Reports

Sediment Transport in a Precambrian Ice Age: The Huronian Gowganda Formation

Abstract. *The Gowganda Formation of Ontario consists of conglomerates, quartzites, and argillites deposited in a glacial environment. The distribution of varved argillites and silty limestones suggests continental and marine facies, respectively. Pebble and ripple-drift orientations, distribution of limestones, striated pavements, distribution of the underlying Bruce Group, and Huronian quartzite paleocurrents support the conclusion that sediment transport was from north to south.*

Controversy has raged about the origin of the Gowganda Formation since Miller and Coleman first proposed the glacial hypothesis more than half a century ago (*1*). Later, Bain and McConnell argued for an alluvial fan interpretation, with Bain favoring a southern source (*2*). With the rising popularity of the turbidity flow concept in sedimentation, recent workers have suggested that a combination of glacial ice and turbidity flows was responsible for the deposition of the Gowganda (*3*).

Cropping out in an irregular belt from Lake Superior to Quebec (Fig. 1), the Gowganda Formation is a complex assemblage of conglomerate, argillite, and quartzite. It is part of the thick sequence of sediments designated Huronian and shown by radiometric dating to be about 2 billion years old (*4*). Along the north shore of Lake Huron, it rests on older Huronian sediments; but between Sudbury and Quebec, it directly overlies the Archean basement. The Lorrain Quartzite overlies the Gowganda Formation.

Two types of conglomerate (paraconglomerate and orthoconglomerate) characterize the Gowganda Formation (*5*). Conglomerate with a dispersed framework of clasts that vary greatly in size (paraconglomerate) (*6*) is widely distributed regionally and stratigraphically. Many or all of the paraconglomerates are interpreted to be glacial moraine deposits. Pink and red granite clasts dominate east of Sault Sainte Marie and south of Sudbury; a greater variation is found northeast of Sudbury, where metavolcanic clasts are locally significant. Throughout, clast axes have a marked preferred orientation (Fig. 1). The matrix is a fine-grained mixture of angular quartz, feldspar, and chlorite. Usually the paraconglomerates are unstratified, but locally they may contain pebbly bands and sand lenses.

Framework-supported conglomerate (orthoconglomerate) (*6*) occurs less commonly than paraconglomerate, and is usually associated with it. Probably it is a fluvial or glacio-fluvial deposit. Orthoconglomerate is characterized by sorted, subrounded clasts and by crude stratification. The pebbles are commonly of diverse lithologies, and the matrix may be either sand or silt. Clasts in the orthoconglomerate may also show a preferred orientation.

Tan or brown outcrops of quartzite are most commonly massive-bedded. Locally, where quartzite is interbedded with argillite, ripple mark, ripple-drift, and load casts are abundant. Coarse, angular grains dominate the framework, and pebble bands may be present.

The Gowganda argillites commonly show continuous, parallel laminations, in some cases as thin, graded couplets resembling Pleistocene varves (*7*). However, wavy lamination characterizes other argillites. Starved ripples and ribbons of sand may be present, and rafted clasts are locally abundant. Probably many of the argillites were formed in fresh-water lakes. On the other hand, in some areas where silty limestones are associated with the Gowganda, the argillites fail to display convincing varve structure, and the association suggests marine conditions. Twenty-two localities where varved argillite was identified and four localities where silty limestone is known were plotted on a map. The regional distribution of the two facies suggests a continental and a marine facies in the Gowganda (Fig. 2).

Two indicators of sediment transport direction were measured. Pebble orientations were measured on surfaces parallel to the bedding plane in the paraconglomerates. The method of measurement suggested by Pettijohn was followed (*8*). A grid of 1-foot

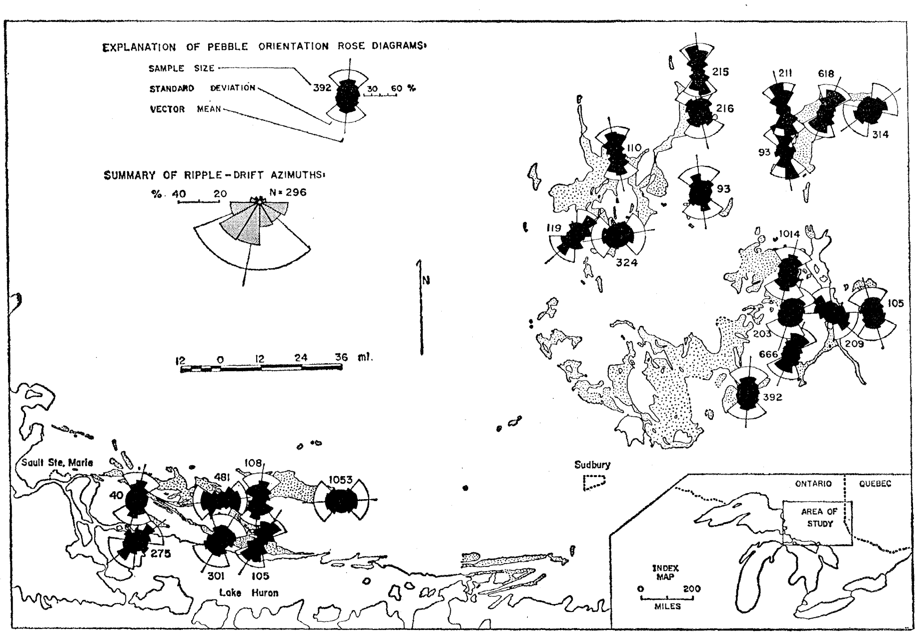

Fig. 1. Pebble orientations and ripple-drift as indicators of paleotransport directions in the Gowganda Formation.

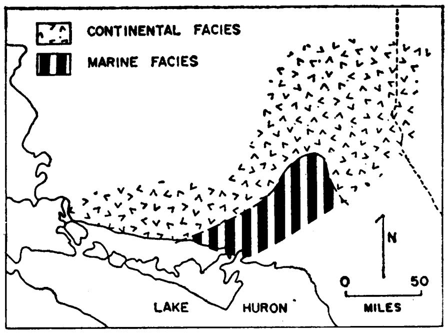

Fig. 2. Suggested distribution of continental and marine glacial facies in the Gowganda Formation as indicated by the occurrence of varved argillite and silty limestone.

squares was laid out on the surface to be studied. In each square the apparent long axis of pebbles having an apparent axial ratio of 2:1 was measured with a Brunton compass. Usually, about 100 measurements were taken at each station. Similar data were collected from a few orthoconglomerate outcrops. The data for each station were plotted on a map. To collect and summarize the data, a grid was placed over the map; each square area of the grid contained 144 square miles. Data from all the stations in each grid square were combined, compiled into 30-degree classes, and plotted at the center of their respective squares (Fig. 1). Statistics shown for the data were computed according to the methods of treating semicircular normal distributions (*9*). The resulting vector means were consistently north-south for most of the areas northeast of Sudbury, but were both east-west and north-south near Sault Sainte Marie. Studies of Pleistocene tills have shown that, in general, the long axes of till stones are parallel to the direction of ice movement, though a secondary orientation may be perpendicular (*10*). With the results of Pleistocene studies as a guide, the data suggest that the Gowganda ice sheets moved generally along a north-south line.

Two problems influence the value of pebble orientation data as a paleotransport indicator in the Gowganda. One, most apparent east of Sault Sainte Marie, is the variability of the mean direction. Measurements in paraconglomerates from different stratigraphic horizons in the section north of Elliot Lake, Ontario, for example, show considerable variability, suggesting that the variation of the mean direction results from indiscriminate sampling of more than one till sheet. The second problem is tectonic deformation of the pebbles. No localities exhibiting visible internal deformation were sampled, and no localities were taken in the Gowganda south of Sudbury, where high dip angles and tectonic fabric are common. The best evidence against a pebble fabric of tectonic origin is the consistency of the vector means from different localities northeast of Sudbury. Nearly flat-lying, undeformed outcrops of paraconglomerate near Cobalt and Virginiatown, Ontario, produced abundant data with a consistent north-south mean.

A second criterion of transport direction is ripple-drift. Ripple-drift, or cross-lamination on a small scale, is locally abundant in starved ripples and ribbon beds of sand in the argillite lake deposits. A summary of 296 readings taken at widely dispersed localities shows a vector mean of 191 degrees (Fig. 1). Evidently the Gowganda lakes were part of an extensive drainage system which flowed generally south, although individual localities yield different or random data.

The paleotransport data are in general agreement with information from rare striated pavements beneath the Gowganda. Striae reported near Opasatika Lake, Quebec, are aligned northeast-southwest (*11*). The striated pavement south of Lake Timagami indicates that the ice moved southwest (*12*).

The problem of the direction of ice movement during Gowganda time can be answered by considering the following arguments. The southerly mean of the ripple-drift data indicates that the regional drainage system flowed generally south, a conclusion which agrees with the suggested distribution of continental and marine facies. Previously reported striated pavements are in agreement with the paleotransport data. Two additional considerations also support a southerly paleoslope. The presence of the Bruce Group beneath the Gowganda south and west of Sudbury, as well as the disappearance of the Bruce northeast of Sudbury, indicates a positive area to the north. The paleocurrent studies of Huronian quartzites have all indicated a northerly or northwesterly source (*13*). The evidence for a northerly source for the Gowganda is compelling, and in the region northeast of Sudbury the alignment of pebble fabric indicates that the Gowganda glaciers moved almost due south.

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Pseudo-Fivefold Symmetry in Carbonyl Process Nickel

Abstract. *Grains with pseudo-fivefold symmetry have been observed in nickel prepared by thermal decomposition of nickel carbonyl. These grains were studied by transmission electron microscopy and electron diffraction techniques. The defect structure and composite symmetry varied within a given sample, and the size of the grains varied with the thickness of the sample.*

Fivefold symmetry in vapor-deposited films and whiskers has been reported (*1*). We observed this unusual symmetry in etch pits developed during electrochemical machining of parts which had been nickel-plated by the carbonyl process. Etch pits as large as 20 μ in diameter were formed. Since there had

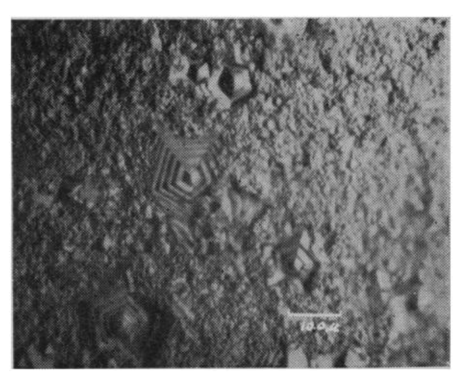

Fig. 1. Optical micrograph of etch pits developed on carbonyl nickel-plated portion.