be accommodated by deposition within 200 m of water or less by subglacial conduits.

The overlying thick series of coarsening-upward cycles are considered to represent deltaic sedimentation. The occurrence of apparent hummocky crossstratified (HCS) sand was used to suggest a marine environment for the upper Gowganda Formation. However, it was also suggested by trip members that the apparent HCS was in fact cross-strata with differing angles of ripple climb (Shaw and Archer, 1978) and was not necessarily indicative of a sub-tidal marine environment. The topset sandstones of the uppermost Gowganda appeared to be transitional to the fluvial Lorrain Formation.

Other sedimentary features of special note included massive and graded sand beds occurring infrequently within the diamictite units. Angular clasts "floating" in graded sands generated some discussion as to whether they had been glacially transported prior to deposition. The contacts of the graded sand units were sharp-based and commonly loaded indicating rapid sedimentation. Large channel cut and fill sequences were common in the upper diamictite member at Whitefish Falls and again these features commonly showed loaded basal contacts with flame structures, ball-and-pillow structures, vertical piping and other features of rapid sedimentation, instability and water escape events. These features by themselves are not indicative of glaciomarine or glaciolacustrine sedimentation but they are indicative of episodic, variable, rapid sedimentation within a basin and close to a sediment source. As is being increasingly recognized, these sedimentary features are common to ice-proximal environments (Cheel and Rust, 1982; Mackiewicz and Powell, 1982; McCabe *et al.*, 1984; Gravenor *et al.*, 1984). On the other hand these facies are common in continental-slope deposits (Walker, 1984).

An overall interpretation was that the Gowganda rocks are a resedimented basin assemblage controlled by continental tectonics (Young, 1984). This assumes, however, that uplifted flanks of continental margins are centres of glaciation. The proposal that tectonics may have initiated the glaciation was received with some skepticism. Altitude is seldom a sufficient condition for glaciation (especially continental ice-sheet formation) and depressional areas generally have the thickest glacier accumulations. Influx of water to the interior of the continent, during continental breakup would, however, help nourish a continental glacier. Young's view of the Gowganda representing glaciomarine sedimentation and submarine reworking by sediment gravity flows into deep water creates the problem of consistent supply of coarse sediment over a large area (including movement of sediments to the shelf edge to begin with). The glaciomarine model proposed by Miall (1983), that a large ice-shelf supplied debris flows (tills) from ice rises or grounding lines, attempts to solve the problem of local supply of abundant coarse debris. McCabe *et al.* (1984) highlight the significance of ice-marginal supply of debris in discussing late Pleistocene submarine-moraine complexes from Ireland.

### Cobalt Area

The Gowganda Formation in the Cobalt area consists of the glaciogenic Coleman Member and the deltaic Firstbrook Member. Economic interest in the Gowganda Formation at Cobalt involves possible stratiform base metals (Cu, Zn, Pb) and precious metals (Ag, Au) in Coleman Member beds (Donaldson *et al.*, 1984).

The major lithologic units of the Coleman Member comprise, from the base up: (1) a basal breccia unit of angular boulders that occurs in topographic lows on the Archean surface. The overlying massive diamictite (2) is unsorted, widespread and occurs on topographic highs of the Archean surface. Pebble fabrics show a north-south orientation. The diamictite suite is followed by a sequence of argillites, sandstones and orthoconglomerates that coarsen upward (3). The argillites are typically distinctly graded, show microlamination, and contain diamicton (till) pellets and dropstones. The sandstone units show ball-and-pillow structures, tabular cross-bedding, asymmetric ripple marks and rare graded-bedding. Unit three (3) contains an upper diamictite with numerous intercalated, laminated siltstone, sandstone, and orthoconglomerate.

The upper Gowganda (Firstbrook Member) comprises laminated mudstones, siltstones and arkose (Rainbird and Donaldson, 1985). These arkoses pass comformably upward to arkoses of the Lorrain Formation, as they also appear to at Whitefish Falls. The above units are interpreted as subfacies of a prograding river-dominated delta.

The interpretation presented by Mustard for discussion of the Coleman Member units is that the breccia (unit 1) is a periglacial regolith considered to be augmented by subglacial freeze-thaw action. Other participants suggested that finer detritus would result from repeated freeze-thaw activity and, conversely, local evidence permits that the breccia may be a slope deposit. However, the occurrence of the overlying diamicton (on local high-points) and a preferred pebble orientation (north-south) imply a subglacial origin as a till. The presence of diamicton (till) pellets and dropstones in the overlying rhythmites supports glacial origin. The sandstones that are interbedded with the argillite (rhythmites) are rapidly sedimented subaqueous deposits (ball-and-pillow structures, graded beds). Rounded clasts in the overlying orthoconglomerates indicate traction activity along a delta surface or in subglacial meltwater channels. The combined, upward-coarsening sequence is representative of facies distribution in a subaqueous outwash fan. This fan surface underwent failures and slumps that produced sediment gravity flows that are represented by diamictites and irregular interbedded laminated siltstone, sandstone and orthoconglomerate (Mustard *et al.*, 1984; Mustard and Donaldson, 1985).

A subaqueous fan origin for unit three (3) of the Coleman Member seemed reasonable to most observers on the field trip as discussion shows. The occurrence of large channel-fill sequences in these variable fan sediments is consistent with the subaqueous glaciomarine fan model of Rust and Romanelli (1975), Rust (1977) and Cheel and Rust (1982). A characteristic feature of these channel-fill sequences in the Cobalt area is that they exhibit rapid lateral facies changes from massive diamictites and orthoconglomerates to finer- and thinner-bedded pebbly and sorted sandstones, siltstones and rhythmites. These rapid lateral facies changes (diamictites to rhythmites in tens of metres) have counterparts in subglacial conduit deposits at grounded ice-margins of the Champlain Sea. In the Champlain Sea deposits, the pattern is clearly one of ice-marginal sedimentation. The configuration of the Champlain Sea basin (shallow inner-shelf embayment) is a good analogue for the apparent embayment represented by the Gowganda Formation in the Cobalt area.

A further point about the regional setting concerns the fact that, both at Whitefish Falls and Cobalt, the upper Gowganda comprises deltaic sequences that are transitional upward to terrestrial or shallow water sandstones. This general setting may be more compatible with an ice-proximal rather than a deeper water depositional environment for the diamictites and conglomerates of the lower Gowganda Formation.

## Summary

In summary, several persistent problems seemed evident from this quick introduction to the Gowganda sedimentary rocks: (A) The need to explain thick, widespread sequences of coarse sediment in association with rhythmites of glacial origin. (B) The need to determine a plausible method for transporting glacial drift to a deeper marine(?) basin. (C) How has resedimentation taken place? (D) How much primary sedimentation has taken place? (E) The need to identify analogues for the local depositional models that are being described by recent studies. (F) The need to test these local models in other parts of the basin.

In conclusion, the direct evidence of glacial activity is the rhythmites with dropstones. There is local evidence for grounded ice despite the base of the Gowganda having limited exposure. There also is good evidence (channel-fills) for subaqueous fan deposition. The question is whether this is ice-proximal or deep-sea in origin or both. A key constraint is the need for a high energy source for the abundant coarse sediment. There is clearly a need to generate more local facies models within the Gowganda Formation before more general models can be distilled.

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## References

Cheel, R.J. and B.R. Rust, 1982, Coarse-grained facies of glaciomarine deposits near Ottawa, Canada: *in* Research in glacial, glacio-fluvial and glacio-lacustrine systems, R. Davidson-Arnott, W. Nickling and B.D. Fahey, eds., Geo-Books, Norwich, p. 279–295.

Coleman, A.P., 1907, A Lower Huronian ice age. American Journal of Science, Series 4, v. 23, p. 187–192.

Colman, S.M., 1982, Chemical weathering of basalts and andesites: Evidence from weathering rinds: United States Geological Survey Professional Paper 1246, 51 p.

Domach, E.W., 1984, Rhythmically bedded glaciomarine sediments on Whidbey Island, Washington: Journal of Sedimentary Petrology, v. 54, p. 589–602.

Donaldson, J.A., M.P. Goodz, F.A. Michel, P. Mustard, R. Rainbird, B.R. Rust, D.H. Watkinson and B. Wilson, 1984, Sedimentary Rocks and Stratabound Mineralization in the Cobalt Region: *in* Geoscience Research Grant Program, Summary of Research 1983–1984, V.G. Milne, ed., Ontario Geological Survey Miscellaneous Paper 121., p. 198–210.

Donaldson, J.A. and I. Munro, 1982, Precambrian Geology of the Cobalt area, Northern Ontario: International Association of Sedimentologists, 11th International Congress on Sedimentology, Hamilton, Ontario, Field Excursion Guidebook, 16B, 72 p.

Elverhoi, A., 1982, Glacial–Post-glacial Shelf Sedimentation: International Association of Sedimentologists, 11th International Congress on Sedimentology, Hamilton, Ontario, Abstract, p. 75.

Gravenor, C.P., V. VonBrunn and A. Dreimanis, 1984, Nature and classification of waterlain glaciogenic sediments exemplified by Pleistocene, late Paleozoic and Late Precambrian Deposits: Earth-Science Reviews, v. 20, p. 105–166.

Lindsey, D.A., 1969, Glacial Sedimentology of the Precambrian Gowganda Formation, Ontario, Canada: Geological Society of America Bulletin, v. 80, p. 1685–1702.

Lindsey, D.A., 1971, Glacial marine sediments in the Precambrian Gowganda Formation at Whitefish Falls, Ontario (Canada): Paleogeography, Paleoclimatology, Paleoecology, v. 9, p. 7–25.

McCabe, A.M., G.F. Dardis and P.M. Hanvey, 1984, Sedimentology of a late Pleistocene submarine-moraine complex, County Down, Northern Ireland: Journal of Sedimentary Petrology, v. 54, p. 716–730.

Mackiewicz, N. and R.D. Powell, 1982, Laminated ice-proximal glaciomarine sediments: International Association of Sedimentologists, 11th International Congress on Sedimentology, Hamilton, Ontario, Abstracts, p. 74.

Miall, A.D., 1983, Glaciomarine sedimentation in the Gowganda Formation (Huronian), Northern Ontario: Journal of Sedimentary Petrology, v. 53, p. 477–491.

Miall, A.D., 1985, Sedimentation on an early Proterozoic continental margin: the Gowganda Formation (Huronian), Elliot Lake area, Ontario, Canada: Sedimentology, v. 32, in press.

Mustard, P.S. and J.A. Donaldson, 1985, Depositional Models for Glaciogenic sediments of the Gowganda Formation: Geological Society of America, North-central Sectional Meeting, Abstracts with Programs 1985, v. 17.

Mustard, P.S., R.J. Scammell and J.A. Donaldson, 1984, Sedimentology of the Lower Gowganda Formation at Cobalt, Ontario Canada: Geological Society of America, Annual Meeting, Reno, Abstracts with Programs 1984, v. 16, p. 605.

Nesbitt, H.W. and G.M. Young, 1982, Early Proterozoic climates and plate motions inferred from major element chemistry of lutites: Nature, v. 299, p. 715–717.

Powell, R.D., 1983, Glacial-marine sedimentation processes and lithofacies of temperate tidewater glaciers, Glacier Bay, Alaska: *in* Glacial-Marine Sedimentation, B.F. Molnia, ed., Plenum Press, New York, p.185–232.

Rainbird, R. and J.A. Donaldson, 1985, Firstbrook Member of the Gowganda Formation: Example of a Huronian (early Proterozoic) river-dominated deltaic sequence: Geological Association of Canada—Mineralogical Association of Canada, Program with Abstracts, v. 10, p. A50

Rust, B.R., 1977, Mass flow deposits in a Quaternary succession near Ottawa, Canada: diagnostic criteria for subaqueous outwash, Canadian Journal of Earth Sciences, v. 14, p. 175–184

Rust, B.R. and R. Romanelli, 1975, Late Quaternary subaqueous outwash deposits near Ottawa, Canada: *in* Glaciofluvial and Glaciolacustrine Sedimentation, A.V. Jopling and B.C. MacDonald, eds., Society of Economic Paleontologists and Mineralogists, Special Publication 23, p. 172–192.

Shaw, J. and J. Archer, 1978, Winter turbidity current deposits in Late Pleistocene glaciolacustrine varves, Okanagan Valley, British Columbia, Canada: Boreas, v. 7, p. 123–130.

Walker, R.G., 1984, Turbidites and associated coarse clastic deposits: *in* Facies Models, Second Edition, Geoscience Canada Reprint Series Number 1, Roger G. Walker, ed., Geological Association of Canada, Toronto, p. 171–188.

Young, G.M., 1982, Depositional environments and tectonic setting of the Early Proterozoic Huronian Supergroup: International Association Sedimentologists, 11th International Congress on Sedimentology, Hamilton, Ontario, Field Excursion Guidebook 13B, 79 p.

Young, G.M., 1984, The Proterozoic of North America: some aspects of subdivision and correlation: Proceedings of the 27th International Geological Congress, v. 5, Precambrian Geology, p. 95–124.

Young, G.M., unpublished, Stratigraphy, Sedimentology and Tectonic setting of the Gowganda Formation in the southern part of the Huronian outcrop belt; unpublished lecture, Ottawa-Carleton Geoscience Centre, University of Ottawa, February 1984.

Young, G.M. and W.H. Nesbitt, in press, The lower Gowganda Formation in the southern part of the Huronian outcrop belt, Ontario, Canada: stratigraphy, depositional environments and tectonic setting: Precambrian Research.

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