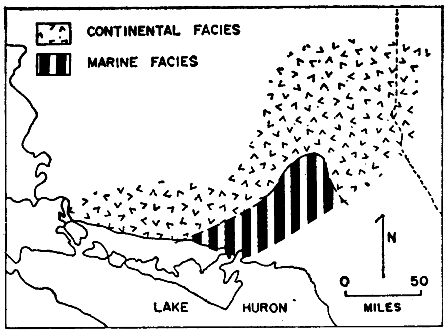

Fig. 2. Suggested distribution of continental and marine glacial facies in the Gowganda Formation as indicated by the occurrence of varved argillite and silty limestone.

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

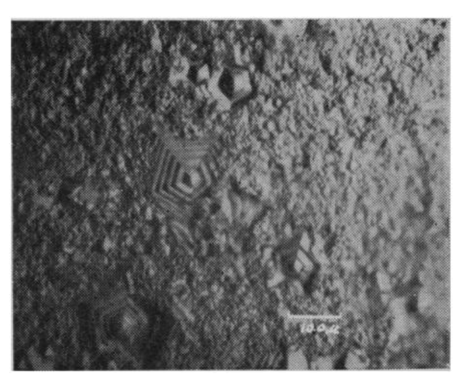
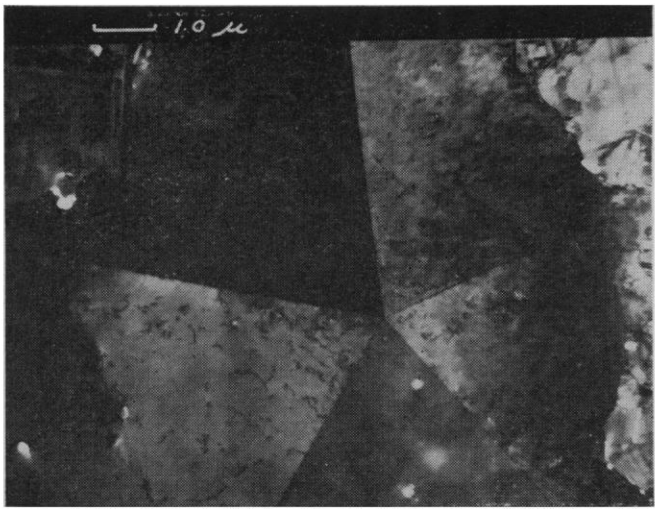


Fig. 1. Optical micrograph of etch pits developed on carbonyl nickel-plated portion.



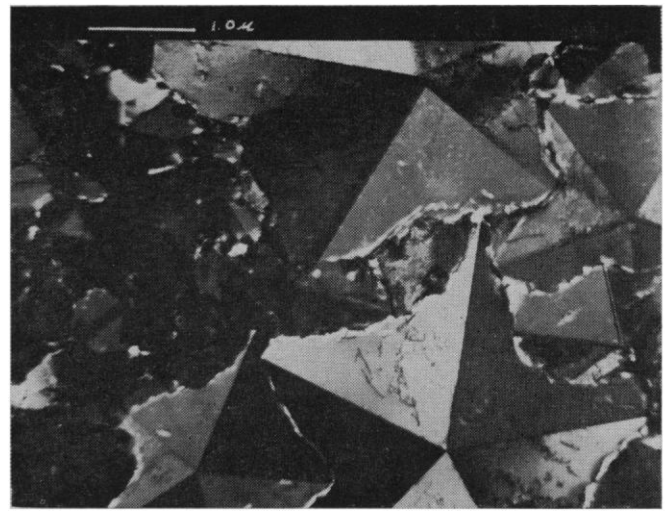


Fig. 2 (left). Transmission electron micrograph of a pseudo-fivefold nickel grain oriented normal to the foil. Fig. 3 (right). Electron micrograph showing both tilted and nontilted pseudo-fivefold grains.

been no previous investigation of this symmetry with transmission electron microscopy, samples 0.125 to 0.200 mm thick were thinned for study by this technique. The thin foils were found to contain pseudo-fivefold grains, varying in both defect structure and composite symmetry.

The majority of the grains with pseudo-fivefold symmetry were found to agree well with the model proposed by Melmed and Hayward (*1*). In this model, the normal to the fivefold grain is the $\langle 110 \rangle$ direction, and the boundaries between the five subgrains are parallel to (111) planes. Because the angle between (111) planes which intersect along a $\langle 110 \rangle$ direction is $70°32'$ and the repetition angle for fivefold symmetry is 72°, there is a total mismatch of $7°20'$ which is accommodated by the defect structure of the subboundaries between the component subgrains. In some grains, this mismatch seems to be distributed somewhat evenly among the five subboundaries.

There are at least three other simple ways of obtaining this symmetry. First, with the fivefold axis still the $\langle 110 \rangle$ direction, the subboundaries could be (112) planes which are also separated by $70°32'$. Then, if a face-centered cubic (fcc) structure twins along a (111) plane, (110) planes, which are $70°32'$ apart, are generated. Five such twins can produce a grain with pseudo-tenfold symmetry, having five (110) plane boundaries which are bisected by the (111) twin boundaries. Finally, it is also possible to have various combinations of the above types.

An example of the most generally observed type of grain with pseudo-fivefold symmetry is shown in Fig. 2. The diffraction pattern from this type grain has the symmetry of five nearly perfect twins around a common $\langle 110 \rangle$ axis which is normal to the plane of the foil. The subboundaries between the subgrains are parallel to (111) planes. The subboundaries possess a defect structure which arises from an approximately 1° to 2° mismatch between these twin-related subgrains. This defect structure is clearly visible in the subboundaries of the grain in the upper portion of Fig. 3. These defects appear to be edge dislocations lying parallel to the $\langle 110 \rangle$ direction. Assuming this to be the case, the misorientation from a perfect twin relationship can be visualized as a low angle tilt which can be calculated from the dislocation spacings. For the grain mentioned above, the angles of the four tilt boundaries are $1°20'$, $1°40'$, $2°6'$, and 2°. For five equal boundaries the angles would be $1°28'$.

In other grains, however, we observed that one of the subboundaries was a slip trace. There are only four subgrains making up these grains since a slip trace is not a boundary surface. Most of the $7°20'$ misfit is apparently taken up in the other four boundaries. A similar grain was observed in which stacking faults extended from one of the boundaries. Many of the observed grains had large numbers of microtwins running parallel to the subboundaries.

We also found what appeared to be a grain with pseudo-tenfold symmetry. This grain is believed to be an example of the pseudo-tenfold grain previously discussed, the subboundaries of which are proposed to be (110) planes with bisecting (111) twin boundaries.

There appears to be a correlation between coating thickness and size of the fivefold grains. In most of the coatings (0.125 to 0.200 mm thick) stripped for transmission studies, the diameter of the grains was only 1 or 2 μ, or less. The coatings on the nickel-plated parts in which etch pits were observed were about 0.5 to 0.625 mm thick. Thicker samples, ranging from 1.5 to 2 cm thick were thin-sectioned; the fivefold grains were from 10 to 15 μ in diameter. Because the size of the grains increased greatly, going from 0.2 to 0.5 mm coatings, and because no further increase in size was observed when the coating thickness was increased to 20 mm, we believe approximately 20 μ is a possible size limit for these grains.

Melmed and Hayward (*1*) obtained whiskers with fivefold symmetry when impurity gases were present during deposition. This was given as a possible cause for this unusual growth symmetry. Our observations agree with theirs because carbon monoxide is present during the decomposition of nickel carbonyl.

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