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The Influence of Researchers Upon Glacial Stratigraphy

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Résumé de l'article

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engineers, as well as geologists and geographers, were attracted to studies of glaciers. Symposia yearly now draw more than 100 participants, whereas 40 years ago you could count the world's real glaciologists on your fingers.

Glacial geology, too, which had grown some earlier, expanded even more after 1950. It has become more process oriented, and highly physical. Whereas in 1933 the Friends of the Pleistocene drew less than a dozen people in New England, by 1980 there were four branches, across USA and Canada, struggling to limit meetings to a manageable 100 people! The time frame of chronologies had been enlarged as well; Quaternary Period was now over 2.2 million years long (it had been just one million). INQUA, the international Quaternary association, grew by leaps and bounds from its humble 1932 beginnings. Every province and state had several enthusiastic field workers and they were joined, in most cases, by good soils people. Quaternary studies are emphasizing the environmental insight from pollen, insects, animals, and the archaeology of man himself. As with many other scientific disciplines, after a half century of development of the theoretical, we now seek all the practical applications and uses of glacial geology and glaciology.

In the mushroom growth of these two disciplines Aleksis Dreimanis made his start in North America just at the right time. The combination of glacial process, bearing on glaciology, and careful glacial history, based upon stratigraphy and absolute dating, was just right for Aleksis to step into, work hard, and make lasting contributions. By virtue of his INQUA commission chairmanship he has indeed become "Mr. Till". We cherish and celebrate his great part in the last three decades.

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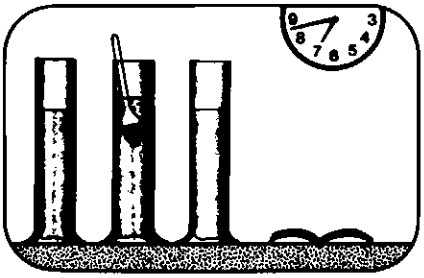

The Influence of Researchers Upon Glacial Stratigraphy

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Abstract

In order to illustrate how glacial stratigraphy may become influenced by the subjectivity of researchers, the grain size composition of till will be discussed as an example. Most particle size data do not refer to the entire till, but mainly to its matrix, plus smaller clasts. Though the granulometric data, even if just referring to till matrix, are considered to be reliable and objective, various amounts of subjectivity enter the analytic results during the sampling, pretreatment, analyses and statistical evaluation of data.

The subsequent interpretation involves even more subjectivity. This will be illustrated by using tills of Southwestern Ontario and Denmark as examples. While colour and texture of till once used to be the main criteria for differentiation and correlation of tills, more complex multiple criteria are applied now. During the last 15 years a score of genetic varieties of tills have become recognized, each of them playing its role in stratigraphic interpretation. Now more attention than before is paid to glaciotectonic deformations and fabric in deciphering stratigraphy of glaciogenic sequences.

Quaternary glacial deposits cover most of Canada. If their stratigraphy has been properly deciphered, the extraction of Quaternary economic deposits and the planning of major construction projects may be done rationally. The knowledge of glacial stratigraphy is useful also in hydrogeology and in planning waste disposal. In the search for bedrock ore deposits by indicator tracing, an understanding of Quaternary glacial stratigraphy is essential in areas with more than one layer of glaciogenic deposits over bedrock.

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Introduction

Glacial stratigraphy implies a dominance of glaciogenic deposits or effects of glacial activity, such as glaciotectonic deformations. Some nonglacial components are usually included in the glacial sequences, e.g., interglacial or interstadial deposits and/or weathering horizons. Though in most minds glacial stratigraphy is associated with the Quaternary, it may be developed in any part of the stratigraphic column where glacial activity has been prevalent.

The interrelationship of glacial stratigraphy and man may be viewed from two perspectives: (a) how are the stratigraphic schemes influenced by the thinking of man, and (b) how useful is the knowledge of glacial stratigraphy to man? I will mainly discuss point (a), since (b) is covered by several of the ensuing papers.

Every stratigraphic scheme consists of factual data and their interpretation. The interpretation is considered particularly vulnerable to subjectivity since it depends upon the interpreter - the stratigrapher. Actually various degrees of subjectivity may be present in both the data and in their interpretation. I will mention a few examples from investigations of till, as till, being a glacial deposit, is the most important sediment in glacial stratigraphy and is equally important in various applied sciences.

Data

Till is a diamicton composed of various size particles ranging from the microscopic clay size to large boulders. Most granulometric data on till are restricted to its matrix, including the fine clasts up to 2 mm, 4 mm or 20 mm. This means an exclusion of boulders, cobbles and even pebbles, if 2 or 4 mm form the upper analytical boundary. A till (Figs. 1 and 2) may contain just a few per cent, or even more than 80% (Jφrgensen, 1977; Virkkala, 1974) of clasts that are not included in usual textural analyses. For local stratigraphic correlations the usual granulometric analyses of the till matrix, or matrix plus pebbles, are quite sufficient, as proven by many regional investigations. However, such data may not be sufficient, if the analyses are meant for an engineering project where a certain till has to be excavated in large quantities, as it was in the St. Lawrence Seaway project, or where till is used for building an earth dam. I will not go into methodology, how to obtain statistically reliable data on the quantity of coarse clasts of tills, but Figure 1 illustrates that there may be problems in particle size analyses of the total till, if large clasts are very abundant.

Figure 1 *Extremely stony till rich in large limestone boulders at the Marmora iron ore mine, southern Ontario. (Photo A. Dreimanis).*

To give some idea what differences may be expected between the cumulative curves from the usual analyses of till (with 2 mm as the upper boundary) and from total till, two cumulative curves from the sandy and moderately stony Wentworth till near Galt, Ontario (Dreimanis and Vagners, 1972) may be compared (Fig. 2). Even though the right curve still does not represent the entire till (boulders were not considered), the inclusion of some 30% of cobbles, pebbles and granules with the till matrix results in a reduction of sand from 50% in the left curve to 35% in the right curve, and in a reduction of silt from 45% to 33%. The difference would be still greater, if boulders were included.

Particle size analyses of the total till are very time-consuming, and seldom are they performed (for discussions of such analyses in Scandinavia see Jφrgensen, 1977, p. 150, and Lundqvist, 1977, p. 74-75). Still, we shall keep in mind that the usual granulometric data on tills are human selections, and they do not represent the entire till.

Further, we should consider also a few other human influences upon the granulometric data of tills. Several of them may be mentioned.

1) The *sampling of till* may be done in many different ways (Krumbein and Pettijohn, 1938; May and Dreimanis, 1976). A special sampling plan may be necessary for the entire section investigated that takes into account the vertical and horizontal variability of till (Fig. 2). Care should be taken not to transgress sedimentologic boundaries, nor to include unconsolidated clasts or weathering products, that may disintegrate during the disaggregation of sample. In some inhomogeneous tills a sample may have to be taken from a very long channel, in order to be representative: in the Catfish Creek Till at Bradtville (May and Dreimanis, 1976, Fig. 4) the channels should be 3 m long according to May's calculations (May and Dreimanis, 1976, p. 114 and 115) in order to obtain a reliable estimate of the mean composition of that till. If most of the till analyses published are not representative of the mean composition of the till, we should exercise some caution in using these data, and the range of variability per section or per area, e.g., as a mean ± standard deviation, should be indicated.

2) The *laboratory pretreatment* of the till samples prior to their granulometric analyses may influence the data obtained, depending upon the composition of till and the harshness of the pretreatment to disperse the clastic components of till. The following pretreatments commonly applied (Krumbein and Pettijohn, 1938): crushing, and chemical plus mechanical dispersion in a liquid. Some analysts of till, apparently influenced by pedologists who remove the secondary carbonates by acid pretreatment, have been even removing the clastic carbonates, thus distorting the granulometric composition of till. A thorough mixing of the sample to be analysed

before taking the subsample for the analysis, and a thorough mixing of the subsample in the dispersing solution just before beginning the analytical procedure are also very important for obtaining reliable data.

3) Another factor may be the *analytical method* chosen: by hydrometer, pipette, settling tube, elutriator, photosedimentometer or any other equipment (Krumbein and Pettijohn, 1938; Raukas *et al.*, 1978). Each of the methods has its advantages and disadvantages, and their results tend to differ in one or another particle size range. If two methods are combined in analysing a till sample, e.g., wet sieving with the hydrometer method, or wet sieving with the pipette method, the cumulative curves derived from the results of the two methods often do not match (Fig. 3). Their "break" is inherited from the principal differences in the two methods that are combined. Most analysts who experience such "breaks" try to 'heal' them according to their subjective considerations. Though this problem has been discussed in oral presentation of data, I still have not seen any objective written discussion about what is the proper way to solve it.

4) The *particle boundaries chosen*, e.g., for sand/silt, silt/clay size may influence the comparison of data of various workers. Many authors do not list the particle size boundaries they are using, probably assuming that everybody else uses the same boundary they do. This applies particularly to the silt/clay size boundary: on this continent it is usually either 4 μ or 2 μ, and choosing one or the other makes quite a difference in the clay and silt percentages reported.

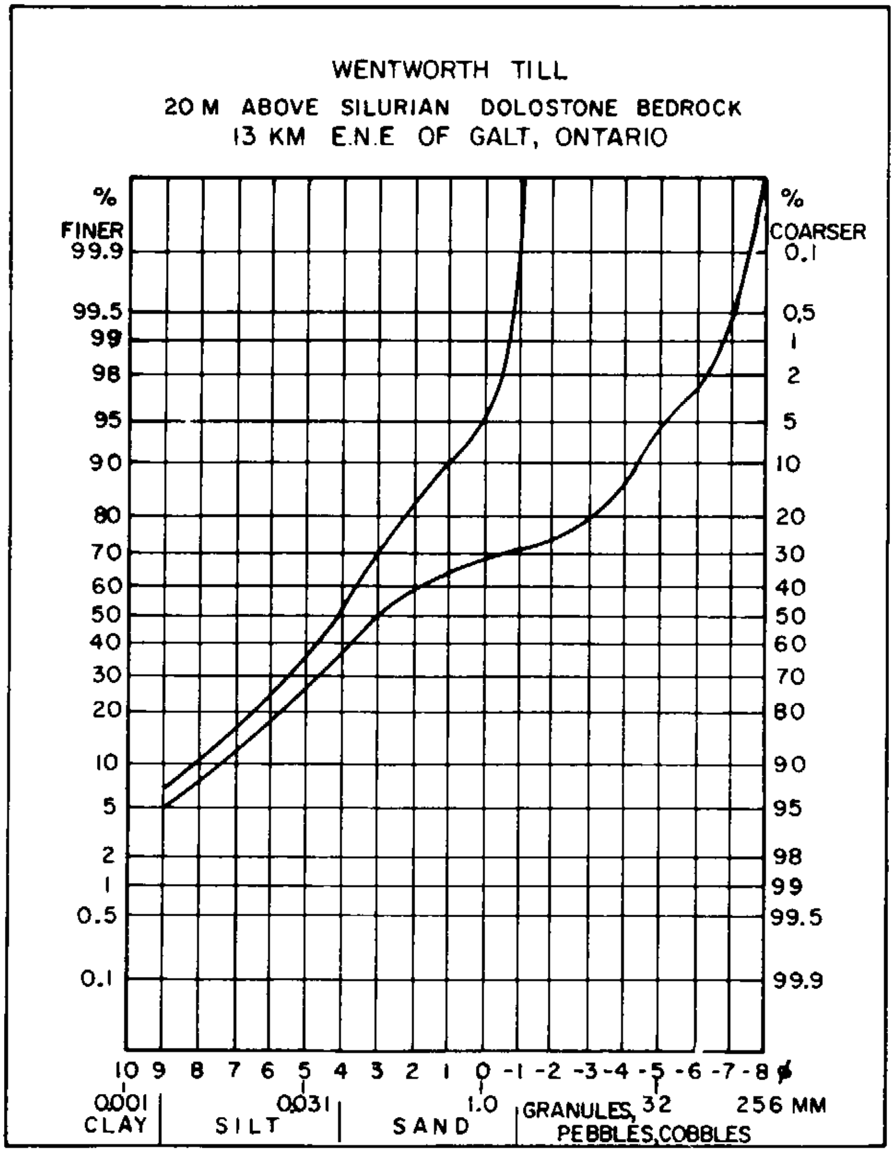

Figure 2 *Cumulative granulometric curves of a Wentworth Till sample depending upon the upper boundary chosen. (Fig. 2 in Dreimanis and Vagners, 1972; reproduced by permission of the Univ. of Guelph Geography Dept.)*

5) *Statistical parameters* - mean, median, modes, measures of uniformity, skewness, and kurtosis (Folk, 1966), size factors (Shepps, 1958), etc., are being used more and more often, particularly for comparison of a multitude of data. However, several of them, for instance the measures of uniformity, may be determined by a variety of formulae, but some authors do not disclose what formulae they were using.

6) *Graphic presentation of data* by cumulative curves, ternary diagrams, histograms, frequency curves, scatter plots relating two parameters, trend surface diagrams, etc., are very useful for comparison or summation of analytical data. However, the choice of the most suitable way of presentation may also be subjective, emphasizing certain parameters, for instance, by preferring log-probability paper for cumulative curves (Gillberg, 1979).

Granulometric analyses are not the only analytical procedures that may produce a variety of subjectively influenced data. The same applies to various lithologic, geochemical, fabric, structural, and paleontologic investigations and age determinations.

In summary, the so-called 'objective data' on tills and also other materials that are investigated for developing glacial stratigraphy may be influenced to various

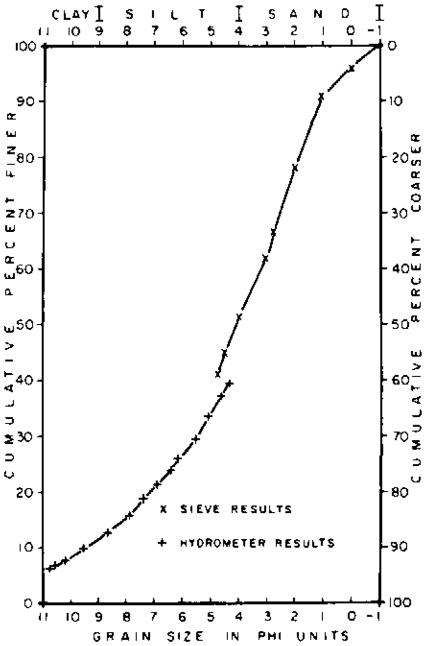

Figure 3 *Break in a cumulative curve of Catfish Creek Till from the Lake Erie cliff at 'Bradtville', Ontario (Section B, lower unit; see May and Dreimanis, 1976, Figs. 3 and 4, for the location and section). Discussion in text.*

degrees by human attitude: by the persons who are collecting samples, who are doing the analyses, and who are reporting the data and calculating their statistical parameters. In order to be aware of the possible errors or biases, a general rule should be followed strictly by everybody who publishes analytical data: a description of the sampling and the analytical procedures, the particle size boundaries, and the formulae for statistical parameters should be given. In order to check for human errors in performing the analyses, duplicate samples should be analysed by several operators.

Interpretation of Data

If the obtaining of analytical data for glacial stratigraphy or any applied project requires mainly technical skills, a knowledge of the theory pertinent to each analytical procedure, and some basics of glacial geology, then the interpretation of data is already more complex. It requires good up-to-date knowledge of glacial geology, a broad and not just local knowledge of the stratigraphic interval investigated, and appreciation of the interdisciplinary character of Quaternary studies. In addition to this professional knowledge, a glacial stratigrapher needs a good, but not excessive, amount of imagination coupled with logical reasoning, particularly for bridging the gaps in factual data - and such gaps are abundant! Any flaws in the background knowledge and in the way it is used, will increase the subjectivity of interpretation. Considering the many possibilities how subjectivity may enter the interpretation of various sets of data, I may be justified to say that all interpretations contain a subjective imprint characteristic for each individual scientist. Most scientists try hard to be objective but in their interpretations they are not free of subjective, often erroneous, conclusions, either because of lack of some of the background knowledge, or because of adherance to models that are applicable under certain conditions but not everywhere. Thus correlation of tills by their colour or grain-size composition works out very well in some instances, but is not applicable in others. At one time every red till in the Central Great Lakes Region was considered to be Valders, but not any more.

The grain size composition may be quite uniform in some areas, where the substratum of till was uniform. Thus in an area of about 500 sq. km. south and southeast of London it has been easy to differentiate the uppermost Port Stanley Till from the next older Catfish Creek Till by the granulometric composition of their matrix (Dreimanis, 1976, Figs. 7 and 8). However, an increase in clay-sized particles due to incorporation of glaciolacustrine clays is noticeable when going westwards along Lake Erie, and an increase in sand, when going inland from Lake Erie to London, probably because of incorporation of the more sandy Catfish Creek Till. Trend surface diagrams (e.g., Fig. 8 in Cowan, 1978) are useful in presenting graphically these lateral changes.

In the London, Ontario area, the particle size analyses alone are not sufficient to differentiate the Erie lobe Port Stanley Till from the still unnamed Huron lobe till west of London and the Lobo and St. Joseph tills farther northwest in the Huron lobe area: all of them are very clayey. However, other criteria - structural, lithologic and geochemical - make it possible to distinguish them.

Returning to the Port Stanley Till, it should be mentioned that two varieties of it are coarser textured than a typical subglacial Port Stanley Till. One of them occurs in a stratigraphically very important section southeast of Port Talbot (Mörner and Dreimanis, 1973). Here the basal 0.5 to 1.5 m. of Port Stanley Till overlying the Erie Interstadial littoral gravelly sand, is extremely enriched by these sands derived from reworked Catfish Creek Drift. Therefore both texturally and lithologically the basal part of Port Stanley Till resembles more the Catfish Creek than the Port Stanley Till. If identified from individual samples taken from test drillings, this part of Port Stanley till could have been subjectively classified as Catfish Creek Till. However, the field relations in a section showed clearly that it was the basal portion of Port Stanley till (Mörner and Dreimanis, 1973).

The enrichment in local substratum material is common in many basal portions of subglacial till. Thus for stratigraphic correlations the composition of basal 0.5 to 1.5 m of subglacial till should not be used as it consists of mixed material: reworked substratum plus the drift of the stratigraphic unit to be correlated. However, the glaciodynamic structures and fabric in the basal portion of subglacial till are usually diagnostic of the ice flow direction that deposited the entire stratigraphic unit, in this case the northwestward rising shear planes in the Port Stanley till (Mörner and Dreimanis, 1973).

The very top portion of the Port Stanley Till in the area between London and Lake Erie which has been interpreted as ablation till (Dreimanis, 1976, Fig. 8) has a granulometric composition which partly overlaps with the typical subglacial Port Stanley Till, partly with the next older Catfish Creek Till. Again, the field relationship - the supraglacial ablation till constitutes the uppermost 0.3 to 1.0 m of the Port Stanley Till - aids in avoiding an erroneous subjective correlation with the Catfish Creek Till.

The last example brings us to the necessity of understanding the origin or genesis of till and the need of recognition of the criteria for various possible genetic types of till.

Goldthwait (1971, p. 4), in the introduction to the first book published solely on till, pointed out that "till has more variations than any other sediment with a single name". The number of the varieties of till has been increasing with every year, particularly during the last decade, and it is hard for the glacial stratigraphers to catch up with the development of the genetic classifications of tills, even though they are of much greater importance to the glacial stratigraphy than it has been realized in the past. Actually the distinction of the "upper" from the "lower" till has been bothering the glacial geologists of New England for more than 100 years: (1) are they merely two genetic varieties of a single lithostratigraphic till unit, the "upper" being the supraglacial ablation till and the "lower" the basal or subglacial till, or (2) are they two subglacial tills of two different time-stratigraphic units? For a discussion of this stratigraphically very important problem, as it leads to two quite different stratigraphic models, see Goldthwait (1971, p. 18-19), Drake (1971, p. 73-89), Pessl (1971, p. 92-105).

Till studies of the last 15 years indicate that there are more than just two genetic varieties of till. Lack of their proper identification may result in erroneous schemes of glacial stratigraphy, or erroneous correlations, e.g., correlating the supraglacial ablation till of one area with the subglacial till of a different age of another area, just by their textural, lithologic or other similarities, as it could have happened also with the three varieties of the Port Stanley Till mentioned above.

If we consider the major events in glacial stratigraphy - glacial advances and retreats, we shall realize also that some glacial advances have not left any tills nor other glaciogenic deposits in some areas: these deposits were eroded or they were never deposited. Still, these glacial advances may have left evidence in the form of glaciotectonic deformations or re-orientation of fabric in the underlying deposits. (Though this has been recognized sporadically in the past, glaciotectonic deformations helped me to decipher a sequence of four Late Vistulian glacial advances in a section I studied as a student in 1934: Dreimanis, 1935).

Berthelsen (1973, 1979) has developed a new type of stratigraphic unit - the kineto-stratigraphic unit, based mainly upon structural and fabric analyses of glaciogenic deposits in southeastern Denmark where spectacular glaciotectonic deformations can be seen along the seashore cliffs, for instance on Mφn Island. By applying kineto-stratigraphic interpretations, Berthelsen (1979) has concluded that four glacial advances invaded Denmark during the Late Weichselian: two from south-east, one from northwest, and one from north-east. These conclusions are in agreement with lithologic investigations by various Danish authors. In contrast Marcussen (1977) concludes, by using morphologic and sedimentologic observations, that the Late Weichselian landforms of Denmark have resulted from a single deglaciation of a cold ice sheet - two completely different interpretations for the same region: Berthelsen's four glacial advances of dynamically active ice lobes versus Marcussen's passive downwasting of a single ice sheet, after one advance! Choosing one or another interpretation is crucial for large engineering projects, hydrogeology, and in search for gravel deposits.

In order to avoid too much subjective interpretation of glacial stratigraphy, we have to understand the glaciogenic processes and to recognize the criteria of various genetic types of glaciogenic deposits much better than we do now. The INQUA Commission on genesis and lithology of Quaternary deposits has been working on genetic classification of till and the criteria for recognition of its varieties for at least 15 years, with some 100 members from 24 countries participating in this project, and hopefully we will come to some agreement during the next two years. Still, there will be individual variance in interpretations, and, while testing the criteria, different workers may come to different conclusions as to their significance.

Besides the differences in opinions about the origin of various glaciogenic deposits, deformations and erosional features, there may be many other reasons for the differences in interpretations of data, while developing glacial stratigraphy of a region and when correlating one region with another. An entire symposium may be devoted to these problems, methodology, pitfalls, case histories, with differences in opinions and plenty of time for discussions. Differences in interpretation of the same data may create arguments which disturb those scientists who like to work quietly or who believe strongly that they are right. However, from time to time we have to re-evaluate the accepted and entrenched interpretations, including our own models. It would not be good at all if everybody agreed on one interpretation, without much thinking, without expressing any doubts, any criticism. Then we would never find out if there was any error in a generally accepted interpretation.

It may appear strange that so much attention has been spent in this paper on theoretical matters in a symposium volume on applied Quaternary geology. However, if the differences in reasoning by glacial geologist may cause considerable variance in their theoretical conclusions, this variance will influence also the applied aspects to be covered by the ensuing authors. Also, in applied geology, the influence of man upon the gathering of data is the same as in theoretical studies, sometimes even greater, since many of the procedures are used in routine work without questioning them.

As a transition to the applied topics that follow, I would like to emphasize that all of Canada has been affected by glaciers or glacial climate during the Quaternary at one time or another. If the stratigraphy of glaciogenic deposits is properly deciphered while mapping the surficial geology, the extraction of Quaternary economic deposits, such as gravel, sand, clay, etc., and the planning of major construction projects may be done rationally. The knowledge of glacial stratigraphy is useful also in hydrogeology and in planning waste disposal or evaluating health hazards. In the search for bedrock ore depostis by indicator tracing, proper understanding of Quaternary glacial stratigraphy is essential in areas with more than one layer of glaciogenic deposits over bedrock.

Returning to the main part of this paper, I would like to repeat that both the gathering of data and their interpretation in Quaternary geology has been, and will be, strongly influenced by the thinking and mental attitudes of the Quaternary scientists. While we strive for objectivity in our conclusions, we have to admit also our subjectivity. If we recognize it, we will gradually become more objective. This applies not only to glacial stratigraphy, but also to the application of theoretical knowledge of glacial geology to the solution of practical problems.

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Glacial Dispersal - Principles and Practical Applications

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Abstract

Glacial dispersal, the process of glacial erosion, transportation and deposition, has distorted the bedrock signatures on overlying surficial sediments and soils in most of Canada. Buffering components, such as carbonate minerals, which mitigate the effects of acid rain have been dispersed across Precambrian terrane in eastern Ontario in patterns that reflect several principles of glacial dispersal. Dispersal trains of boulders, minerals, and trace elements may enhance the size of mineral exploration targets by several times. By using appropriate analytical strategies and knowledge of dispersal, the source mineralizations can be found, as illustrated by an example of dispersal of nickel from the District of Keewatin. One other way dispersal principles have been applied has been to calculate the volume of material dispersed from a particular source outcrop. Dividing that volume by outcrop area yields average depth of glacial erosion, an important parameter to consider in selecting minimum depths for burial of long-lived radioactive waste.

Introduction

In 95 per cent of Canada and throughout the north-central and northeastern United States, the chemical and physical signature of bedrock on soils and surficial sediments has been distorted by glacial dispersal. Glacial dispersal is a term that describes the processes through which debris is entrained in ice at a source area, transported, and deposited some distance away.

The unique and most widespread surficial sediment produced by glaciation is till, generally defined as a heterogeneous mixture of various types and sizes of mineral and rock fragments. Till at any particular site, no matter what the details of its mode of deposition, is composed largely of a mixture of crushed and abraded fragments from bedrock outcrops located up glacier. The proportion of each bedrock component is dependent on a complex interrelationship of factors such as distance from source, topography of source and dispersal area, physical nature of minerals or rock, and diagenetic changes that have taken place at the site of deposition. In short, till is displaced bedrock with or without components derived from unconsolidated, previously deposited or formed glacial or non-glacial sediments and soils. Till can be described as the first derivative of bedrock - crushed, transported bedrock that has undergone little or no sorting by water or wind and has suffered little or no chemical alteration other than groundwater and soil-forming processes that act on it after deposition.

Other sediments of a glaciated landscape, pro- or subglacial marine, lacustrine, aeolian, fluvial sediments, and postglacial sediments formed in similar environments of deposition but without the presence of nearby ice, are closely related to till and can therefore be regarded as higher order derivatives of bedrock. The clastic constituents of these sediments have undergone additional transport after being liberated from the ice. Proglacial sediments are second order derivatives of bedrock, till that has been further transported and split into various size components by water or wind-sorting. Postglacial or modern sediments are third or higher order derivatives of bedrock, consisting of till or proglacial sediments that have been eroded, reworked, further dispersed, and subjected to chemical or biogenic alterations due to their exposure to surface weathering processes during thousands of years of postglacial time.

Because all galcial and postglacial sediments in the glaciated landscape bear some ancestral relationship to till (i.e, the load the glaciers were carrying), defining the controls on glacial dispersal of the material that comprises till is essential to an understanding of the composition and properties of the unconsolidated sediment that forms our present-day landscape.

Glacial Dispersal

In its simplest form, glacial dispersal may be described as the erosion of a type or

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