

DIAMICTITES: ICE-AGES OR GRAVITY FLOWS?

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ABSTRACT

A literature study directed mainly on sedimentological/erosional structures, combined with limited field work, give good grounds for rejecting the normal ice-age interpretation for relics from Pre-Pleistocene "ice-ages", in favour of an interpretation as (mainly) different kinds of gravity flows. The long ages held by uniformitarian geologists for the formation of these structures are therefore no longer necessary, and the data instead point to an interpretation favouring a short timescale.

Deposits from especially dense gravity flows can look very similar to till. Also, many structures formed in gravity flows can look very similar to structures formed or influenced by glaciers. Some examples are till fabric, the occurrence of erratics, polished and striated stones and bedrock, the occurrence of dropstones and periglacial phenomena.

The following regularly occurring structures are features of Pre-Pleistocene "tillites" which are never or rarely formed by glaciers, but are usually formed by gravity flows: A) the small extension and great depth of the "tillites", B) the small size of erratics, C) stones pressed down in the underlying material, D-E) sorting of stones and erratics, F) channels eroded by water below the "tillites", G) layers of dolomite and coal in close connection with the "tillites", H) boulder pavements, I) no weathered till or soil profiles between different "tillite layers", and J) the geographical occurrence and extension of late Precambrian "tillites".

All the above speaks against the interpretation of diamictites as glacial deposits, but favours gravity flows.

INTRODUCTION

Ever since the recognition of Pleistocene ice-ages, diamictites found in the geologic column have been interpreted as deposits from ancient ice-ages. Lately, however, it has been recognized that many supposed "ice-age remains" have been deposited by different kinds of gravity flows, for example turbidity currents and debris flows. Many geological structures show that one ought to question (or at least be less conclusive about) all interpretations which so far have been made in favour of Pre-Pleistocene ice-ages.

L. J. G. Schermerhorn is one of the foremost proponents for the gravity flow interpretation, shown in his classic work on late Precambrian diamictites (Schermerhorn 1974a, 1976a, 1976b, 1977). Many other researchers have shown the similarities between ice-age deposits and structures formed by different kinds of mass flows, especially more dense gravity flows (Crowell 1964, Mountjoy et al 1972, Derbyshire 1979).

SIMILARITIES BETWEEN GRAVITY FLOWS AND ICE-AGE DEPOSITS

The following is a short review of structures which are normally formed in connection with ice-ages, but which are also formed in connection with different kinds of gravity flows and other processes.

1) TILLITE STRUCTURE: Deposits from different kinds of gravity flows, and especially more dense gravity flows, often have a similar structure to till, with unsorted sharp-edged rock-material in a clayey matrix. Gravity flow deposits are sometimes indistinguishable from true tills (Lowe 1982, Visser 1983). A recent volcanic gravity flow has therefore been

misinterpreted as till (Schermerhorn 1974a).

In both tills and different kinds of gravity flows there is often a fabric. The long axes of pebbles in Pleistocene tills often show a 10-20 degree dip in the direction of the ice movement. In gravity flows the fabric can be similar to till fabric, but it can also display differences changing with the height in the sedimentary sequence, for example as in the "tillites" in Antarctica (Lindsay 1970). Therefore it is sometimes possible to decide whether a formation has been deposited as a gravity flow or not, but it can be more difficult to decide if the diamictite is a till (Lindsay 1968).

"Tillites" are often disturbed by gravity flows, or mainly deposited by "glacial marine sedimentation", and therefore it is difficult to distinguish them from normal gravity flows (Aalto 1971, Martin 1981, von Brunn & Stratten 1981, Gravenor et al 1984).

2) ERRATICS AND EXOTIC PEBBLES: Erratics can easily be transported by gravity flows. The largest known transported blocks are hundreds of square kilometers large and many blocks are more than one kilometer long. They have been moved many tens or hundreds of kilometers (Maxwell 1959, Wilson 1969, Mountjoy et al 1972, Schermerhorn 1975). Gravity flows contain more far-transported clasts than is contained in lodgement till (Visser 1983).

The largest known erratics in "ancient tills" are 40 and 320 meters long, and they can be shown to have been transported by gravity flows (Schermerhorn 1975).

Turbidity currents and other mass flows can transport debris many hundreds (Wilson 1969, Komar 1970) or thousands (Kuenen 1964) of kilometers, especially in a large catastrophe or if many gravity flows follow after each other (during a longer or shorter period of time). Far-transported clasts could become incorporated in sediments (Embley 1982), which after deposition once again became instable and took part in movement in a shorter and more dense gravity flow, which after deposition looked similar to a till. This would seem quite natural, because it always takes some time until a newly and quickly deposited sediment settles to stability. A similar interpretation was made for some exotic pebbles transported approximately 400 kilometers, which earlier were thought to have been ice-rafted (Jansa & Carozzi 1970).

The slope necessary for a gravity flow is less than 0,1 degrees, and sometimes less than 1 meter in height on 1000 meters in length (Kuenen 1964, Komar 1970, Embley 1982). If one compares with ancient "tillites", the slope in, for example, the Ordovician "tillites" in the Sahara is 1 degree (Fairbridge 1971), and in different places with "tillites" in South America the slope is 0.25-1 degree (Caputo & Crowell 1985).

3) POLISHED, FACETED AND STRIATED STONES: Polished, faceted and striated stones can form in different kinds of gravity flows, under water or on land, in overthrusts and even as a result of smaller movements in the bedrock, like uplifts or folding (Crowell 1957, Flint 1961, Schermerhorn & Stanton 1963, Winterer 1964, Leeder 1982, Hambrey 1983). Stones polished, faceted or striated in bedrock movements can later be transported with different kinds of gravity flows. Stones formed under these circumstances are often impossible to distinguish from stones polished, faceted and striated by the action of ice-movement.

In a recent gravity flow, one block of quartzite became striated (Schermerhorn 1974a). In a recent gravity flow in Australia almost half of the stones became striated (Winterer & von der Borsch 1968). The Australian gravity flow contained mostly sand. Only about 1 % of the grains were larger than sand-size, so one ought not to find many striated stones. In tills and "tillites", often not more than 10-20 % of the stones are striated and faceted (Schermerhorn 1974a).

The internal structure of some stones can give them an appearance of being striated, and mistakes have been made in the classification of "tillites" (Vellutini & Vicat 1983).

4) STRIATED, GROOVED AND POLISHED BEDROCK: Striated, grooved and polished bedrock can form as a result of different kinds of gravity flows - volcanic flows, avalanches, rock flows, earth slides and all kinds of underwater gravity flows (Wilson 1969, Harrington 1971, Daily et al 1973). The bedrock also can be grooved and polished by icebergs and overthrusts (Sandberg 1928, Flint 1961, Schermerhorn & Stanton 1963, Frakes et al 1969, Leeder 1982). Striations and grooves in underlying material have been formed in experimentally performed gravity flows (Evenson 1977). In at least some "tillites" there is a thin unit of sorted sediment in between the grooved pavement and the "tillite" - and there are grooved pavements only if there is a sorted sediment in between (Lindsay 1970).

If the gravity flow was denser, it would behave more plastically and similarly to glacier ice, and therefore striations, grooves and polishing would look similar to erosion made by glacier ice, at least on a local scale.

Many striations and grooves in sediments from "ancient ice-ages" have been formed in unconsolidated material (Lindsay 1970, Savage 1972).

On the island of Svalbard, in the Arctic Sea, 2-3 meter long striations and "ice-polished bedrock" (sandstone and shale) have been formed under the action of sea-ice and waves (Hoppe 1981). First these cliffs were thought to have been formed by action of glacier ice (Hoppe et al 1969).

5) DROPSTONES: Stones, gravel and sand can be transported together with floating roots from trees or floating algae. Especially if there would have been a large catastrophe much material would have been transported with up-rooted trees. In coal, boulders with weights up to 70 kg have been found. These boulders have been transported up to 100 kilometers or more, and one good explanation as to how they were transported is by floating entwined in roots (Price 1932).

Stones with diameters of 15 centimeters have been transported more than 400 kilometers, probably with the help of water and gravity flows. After deposition they have become incorporated in local gravity flows. Earlier these stones were thought to have been transported with icebergs (Jansa & Carozzi 1970).

Stones that are transported by gravity flows can be deposited high up in the sedimentary sequence, and therefore look like stones transported by icebergs - i. e. "left-overs" (Crowell 1964, Schermerhorn 1974a). One explanation to why "ice-transported" clasts are found in gravity flow deposits, is that they are just such "left-overs"; an explanation which can be proven by fabric analyses (Lindsay et al 1970). Clasts are often transported with gravity flows and found embedded in a clay matrix (Bouma 1964, Embley 1982).

Sand and chert can sometimes float directly on the surface of the sea (Hume 1963).

6) VARVED SEDIMENTS: "Varved sediments" (laminated beds) believed to have been deposited on a yearly basis, for example on the edge of a glacier, can form immediately by gravity flows (Kuenen 1964). Misinterpretations have been made, for example in the Gowganda formation (Miall 1983).

7) MARINE (AND LAKE) TILLITES: Till-material which is assumed to have been deposited in the sea, just outside a glacier, is often very disturbed by the action of water, streams, and gravity flows of different kinds. Therefore it may be very difficult, or impossible, to distinguish this material from deposits from gravity flows. Moreover, more and more of all known "tillites" are being reinterpreted as glaciomarine sediments, and the only evidence given for glaciation is dropstones (Frakes et al 1969, Binda & Eden 1972, McCann & Kennedy 1974).

8) PERIGLACIAL STRUCTURES: "Periglacial" structures can form by other processes than freeze and thaw, for example wetting and drying (Yehle 1954, Flint 1961, Wright & Moseley 1975, Black 1976, Walters 1978). "Ice wedges" from the Ordovician "glacial" of the Sahara were, in fact, sandstone dikes radiating from sand volcanoes (Fairbridge 1970).

DIFFERENCES BETWEEN GRAVITY FLOWS AND ICE-AGE DEPOSITS

Structures formed by the action of glaciers can, as shown above, also form from a lot of other different processes, mainly gravity flows. Although many processes have only been studied either locally or very seldom, we can not reject these explanations only on the basis of uniformitarian reasoning. What do we know of the past? Many kinds of catastrophes may have occurred, and the processes we have seen only on a local scale might on a number of occasions have been widespread, covering even continents (Ager 1981).

In addition to the argument that "ice-age structures" can be formed under different climates and with different processes, there are a lot of structures in deposits from "ancient ice-ages" which have very rarely or never been formed by Pleistocene ice-ages. Therefore these structures argue against the ice-age interpretation, but at the same time can give a good argument in favour of the gravity flow interpretation. Some of the structures which distinguish "ancient ice-ages" from the Pleistocene ice-ages are as follows:

A) The geographical extension of "tills" from "ancient ice-ages" is often comparatively small. The "tillites" are often dispersed as separate hills (Lindsay 1966, Finkl & Fairbridge 1979, Fairbridge & Finkl 1980). The "tillites" are also often many hundreds of meters to many kilometers thick (Volkheimer 1969, Schermerhorn 1974a), as are deposits from turbidity currents (Kuenen 1964).

In contrast to this, the last ice-age left extensive layers of tills, tens of thousands to

hundreds of thousands of kilometers in extent. Separate till layers, with characteristic structure and mineral content, can be traced over thousands of kilometers and are often less than five meters thick. The thickest known till layer from the Pleistocene is only 400 meters thick. Most layers are less than 100 meters thick, and usually not more than 10 meters thick (in the county of Västerbotten, northern Sweden, the mean thickness of the till-layer is 8.2 meters; Rudberg 1954).

B) In all deposits from "ancient ice-ages" the erratics are mostly not larger than a few meters in diameter, and even erratics as large as one meter in diameter are rare (Kulling 1951, Flint 1961, Schwarzbach 1961). Very rarely have blocks larger than five meters in diameter been found.

The Pleistocene glaciers transported scores of large stones and boulders. Great areas are covered with thousands upon thousands of boulders with diameters larger than one meter. Erratics with diameters larger than 5-10 meters are not rare, and some erratics are hundreds of meter in diameter (Embleton & King 1968). The largest known block, which might have been transported with glacier ice measures 4000 x 2000 x 120 meters (Sugden & John 1982).

The above mentioned facts can be interpreted in favour of the gravity flow theory, especially gravity flows deposited under water. In water, the velocity and strength of the flow must be very large, before large stones can be transported (Komar 1970). The largest known transported boulders which have been found in the geological column, show many features that indicate catastrophic transportation by gravity flows in water. But, when gravity flows are less strong, when there is less water involved, and when the gravity flows are much denser, then the deposits ought to look more like tills. Here we can maybe find the explanation as to why deposits from "ancient ice-ages" do not contain many large erratics (Lowe 1982). They may have been formed by gravity flows, and, if this is correct, it seems that a size of 1-3 meters in diameter is most often the maximum size of the stones which can be transported by dense gravity flows (see Komar 1970, for further information on transportation of large stones by turbidity currents). When the stones are larger, stronger currents are necessary, and the sedimentary structures (for example, fluvial structures and different kinds of structures made by slides) more clearly indicate that there has been a gravity flow, and the difference between the deposit and a till is clear cut.

C) Stones in "tillites" from "ancient ice-ages" have been found pressed down into the underlying "bedrock" (Lindsay 1970, Hambrey 1983). This can easily be explained by a gravity flow over an unconsolidated sediment (but it does not rule out a glacial origin).

D) The largest boulders in "tillites" from "ancient ice-ages" are often found in the thickest sedimentary layer (Schermerhorn 1974a). This indicates transport by water and gravity flows (Dott 1963, Kuenen 1964, Derbyshire 1979, Lowe 1982). Transportation with ice gives a more random deposition.

E) "Tillites" which have been deposited in the sea or on land sometimes display graded bedding (Kulling 1951, Bowen 1969) - a clear indication of transportation by gravity flows approaching a turbidity flow.

F) The sedimentary layers below "ancient tillites" sometimes have erosional channels in their upper sections, formed by flowing water. These structures can indicate that the fastest flowing parts of a gravity flow first eroded the underlying sediments. Shortly afterwards, the more dense parts of the gravity flow arrived, and covered the erosional channels with sediments.

G) Layers of dolomite and coal are often found close to or in between deposits from "ancient ice-ages" (Coleman 1908, Engeln & Caster 1952, "Geophys. Disc." 1960, Plumstead 1964, Lindsay 1970, McKelvey et al 1972, Finkl & Fairbridge 1979, Gravenor et al 1984). Coal indicates a warm to subtropical climate and dolomite only forms in areas of high evaporation (Zenger 1980, Schermerhorn 1983). There is no indication that the *Glossopteris* flora is a cold climate flora, except the argument that the Dwyka formation and other Carboniferous/Permian deposits are formed from an ancient ice-age. It would seem as reasonable to argue that because there are a lot of warm climate fossils connected with the "tillites", the deposits cannot be tillites, and are therefore more probably gravity flow deposits. There are no similarities between ancient coal-forming processes and recent peat-forming processes. Coal seems to have been formed under catastrophic circumstances, from mats of floating trees (Austin 1979, Scheven 1986).

H) Many boulder pavements have been found in deposits from Pre-Pleistocene "tillites", in contrast to the deposits from the Pleistocene ice-ages (Derbyshire 1979, Martin 1981, von Brunn & Stratton 1981). They are often at the base of the "tillites" (Ghosh & Mitra 1969), and can sometimes be traced back to channel deposits (Lindsay 1970), similar to channel deposits from turbidity currents (Komar 1970). An origin by mudflow seems at least as possible as an

origin beneath a glacier (Lowe 1982).

I) Weathered tills and soil profiles are not present in old "tillites", in contrast to deposits from Pleistocene ice-ages.

J) The late Precambrian "tillites" are spread over the whole world. Even if one takes continental drift and the many millions of years into account, it is difficult to avoid having ice-ages over large areas of the earth nearly simultaneously. In contrast, the dolomite layers argue for a warm climate. Deposits from most of the late Precambrian "ice-ages" are found in geosynclines, and very rarely are there any deposits on more stable bedrock. This can be taken as an indication that the deposits have been transported by gravity flows, from higher to lower areas. Deposits from all later ice-ages have been accumulated on stable bedrock (Schermerhorn 1974a).

K) There are also some general problems with the interpretation of "tillites". For example, climatic models and polar wander-paths give (at the very least) some opposing results (Schermerhorn 1971, McCann & Kennedy 1974, Caputo & Crowell 1985, Deynoux 1985, Crowley et al 1987).

AREAS WITH DEPOSITS FROM PRESUMED ICE AGES, SOME EXAMPLES AND INTERPRETATIONS

After this review of structures it can be interesting to see what kind of structures we find in so-called tillites. With a few examples, from some of the best known places, we can argue for deposition by gravity flows, with at least as much facts on hand as the uniformitarian ice-age theorists.

Except for the structures mentioned below, there are present a lot of structures, in all places, which can be found both in tills and in gravity flow deposits. I will not delve more into the structures that have equivocal interpretations, in this short review.

Dwyka, South Africa:

The Dwyka in South Africa is often put forth as one of the most well-documented ancient ice-ages on our planet.

The deposits contain in certain places sedimentary structures which have been demonstrated to be formed by gravity flows, containing boulders with a size of up to 30 meters in diameter (Martin 1981), traces of invertebrates and fishes, erosional channels and graded bedding (Gravenor et al 1984). Many boulder pavements have been found (Derbyshire 1979, Martin 1981, von Brunn & Stratten 1981). Many of the striations and grooves in the underlying "bedrock" are made in unconsolidated material (Savage 1972, Gravenor et al 1984). The "till" fabric seldom seems to show any preferred orientation (Bond 1981a). The thickness of the "tillite" varies between some tens of meters in the north to more than 1000 meters in the south (Flint 1975, John 1979). The largest erratics are about 5 meters in diameter (Du Toit 1926, von Brunn & Stratten 1981). Fossils of plants have been found between the "tillite" and the underlying "ice-polished bedrock" (Du Toit 1926, von Brunn & Stratten 1981). Coalified plant fragments and other fossils (Visser 1989) occur in some "tillite" layers, and layers of coal are situated on and between the "tillites" (Du Toit 1926, Sandberg 1928, Adie 1975, John 1979, Bond 1981a, 1981b, Gravenor et al 1984, Visser 1989). The plants are not typically cold-climate plants. They are more probably subtropical or tropical (Dott & Batten 1976), and they could probably not have grown close to a large continental glacier. Attempts to explain the history of the Dwyka "glaciation" seem to give opposing results from different areas (Truswell 1970, John 1979, Visser 1989).

There are researchers who have interpreted the Dwyka deposits as a volcanic flow (Sandberg 1928) or a mudflow ("Geophys. Disc." 1960). Most of the the Dwyka deposits have recently been interpreted as "glacial marine", mid-latitude (50-65 degrees) sedimentation, possibly in brackish water (Visser 1989), thus making it very difficult to distinguish the deposits from gravity flows.

The Sahara, Ordovician:

The Ordovician "glacial" of Sahara has only relatively recently been investigated more carefully (Biju-Duval et al 1981). Together with the Dwyka deposits, the Sahara deposits are considered to be one of the most well-documented ancient ice-ages.

At the bottom of the sedimentary sequence in the Sahara, on top of the Precambrian (layer I), there is a conglomerate followed by a layer of cross-bedded sandstone, 2 million square kilometers in area (layer II). The current direction is towards the north. After this follows

a layer containing many twisted sedimentary structures formed by gravity flows and folds (layer III). In this layer "valleys" have been eroded, which are up to 300 meters deep. The valleys, together with the next layer in the sedimentary sequence (layer IV), contain, for example "till", "permafrost structures" and "eskers", and are regarded to have been formed by a large glacier.

Striations, grooves and other erosional structures have been formed on top of layer III when the sediment was still unconsolidated. Also, the striations are situated in many different layers, on top of each other, and there is an abundance of striations - in spite of the fact that there are very few clasts in the "tillite" - a highly unexplainable phenomenon for an "ice-age" deposit (Schermerhorn 1970, 1971). Also, at right angles to the striations there are sometimes minor ripples (Fairbridge 1971). These facts indicate a gravity flow origin.

The flow direction of the "ice" is the same as for the underlying crossbedded sandstone, which can be taken as an argument that the entire sequence may have been formed in one single great catastrophe, as the current direction has not changed. (Both the "tillite" and the underlying sediments are sandstones; Fairbridge 1970).

At the same time as all the sediments were unlithified, one has to believe that the hardest clasts of quartzite became heavily faceted and striated (Schermerhorn 1971). The findings would seem to indicate that the stones became striated and faceted earlier and far away, in any kind of abrasional process, and were transported to the present site with already intact structures.

At the top of layer IV there are many sedimentary structures which call for a catastrophic explanation, according to the scientists who have made the most complete research. For example, ripple-marks which are 25 centimeters high with a wave-length of 3 meter, and also water escape structures.

One published drawing which shows the "tillite" (layer IV), doesn't look very till-like, with long "stones" (?) that point in different directions (Allen 1975). A fabric analysis of a "till" similar to the drawing would probably show that it was a gravity flow. The largest diameter of an "erratic boulder" found in Sahara is about 2 meters.

Of all remains from "ancient ice-ages", it is (almost) only in the Sahara that researchers have found "eskers". However, these eskers can be explained as, for example, having been formed due to filling of water-eroded channels with more resistant material. When erosion and weathering processes started to break down the sedimentary sequences, the former channels, which had been filled with more resistant material, did not weather down as fast as the surrounding sediments (Biju-Duval et al 1981). Therefore they now stand up as esker-like formations. I have not seen any reports of glacial tectonic disturbances in these "eskers", similar to the disturbances shown in Pleistocene eskers, when the ice moved over them. Neither have I seen any reports of large erratics on top of or close to the top of the "eskers", which is very common on the Pleistocene eskers.

Fossils of trilobites and orthoceratites have also been found in parts of the "tillite". Complete marine fossils have never been found in Pleistocene till, for example fossils from shrimps and cuttlefish of different kinds (except in pebbles from already deposited and lithified rocks, which have been reworked). The "tillite" is also laminated in many places (Bryan 1983), as if it had been deposited by water. This is a good argument against the tillite interpretation and for the "gravity flow" interpretation.

To explain how this "ice-age" ended, researchers have suggested some kind of catastrophe, maybe connected with a rise of the sea-level by about 500 meters (Fairbridge 1981). This seems easier to explain by catastrophic flooding rather than by uniformitarian theories.

Researchers are urged to make more investigations in this area, to see if there really are any definitive arguments for an ice-age in the Sahara. Schermerhorn (1970, 1971) has earlier suggested an origin by mass-flow, and I have not seen that his arguments have been either falsified or explained in any way that is possible with a glacial origin.

Gowganda, Canada, Precambrian:

The "ice-age" which is thought to be best documented of all Precambrian "ice-ages" resulted in the Gowganda formation, situated north of the great lakes in Canada. The largest erratic found in these layers is 3.4 meters long (Lindsey 1969). A conglomerate below the "tillite" has superficial similarities to the "tillite", and it is not always made up of lithified stones (Frarey 1977) (it is very similar to a conglomerate below the "tillite" in the Varanger fjord, northern Norway; Bjorlykke 1967). There are lee side structures, connected to many stones which are thought to have been ice-rafted, but these structures show rather that the stones

have been deposited in streaming water or by gravity flows. The fabric is different in different layers in the "tillite", which is a good argument for deposition by gravity flows (Lindsay 1968, Lindsey 1969).

It seems that at least some beds have an upper limit of clast size, which argues for a gravity flow (Frarey 1977).

Some researchers have at different times argued that the complete Gowganda formation (Crowell 1964, Miall 1983), or at least parts of it (Frarey 1977, Young 1981), has been deposited by gravity flows, or at least that the "tillite" has been resorted (Coleman 1908).

CONCLUSION

In conclusion, many formations which are thought to form only under a cold climate and by the action of ice, can also be shown to form under a lot of other different environments and due to different processes. Many structures which are not found in the Pleistocene glacial record are found in deposits from the Pre-Pleistocene "glacial" record, but these structures are easier explained with different kinds of gravity flows than with glacial/periglacial erosion and sedimentation. All "ancient ice-ages" might be mainly different kinds of gravity flows, instead of tillites or glaciofluvial material.

At least on one occasion a deposit has been interpreted as an ice-age, only until it was found that the deposit could not be in accordance with the geologic time scale for other areas (Schermerhorn 1974a, p. 809).

More and more researchers become aware of the gravity flow explanation, and that gravity flows form a large number of sedimentary deposits (Mountjoy et al 1972). Furthermore, many "ice-ages" have already been reinterpreted completely or in part as gravity flows or other phenomena (Crowell 1957, Newell 1957, Schermerhorn & Stanton 1963, Schwarzbach 1961, Winterer 1964, Lindsay 1966, Condie 1967 and others mentioned in this paper).

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DISCUSSION

Mr. Molén has done a good job showing how gravity flows can mimic most glacial features, and how many features of diamictites are in more accord with gravity flows. I am confused on one point: If gravity flows and the Pleistocene ice sheets transported large erratics, Mr. Molén should clarify how erratics can be used to distinguish between the two mechanisms, especially since diamictites contain small erratics. Dropstone "varvites" are used to identify ancient ice ages, for instance the Gowanda tillite. How would the author explain this feature as a product of gravity flow? Many investigators admit that gravity flows are common in diamictite, but they counter by saying this is expected in ancient glaciomarine sediments (which most diamictites are claimed), and even in continental tillite as flow tills. What would be the author's response to these investigators? Some investigators realize that gravity flows can duplicate most glacial features. But then they say that when one feature occurs in abundance or when several different features are found in the same diamictite, it must be glaciogenic. How would Mr. Molén answer them?

Michael J. Oard, M.S.
Great Falls, Montana

Tillites of Precambrian and of Palaeozoic provenance can look remarkably similar. It is understandable that Precambrian diamictites have been declared to be of glacial origin. On the basis of a six days' creation - the first three days equalling the Precambrian - ice ages during this period are to be rejected. Mr. Molén's conclusion seems to be correct that gravity flows within synclines can be held responsible for the formation of these localized diamictites. --- The Permo-Carboniferous Dwyka of the Southern Hemisphere is of a different character. In the first place, it is extremely widespread. Its movements seem to follow a pattern consistent with an assumed center of glaciation. Polished and striated pavements bear a striking similarity to Pleistocene occurrences. Pebbles floating in sediment do indeed look like dropstones. But here the similarities end. Unlike a Pleistocene till the matrix of the Dwyka tillite is quite dense and resembles a volcanic rock in which the clastics are suspended. In South Africa the Dwyka may overlie coal no. 1 of the Ecca series. The matrix of dropstones is also indistinguishable from Ecca sediments. Therefore Glacial Dwyka and plant-bearing Ecca beds stand obviously in a close temporal relationship. Since the coals of Ecca are clearly pre-Flood vegetation gradually borne to rest after the Flood year it is conceivable that true glaciogenic processes on the Southern Hemisphere took place already immediately after the Flood. Such Permian glaciation may have required not more than a few decades and yet have left traces of a true ice age before being superseded by the Karoo succession. The reality of this pre-Pleistocene ice age cannot be ruled out.

Joachim Scheven, Ph.D.
Hagen, Germany

Mr. Molén's thorough literature review of published articles on diamictites nicely illustrates the manner in which mainstream scientists continually debate the merits of alternative hypotheses, subjecting each interpretation and the evidence offered in its support to questioning and peer review. The question as to whether any given diamictite is of glacial origin or of non-glacial subaerial or subaqueous origin is not, however, in any way relevant to the question of its geologic age. Evidence of rapid formation of a limited sedimentary sequence (or of a rock body of any origin) is not to be construed as necessarily being evidence of recent occurrence. Geologic ages of diamictites and all other sedimentary accumulations are established on entirely independent criteria, such as radiometric age determination. Mr. Molén's reference to evidence of catastrophic vis-a-vis non-catastrophic ("uniformitarian") processes and events is no longer relevant to the recent-creation/great age controversy because modern mainstream geology fully accommodates all possible natural catastrophic events of both extraterrestrial and terrestrial sources throughout the entire geologic record.

Arthur N. Strahler, Ph.D.
Santa Barbara, California

This paper provides a welcome review of an important class of geological evidences, arguing that gravity flows and related sedimentary processes can have some features similar to Pleistocene tillites, and that they also possess features which distinguish them from tillites. Several of the evidences discussed show that useful scientific work can be undertaken to test the conflicting hypotheses. Examples include the sorting effects of gravity flows, characteristics boulder sizes, the thicknesses of deposits, and the presence of internal sedimentary structures. This paper provides a good reference point for studies of this kind. There is always a potential danger of looking at evidences in isolation, whereas depositional interpretations generally require the investigator to assess the significance of several associated observations. The Saharan Ordovician deposits illustrate the point well: the reported mix of glacial and periglacial phenomena seems compelling, and although Mr. Molén has raised valid questions, the burden of proof still rests on those who challenge the conventional interpretation.

David J. Tyler, M.S.
Cheshire, England

CLOSURE

I want to thank all reviewers for their comments to my paper, and I am glad that my paper has started up some discussions.

Mr. Michael J. Oard's comments:

Erratics: A glacier has high viscosity and can therefore lift up and transport very large erratics long distances with slow speed. A gravity flow, whether it is dense or not, can also transport large erratics, but it seems that there is an upper limit for the transporting power for dense gravity flows. If a large boulder is to be transported, strong currents are needed, and deposits produced by strong currents will show unmistakable evidence of this mechanism of transportation. Therefore, dense gravity flows, which result in the deposits that are the ones that look most like lodgement till, cannot transport boulders above a certain (usually not more than one meter in diameter); because if the current is too strong the flow will behave more like a turbidity flow, and the flow will not "freeze" as it stops, and the deposit will be more or less sorted and may have slide structures that are not present in lodgement till. It seems that the only gravity flows that can lift and transport very large boulders, with diameters larger than c. 3 meters, are the fastest/strongest ones, and therefore deposits made from such flows clearly reveal the mode of transport and are not labeled "tillites".

Dropstone "varvites": See my paper and combine points 3, 5 and 6. Many "varves" form almost simultaneously by any turbidity current; there is no reason to believe that they are yearly varves. Also, the "dropstones" usually are small, and in the Gowganda formation they are connected with lee side structures (see my paper).

Based on my own visit to parts of the Gowganda formation, August 1990, I will pass on the following observations: In the Gowganda formation "dropstones" usually break through the layers which encircle and cover them but not the ones below (the ones below are only compressed); thus giving evidence for erosion by currents on top of and at the side of the stones, and also quick deposition and compression of the sediments; but evidence is lacking for rapid fall down of stones from an iceberg. It seems improbable that all stones were frozen to small pieces of ice, so that they only slowly sunk to the bottom as the pieces of ice melted away. (But of course - the stones were not that big and maybe would not penetrate the layers at any rate. But, even in a gravity flow you would suspect that a few stones could penetrate the layers below.) One of the biggest stones observed (c. 5 cm in diameter) was lying in a thicker "varve" and the "varves" disappeared at both sides of the stone, which indicates that the stone and the "varves" were deposited simultaneously. That would only happen if the deposition was by a current (for example a turbidity flow) and the stone was a "left-over". Sometimes the "dropstones" form thin layers of sand and gravel between "varves", and this "dropped material" shows evidence of current levelling.

Glaciomarine sediments/flow tills: I know of no structure that can distinguish between glaciomarine sediments and different kinds of gravity flows; not when the "glaciomarine sediments" themselves are different kinds of gravity flows! (If there are glaciomarine sediments that do not contain gravity flows, then there are structures that can help to distinguish them from each other; see for example Schermerhorn & Stanton 1963, referred to in my paper.) At present, and maybe also for the future, I know of no other possibility than to look for other structures, for example lodgement "tillite". The same might be for many flow tills that actually are different kinds of gravity flows. It is necessary to find structures that are unique to glacial deposition if one is to prove that there has been an ice age.

Many features or one feature in abundance: You have to examine all features, as I have done in

this paper (see also Schermerhorn & Stanton 1963). If all of the features can be formed by gravity flows, but all except one can be made by glacial action, then I would favor deposition by gravity flow (except in those cases where the gravity flow feature is only a minor part of a larger glacial feature). The other way around is of course also possible, and then I would favor glacial action.

Dr. Joachim Scheven's comments:

As briefly mentioned in my paper: 1) The movement can not be easily explained by an assumed center of glaciation (also, this does not matter very much; both gravity flows and glaciers would tend to slide from higher to lower elevation, thus giving a "pattern"). 2) "Polished and striated pavements" have often formed in soft material in the Dwyka formation, in contrast with the Pleistocene glaciation. 3) The dropstones can be explained as "left-overs"; and in one photo shown by Visser (1983, fig. 10 A) a vertically oriented "dropstone" actually shows a lee side structure. 4) There are coal deposits/plants both below, between and above the "tillites" (actually the Ecca overlies the Dwyka, by definition: von Brunn & Stratten 1981, referred to in my paper).

In addition I would like to mention the following: The Dwyka is about as widespread as the Ordovician "tillite" deposits in North Africa; both of them are in contrast with Precambrian "tillites". In the Dwyka formation there is also sometimes a layer of laminated sediment between the "glaciated pavement" and the "tillite" (Visser 1988, Visser & Loock 1988, see also point no. 4 in my paper).

Dr. Arthur N. Strahler's comments:

I would like to express my thanks to Dr. Strahler for the positive response, especially since he has written the most thorough book against "creationism" that has ever been written ("Science and Earth History - The Creation/Evolution Controversy", Prometheus Books, Buffalo 1987, 552 pages). I believe that one can only work together, and learn from each other, when there is an atmosphere of mutual respect, in spite of having different philosophies. Then, also, the different philosophies and scientific interpretations can be weighed against each other, to see what will hold in the end.

Concerning the comments on radiometric dating etc, Dr. Strahler is correct. But, in my paper I did not write anything about absolute ages, only about how quick a special kind of lithology - diamictites - had formed (as I also stated in the abstract of my paper). His criticism of my paper on this point therefore is misplaced.

There is, however, one more point that is important. "Mainstream geology" has accommodated so many catastrophic events in the geologic column, that there is no longer millions of years left. More and more formations are believed to have been laid down in catastrophes, and the millions of years are in between the sedimentary strata - and are actually not there! My paper shows another instance where thousands or millions of years are diminished to almost no time at all. The question is, therefore: are radiometric dating methods giving true dates, or do they only give "model ages" that do not have any (or very little) absolute time significance? One only has to read one of the main works on this subject (Faure 1986) to get arguments against all time significance for radiometric dating. When one digs deeper in the subject, one finds a lot more ... (Molén 1988/1991).

Mr. David J. Tyler's comments:

As far as I can see Mr. Tyler is pleased with my paper. The only criticism he raises, if one can call an opinion a criticism, is that he thinks that the Ordovician deposits are best explained with a glacial interpretation. I can only refer to my paper, where I have gone through all the main evidences for a glaciation in the Ordovician of Sahara, in general in the first part of my paper and specifically in the later part. The main features are not in favor of an ice age, some features are equivocal, but none can be explained only by an ice age. To me the evidence speaks more of a gravity flow, even though every structure does not yet have a completely adequate explanation.

Until I know why Mr. Tyler favors a glacial interpretation I can not give him a better answer than this.

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