The Glacial Paradox

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The glacial paradox

The glacial theory involves several contradictory, and paradoxical ideas.

Distribution of the ice

Merely looking at a map showing the alleged distribution of ice during the ice age raises doubts about the viability of the glacial theory.

In the glacial theory, ice sheets are postulated to have occupied much of the northern and eastern area of the North American continent, which includes the areas with low elevations, but the ice did not extend across the high plains or the Rocky Mountains in western areas of the USA, and much of Alaska remained ice-free.

In Europe, the areas for which hypothetical ice sheets are invoked include Scotland, most of Ireland, northern England, western Denmark, northern Germany, the eastern Baltic area, Scandinavia, and a separate Alpine ice sheet.

While northern lands allegedly hosted huge ice sheets, similar latitudes in the southern hemisphere apparently had very little ice. Former ice caps in the southern lands were very limited. Small mountain glaciers in western Tasmania pushed up end moraines, and lakes formed in them when the ice melted. High elevation, and a high rate of precipitation characterize the areas where evidence for former glaciers exists.

Centers of ice accumulation for the hypothetical ice sheets in North America were not regions of high precipitation, but were located far inland, where the air is dry, and precipitation relatively low.

Direction of ice flow

The centers of accumulation of the hypothetical ice sheets in North America were apparently not highlands, but relatively low areas, and in some regions these ice sheets are said to have spread from low areas towards areas of higher elevation.

One of the most striking examples of paradoxical ice motions is the region of Lake Ontario. Ice is believed to have flowed out of the lake basin towards the south in New York, and southwest, and towards the west across the Niagara Peninsula, and towards the northwest in Ontario north of the lake. The ice must have flowed up over the Niagara Escarpment from the low side to the higher, but there is little evidence in the rocks of the Niagara Escarpment that an ice sheet has actually scraped over it. There are fragile rock pinnacles and fissure caves in the escarpment in areas west of Lake Ontario that show very little wear and tear of the sort that one would expect if a great ice sheet had scraped over these rocks.

Paradoxical effects of ice

Where the hypothetical ice sheet over-rode drumlins it is believed to have gently molded the surface of the stratified drift that it over-rode, not disturbing the delicate patterns of cross strata in the sandy gravel within the drumlins.

Ice is credited with producing a landscape of smoothly rounded hills, and formed smooth, shiny, polished surfaces on some rocks where drift has been removed. Yet in other areas, the alleged ice sheets eroded bedrock with an astonishing frenzy and power, eroded rock drumlins, and gouged out deep basins in the hardest varieties of rocks, many of which became lakes.

According to those promoting the glacial theory, and movements of ice sheets caused deep grooves in hard rocks, scratches in surfaces of quartzite and granite, and created wide U-shaped valleys in mountains, and eroded deep basins in the coastal fjords to depths far below sea level.

How is it possible for the hypothetical Pleistocene ice sheets to have such contradictory properties? Why would they erode the hardest rocks, but have only a gentle affect upon the drift?

Sequence of events is paradoxical

Let us consider the sequence of events involved. The ice, it is claimed, gouged bedrock and eroded rock material, which was redeposited as the ice melted. Therefore, in regions where we find the mantle of drift today, the drift must have been entirely removed, so that the ice could be in direct contact with the naked rock which it abraded, quarried and scratched. Apparently the theory requires that rocks quarried from the bedrock were abraded and rounded while being carried along in the ice. But for the excavation and quarrying to occur, all the drift must have been displaced from its source, as ice worked upon the rock.

How could the hypothetical ice sheet continue to excavate its rocky bed, if the base of the ice was clogged with the debris already removed? The more debris held within the ice, the more likely it is that deposition would occur, rather than erosion. Any drift present beneath the ice would tend to protect the bedrock surface from further abrasion, so no further excavation could occur.

On the other hand, ice is softer than most rocks, so without tools, the hypothetical glaciers would be ineffective for abrading the rock beneath the ice.

Although some now admit that fluvial action, involving floods of immense volume and power must have caused the drumlins, still other supporters of the glacial theory continue to ignore the fact that streamlined land forms are not at all characteristic of ice, but are more characteristic of fast currents. They claim that drumlins were carved by ice, not water. The really astonishing aspect of that theory, IMO, is that the moving ice is said to have streamlined the surface of the drift, whereas the drift itself is interpreted as debris deposited as the ice sheets melted. How could ice cause streamlining of the drift, if it had already melted?

Hmm... perhaps drumlins were formed by the ghosts of perishing hypothetical ice sheets?

Are drumlins forming today?

Supporters of the glacial theory would like to be able to claim that the various landforms that are attributed to the work of former ice sheets, such as drumlins, kames, and eskers, are now in the process of formation by existing glaciers. People have searched long and hard for more than a century, looking for examples of these structures being formed in glaciated areas like Antarctica, Greenland, Iceland, etc.

Glaciologists define various landforms in terms of mechanisms which can be observed operating at melting glaciers. Drumlins, for example, are sometimes defined as "streamlined hills of till and bedrock that parallel the direction of ice movement." It is not very hard to find linear features at the sites of existing glaciers that fit a definition like this, so they claim that drumlins are observed in the process of formation at the present time.

Where glaciers cause linear features on the ground they over-ride, however small they may be, these are identified defined as drumlins. So, the reasoning goes, drumlins (of this dubious sort, at least) can be seen being manufactured today.

When we examine the first-hand reports of observations of the linear features that are identified as drumlins using a definition such as this, it seems that there is more hopeful interpretation than factual evidence.

Similarly, the reports of so-called "eskers" in formation in glaciers seem pathetic, IMO. The scale is too small; a ridge of debris a few m long, and 1 - 2 m high does not compare too well with the real eskers, ridges 50 to 100 m high, stretching for 20 to 50 km or more, consisting of stratified drift material.

A small ridge of rock debris a few m long in a tunnel near the end of a glacier is called an "esker," when in fact it is nothing more than a pile of glacial debris. There is no evidence of internal structure similar to that present in real eskers. The published reports in geological journals reveal piles of debris formed at existing glaciers have little resemblance to the real eskers.

An report on "recent drumlins" in Iceland appeared in *Journal of Glaciology*, 1995 vol 41.1(139) 596-606. In this article, small ridges, 1-2 m high, 20-30 m long, and 10-20 m wide are labeled drumlins. The photos show rows of boulders, that look nothing at all like real drumlins. But, apparently they fit the definition of "linear features parallel to ice movement." Also 6 "rock drumlins" were reported with average height of 0.7 m. How can these puny features be compared to the real drumlins that are some 100 m high and one or two km long? This is an example of misidentification, and IMO it is the definitions that are flawed.

No one doubts existing glaciers can form linear marks, and can even deposit rows of boulders, etc. But I doubt that the origins of those features have anything in common with the drumlins in the drumlin fields of Southern Ontario, New York, Wisconsin, Ireland, Sweden, and elsewhere. Similarly, the small ridges of debris reported being deposited in crevasses in existing glaciers has no resemblance to the eskers in the drift regions.

Rogen “moraines” may be giant current ripples

Any material that has been deposited at the perimeter of a glacier directly from melting ice can be properly called a moraine.

In the drift there are topographical structures that are sometimes identified as moraines but the terminology might be ill-advised if these in fact have another origin. An example is the phenomenon of rogen moraines, that probably originated as giant current ripples caused by fast currents. They are transverse ripple-like features found upstream or downstream from drumlins. The drumlins are streamlined parallel to the flow direction while the rogen ridges represent ripples transverse to the current in this interpretation. There is more information on this on my web site at:

http://www.sentex.net/~tcc/moraine.html

Another article by John Shaw presenting an interpretation of rogen moraines as giant current ripples generated by the currents of subglacial outburst floods is available at:

http://www.sentex.net/~tcc/rogen/index.html

Shaw uses the term "rogen landscape" instead of "rogen moraine" and says in the article:

> Rogen "moraines", like drumlins, are familiar to the point where they are easily and confidently recognized - see Hättestrand (1997) for an excellent review of the characteristics and the history of ideas on Rogen moraines. Such familiarity commonly leads to a loose definition of Rogen landscapes. The resulting problems are compounded when definitions imply genesis.

The drumlins have variable composition, some drift, some rock, some stratified, some not, some part drift and part rock, some entirely rock. So drumlins are not the same as moraines. The same is true of rogen ridges. The surface of the bedrock below rogen landscape is irregular, as it is below drumlins. Some rogen ridges have cores of rock, and they may have variable composition similar to drumlins. So they are not moraines, even though the terminology suggests they are.

Giant erosional ripples occur at the Milk River Ridge, southern Alberta, with wavelength of about 600 m. They indicate a former current flow towards the SE. The features resemble rogen landscape but are composed of bedrock, so they are not moraines. Glacial definitions of structures in the drift that imply genesis (e.g. "moraines") are often misleading.

Kames, eskers, and the disintegration theory

The kames and eskers are prominent landforms in areas where the drift mantle is thick. Eskers are long, winding ridges of sand and gravel. In built-up areas, these remarkable features have often become sites for gravel excavations. In southern Ontario, they are viewed as one of the non-renewable resources, to be exploited. The gravel and sand is used for road making, and construction. It is crushed, sorted, washed, and added to concrete.

Because the gravel in eskers is often so easy to access, many of the ones in more densely populated areas have now been almost completely removed. For example, only a few remnants of the once prominent Guelph esker remain. This esker once stretched for tens of kilometers northwest of the city of Guelph, Ontario. Its location is now marked by a line of former gravel excavation sites.

Eskers trend up and down hills, and in the glacial theory, it is claimed they represent sites of former rivers in vanished ice sheet, where sand and gravel accumulated, and was left behind as the glacier melted. There has been some debate about whether the eskers represent rivers above the ice, or underneath it.

Kames are related to eskers, and they are conical hills, with many of the same characteristics as eskers. One of the prominent kames near the city of Kitchener, Ontario is the Chicopee ski hill. There was an article on it in a recent issue of the local newspaper, The Record. [http://www.therecord.com] The article included some fine photos.

The author, Jeff Outhit, says in the article:

> Six words tell the history of Chicopee: Glacier, farm, hospital, ski hill, suburb. The dominating hill was formed 12,000 years ago when a retreating glacier formed the Grand River and deposited gravel, clay and boulders in the area.

The Chicopee hill is close to the wide valley of the Grand River. It is thought that the drift in the region, which is well over 100 m thick, was deposited by the former glacier, and the wide valleys were eroded into the drift by meltwaters. The Grand Valley here seems too large to have been formed by the river presently occupying the valley.

The notion that large mounds of sand and gravel, such as the Chicopee ski hill, could have been formed by a glacier is rather astonishing. The idea is that in the hypothetical glacier, there were rivers that carried along sand and boulders. The rivers are thought to have flowed either at the surface of the ice, or in tunnels within the ice.

How all these stones were able to rise up thorough the hypothetical ice, to the site of the river near the surface, is not clear. But it is assumed that they did this, and the stones and pebbles became rounded in the process. At the site of the kame, which is now the Chicopee Ski hill, it is believed the river plunged down a hole in the ice, and the sandy debris, pebbles and boulders transported by the river accumulated in a high mound of stratified sand and gravel.

It is rather interesting, to compare the mechanism outlined above to the one that is offered at Rockwood, Ontario, a park where bedrock is exposed, and it has hundreds of potholes in it. The official explanation offered for the potholes is that waters in a former ice sheet plunged down a crevasse, or "moulin", eroding deep vertical holes in the bedrock below. Essentially the same mechanism, involving water plunging down holes in the vanished ice sheet, is supposed to have drilled deep holes in bedrock at Rockwood, and built up huge hills of stratified sand and gravel at Kitchener! Obviously the theory contradicts itself, and is flawed.

In the disintegration theory of the drift, the origins of both kames and eskers are explained as due to expansion effects. As the mantle of drift formed, in a top-down disintegration process, that formed layers of sand and gravel, there was volume expansion. The lateral effects of this expansion caused horizontal stress in the drift, that was relieved in some areas by mounds and ridges of sand and gravel being thrust up. The ridges are eskers, and they are analogous to pressure ridges in the ice of a frozen lake or pond. Mounds of drift like the Chicopee ski hill are analogous to the mounds of ice that can be observed in the surface of ice cubes formed in a rigid tray in the ice box of a refrigerator.

Fjords and the disintegration theory

The origin of the fjords remains one of the outstanding problems in geology.

The Sognefjord on the west coast of Norway is 204 km long, and its underwater profile is a series of deep rock basins, separated by narrow rock sills, that are hundreds of meters higher than the floors of the deeper basins.

Many people assume that the fjords must have been somehow eroded by glaciers, but the sills that separate the rock basins would act as dams to any former glacier filling the fjords. High walls of rock between basins would prevent any sliding of the base of the ice along the floor of the fjord. So, even if ice of glaciers once filled the fjords, it would have been ineffective for excavating them.

Because the profiles of the floors of the world's largest fjords are basins, separated by sills, rather than a steady downwards slope, (as glaciologists would no doubt prefer) the notion that the fjords represent ancient river valleys that were enlarged by ice, and became drowned, must be rejected.

The origin of many fjords can probably be explained by a combination of two different processes, one involving *in situ* disintegration, and another involving erosion of the disintegration product, (i.e., typical drift gravel and sand), by fast currents.

Conditions giving rise to both the disintegration, and generation of the fast currents, could have involved tectonic uplift of formerly submerged lands. Waters spilled off the raised areas, and generated the fast currents that eroded the drift.

The disintegration probably affected rocks along lines of weakness. Rocks in the vicinity of cracks that formed due to tectonic movements would be subject to disintegration. Currents then removed the drift material formed by disintegration, promoting further disintegration of the exposed rock surfaces. Removal of overburden exposed new rock surfaces to lower pressure, and so the disintegration penetrated even deeper, allowing the formation of fjords and lake basins to depths hundreds of meters below sea level. This mechanism can also explain the alignment of fjords along major joints or faults.

Potholes are sometimes associated with the fjords, and in the disintegration theory, the potholes are attributed to disintegration on a smaller scale. Potholes occur in the rocks of a small island in the middle of one of Norway's fjords. Potholes have also been reported at the head of one of the tributary valleys of Sognefjord.

The disintegration theory suggests more potholes might be present in some of the submerged rock sills separating the basins of fjords.

Environment of drumlin formation

Almost two centuries ago, James Hall of Edinburgh described drumlins of Scotland and attributed them to the action of catastrophic waves or floods that swept in from the sea.

Hall, who had been a friend of James Hutton, tried to show that his theory was reasonable and consistent with the laws of nature. He suggested the floods which swept over the land in the past had been generated by earthquakes on the ocean floor.

More recently, Cox's theory of drumlin origins says they were formed by the streamlining action of floodwaters generated by tectonic uplift of formerly submerged regions of the earth's crust, such as the Canadian Shield. The displaced water spilled off elevated regions and streamlined unconsolidated sediment in surrounding regions. The drift within drumlins was formed by in situ disintegration.

Cox's 1979 article on drumlin origins can be obtained at http://www.sentex.net/~tcc/drumlin1.html

Dr. John Shaw of the University of Alberta and his co-workers have proposed another scenario for drumlin formation. Shaw's theory, first published in 1983, is that during former ice ages, melt waters accumulated beneath melting ice sheets, and sudden breakup of the ice released huge floods of accumulated meltwater. The flow of catastrophic currents of meltwaters caused drumlins in certain areas by streamlining the landscape over vast regions. Discharge of the flood waters was brief, lasting only days or weeks.

The composition of many drumlins consists of bedrock, while in others, where unconsolidated drift is present, a majority of the boulders present resemble local bedrock. This fact appears to support the Cox theory rather than Shaw's theory.

While some drumlins may consist entirely of bedrock; others in the vicinity, having similar form and orientation, may consist of unconsolidated material or drift. In some drumlins the drift mantles a rocky core. This presents problems for an erosional interpretation, either glacial or fluvial, as erosion of drift by ice or water would be much quicker and more effective than erosion of bedrock. Rock drumlins would resist erosion more than drift drumlins. So any erosional hypothesis would predict a difference in form, size, and shape of drumlins, depending on composition, but that is not confirmed by observation.

Since drumlin form and shape in drumlin fields seems to be largely independent of composition, the erosional theories, invoking either ice or water, appear inadequate.

The resemblance of the drift within drumlins to the bedrock in the vicinity suggests it was derived locally. This supports the disintegration hypothesis, rather than a transport and erosion mechanism. There may be considerable variation of the relief of bedrock in a drumlin field. Again, this supports an in situ disintegration origin of the drift in drumlins, rather than a glacial meltwater interpretation.

Some variations of the idea of diluvial currents streamlining bedrock, forming drumlins may be considered. Perhaps the flood waters, being loaded with sediment, were chemically active, and were capable of rapidly dissolving bedrock. This would be more likely in a flood environment where tectonic action was accompanied by submarine volcanic activity, than a glacial environment. Flood waters at elevated temperatures might etch and dissolve the rock surfaces in areas of silicate bedrock, such as the

Canadian Shield.

In the environment of the flood, compaction of sediments could have several effects that might contribute to disintegration effects. Fluids would be expelled as the sediments were exposed, and unloaded by erosion of overburden. If limestone or dolomite bedrock was at elevated temperature during the process of consolidation and lithification, and at the same time the surface was streamlined by rapid current action, the bedrock surface may have been subject to active erosion, streamlining, and disintegration, as flood waters swept over it. This could be adequate as an environment for drumlin formation.

Variation of drumlin form with elevation

The distribution of drumlins with respect to elevation is interesting. In parts of Southern Ontario and Northwestern New York they are best developed at higher elevations, and tend to occur on plateaux, while they are absent from valleys. Drumlins occur on the north and south shores of Lake Ontario but they are not present in the lake itself. The orientation of some of the drumlins is such that the flow direction of the currents (or whatever the agent of streamlining was) that formed them was uphill. This is true northwest and south of Lake Ontario. Flow was evidently both northwest, and south, out of the Lake Ontario Basin, perhaps at different times, during a period of crustal instability, when flood waters were spilled in various directions, forming drumlins with various orientations.

The variation in form of drumlins with elevation in northwestern New York cannot be explained as due to ice being pushed uphill out of Lake Ontario, which would not increase its speed at higher elevations. The drumlins tend to be narrower and more elongated at higher elevations, than at the lower elevations where they tend to be wide and rounded in form. This is consistent with an increase in speed of the currents at the higher elevations, where water depth was shallower. Streamlining was more effective in the fast currents, so the drumlins here were smaller, longer and narrower. There are also examples of small drumlins clustered on another larger drumlin. These observations are more consistent with a fluvial agent of streamlining, than ice action.

Drumlin orientations indicate the current flow which eroded the Finger Lakes and caused the patterns of drumlins in northwestern New York was up slope. The current was probably caused by tectonic movements which tilted submerged lands further north, spilling the flood waters towards the south over southern Ontario and northwestern New York.

As the Allegheny highlands emerged above the water the current flow became restricted to valleys and several deep channels were eroded, some of which became the basins of the Finger Lakes. No former glaciers need to be invoked for the formation of those valleys. Erosion was probably accompanied by *in situ* disintegration of bedrock in many areas so currents may have removed drift rather than rock.

The valley heads drift is probably the product of *in situ* disintegration and possibly some redeposited drift that had been eroded and transported by the currents.

Significance of *roches moutonnées*

Rock drumlins are not the same feature as "roches moutonnées," although they may be related. Rock drumlins are typically identical in form and size and orientation to other drumlins in the same drumlin swarm. The only significant difference between these types of drumlins is their composition. However, if the drumlins were formed by erosional action of former hypothetical ice sheets as claimed in the glacial theory, obviously the ones composed of bedrock would have offered more resistance than those composed of unconsolidated drift. In fact one would expect drift drumlins to be obliterated, not become shaped into hills with the same orientation, and appearance and having the same form as the hills consisting of bedrock.

The *in situ* disintegration interpretation solves this problem by saying both kinds of drumlin, those composed of rock and those composed of drift, were composed of the same material when the streamlining occurred. The material was generally unconsolidated sediment. Subsequently, the sediment became solid rock, and some of the rock was changed to drift, as the disintegration surface penetrated from the top downwards to varying depths. In some cases, where there was a limited amount of disintegration, and a rocky core remained within a drumlin, rapid currents washed away the mantle of drift, and the exposed rock core was further streamlined, and its surface became grooved and scratched by boulders swept by currents. Perhaps this could explain some of the "roches moutonnées."

The distribution of the drift

Shield areas in North America and Scandinavia are at the centers of the main areas where drift occurs. These are probably exhumed basement rocks that once had a sedimentary cover which has ben stripped away. Remnants of Paleozoic rocks remain as outliers in the Canadian Shield in several locations.

Areas with sedimentary rocks at the perimeter of the Shield appear to have been subject to erosion by former fast currents, which are very effective for excavating lake basins, especially where the *in situ* disintegration mechanism was involved.

The areas where evidence for *in situ* disintegration occurs seem to coincide with regions of the earth's crust which have been heavily eroded by fast currents such as the previously mentioned Shield areas and surrounding regions. Evidence for former submergence and crustal tilting abounds in those regions. High shorelines exist in many locations, often no longer horizontal, and former current flow directions are indicated by the patterns of drumlin orientation.

Enigma of stratified drumlins

The material in drumlins may be all bedrock, or part bedrock and part drift, or various types of drift. The stratified drumlins are at least partly composed of stratified drift. The layers of sand and gravel in the drift of these drumlins exhibit cross stratification. Stratified drumlins are common in drumlin fields in many areas, such as those of Northern Ireland, Southern Ontario, New York, Wisconsin, and other areas. They are among the most enigmatic to explain in terms of the glacial theory.

Drumlins offer little support for the notion that continental ice sheets have swept over the land. Since they are streamlined features, their shapes are better explained by fast currents of water. Geologists have looked for evidence of drumlins in the process of formation today, at glaciers in the Antarctic or Iceland or elsewhere, but the examples that have been offered are rather pathetic, with little resemblance to real drumlins.

The stratified drumlins may consist entirely of drift, or part drift, and part bedrock. A bedrock core may be located in the central region, or at either end. Some geologists have supposed ice eroded the central cores of bedrock, and meltwaters deposited drift over the cores. Subsequently, another advance of the hypothetical ice sheets carved the drift into the streamlined shape resembling that of other drumlins in the vicinity. Repeated advances and retreats of the front of a hypothetical ice sheet have been invoked by some, to explain drumlins.

However, the stratified drumlins, with delicate patterns of cross strata preserved in their sandy layers, indicate that no ice sheet could have scraped over them. Any such scraping action, after the stratified drift was in place, would have disturbed the patterns in the sandy strata.

Also, if ice over-rode drumlins of stratified drift, why do these drumlins have similar size and shape of others nearby, composed entirely of bedrock? Erosion by ice would have removed the drumlins composed of softer material entirely, or at least disturbed the patterns in the sandy layers.

The traditional approach to the origin of drumlins assumes that stratified drift is a fluvial deposit. This notion was carried over from the old diluvial theory, prevalent in the early nineteenth century. In the diluvial theory it was assumed that cross strata of the drift was produced by currents. The glacial theory claimed the currents that deposited the drift were currents of meltwater streams flowing from glaciers. This assumption has led to the current drumlin dilemma, and a generally acknowledged failure to explain the origin of drumlins, by generations of glaciologists.

The enigma concerning origin of stratified drumlins can be solved if the idea of an *in situ* disintegration is introduced. The stratified drift in drumlins could have formed by a non-sedimentary mechanism, that penetrated downwards from the surface when the drumlins were formed. Evidence for this non-sedimentary process in the drift is the configuration of the cross strata near pebbles. Directional effects, that are expected in a sedimentary environment, such as erosion at the stoss side of obstacles, and current shadows on the lee side, are absent.

The streamlined shape of drumlins was caused by fast currents. After the sediments became streamlined, and began to turn into rock, the disintegration surface penetrated downwards to varying depths. Layers of sand and gravel formed from the top down, with characteristic patterns. Disintegration ceased at the bedrock surface. Bedrock below the streamlined surface has an irregular shape. In this model the stratified drift in many drumlins would be well preserved.

What caused the Niagara Escarpment?

The question of the origin of the Niagara Escarpment is obviously related to the question of the origin of the Great Lakes. The escarpment is associated with several of the Great Lakes basins, and especially those of Lake Ontario and Georgian Bay (part of Lake Huron) which it overlooks. The tilted strata of the escarpment must have once extended out eastward over these deep lake basins. Whatever it was that excavated the Great Lakes, was also involved in the formation of the escarpment and its features. Obviously weathering and erosional process of the present time would not produce deep rock basins such as the basins of the Great Lakes.

Erosion by powerful currents, generated by differential tectonic uplift of formerly submerged regions of the Canadian Shield somewhere to the northeast of the escarpment, seems the most likely explanation for the excavation of the basins of the Great Lakes, and the removal of all the missing sediment in areas to the north and east of the escarpment. This is a rather old idea that was supported by prominent geologists in the nineteenth century such as Sir William Dawson, founder of McGill University in Montreal.

The Niagara Escarpment is usually explained as an erosional feature, but this is only partly true. It is erosional in the sense that it was caused by removal of the strata that formerly extended eastward over Lake Ontario and Georgian Bay and other regions. However in many places it remains buried underneath unconsolidated drift material, and in this feature, it resembles another similar escarpment in southern Ontario, west of the Niagara Escarpment, that is almost entirely buried, except on the floor of Lake Huron, where it is a very prominent bedrock feature. So the question of the origin of the Niagara Escarpment is connected with the origin of the drift that buries the escarpment in some places, and also conceals other escarpments.

In the gorge of the Niagara River, and in other sites along the escarpment, there are indications of a former *in situ* disintegration of the rock, that converted the sediment to drift material, with a variety of pebbles and rounded stones along with irregularly shaped boulders that formed in place as the material around them disintegrated. There is drift below the talus in the rapids of the upper gorge, and there is the drift-filled "buried St. Davids gorge," and several other drift filled valleys elsewhere along the escarpment, some of which are quite deep.

Some of the so-called "re-entrant valleys" along the escarpment are drift filled. Most of them are too short and wide to have been excavated by former streams, as some have claimed. Also, the fragile nature of some of the features of the rocks of the escarpment, such as thin, overhanging rock ledges in some areas where the escarpment overlooks Georgian Bay, and rock pinnacles at Milton and Mount Nemo and in other areas, and areas of fractured and jointed rock, which show no sign of any glacial action in the past, indicate the idea of former excavation and enlargement of these valleys by former ice sheets is incorrect.

In my view the drift was a product of disintegration, and the vertical penetration of the disintegration surface as overburden was removed by catastrophic currents has formed many of the features of the Niagara Escarpment. Powerful currents from the north and east removed the drift from the vicinity of the escarpment where it is exposed. The direction of these former currents is indicated by the orientation of the drumlins in the vicinity of the escarpment, and by the axes of the various "re-entrant valleys", and by other features. As the escarpment land emerged above water level, the currents were confined to low areas, where erosion was intensified, such as the "re-entrant valley" of Colpoys Bay, at Wiarton. And the effect of this channeling of the currents is especially evident in parts of the Bruce Peninsula and the southern part of Manitoulin Island where there are long parallel grooves in the bedrock, where it has apparently been scoured by the currents, probably when the sedimentary rock was still unconsolidated.

The scouring action of these currents is also evident in the over-deepened sections of the lake basins near the escarpment, such a deep scour in the lake floor off Cabot Head at the northern end of the Bruce Peninsula, and a deep scour in the northeastern end of Lake Erie.

Potholes and the disintegration theory

Potholes occur in many areas where bedrock is exposed, and where drift has been removed. These are deep, vertical, cylindrical holes in the rock. They occur in various types of rock in clusters of up to several hundred holes. They are found in granite along the eastern shore of Georgian Bay, Ontario; on high cliffs of basalt beside the St. Croix River at Taylor's Falls, Wisconsin; in shale at Watkins Glen, NY, and in dolomitic limestone at Rockwood, Ontario. There are potholes in the limestone cliffs of the Niagara Escarpment near Lion's Head, Ontario. Potholes also occur in caves. They are found in the cave floors, and domes resembling "inverted potholes" may occur in the roofs of caves.

At the locations mentioned above, the potholes vary in size and shape. Potholes occur up to 6 m diameter and 20 m deep. They may widen with depth, having a barrel shape. Portions of potholes are often present in the sides of vertical cliffs.

At Rockwood, Ontario, limestone bedrock is exposed, and potholes are found at various elevations. About 300 potholes have been discovered, with various sizes up to about 6 m diameter and about 15 m deep. There are many more partial potholes. Glaciologists claim that their formation was due to erosion by waterfalls tumbling down crevasses in a vanished ice sheet, forming a "moulin". Currents are supposed to have circulated boulders at the bottom, forming a "mill" that drilled deep holes into the rock. Prominent signs near some of the potholes advertise this explanation. An objection to the glacial "moulin" idea is that the hypothetical ice is supposed to have been moving, and so any waterfalls would not have remained in one location long enough to excavate deep holes in the bedrock below.

In the vicinity of Rockwood there are some very large drumlins. These are probably composed at least partly of bedrock. The glacial theory says that moving ice had something to do with their formation, although it is now admitted that they are, after all, more likely to have been formed by fast currents of water, in the subglacial meltwater theory.

If there were holes through the ice to the bedrock, and water flowed down towards bedrock from the surface, the idea of pressurized meltwater beneath the ice eroding the drumlins is in trouble. If there were pressurized water below the ice, flow would be back up the hole, and so no potholes would get drilled into the bedrock.

Anyway, since the hypothetical glacier must have been stationary for long ages at Rockwood, so that the meltwater with the magic vortices could pour down the holes and drill the potholes, how could the ice carve all those big bedrock drumlins nearby? The moving ice must have gone around the stationary ice at Rockwood. (Or, the theory is flawed).

If the hypothetical ice sheet was perfectly stationary, so meltwater flowed down the same holes for long ages, supposing the holes through the ice were not enlarged or modified by the water for long periods of time strains one's credulity. And why drill so many holes, spread over just a few square km? Why wouldn't one or two holes be sufficient to drain the water from the hypothetical glacier?

Action of vortices invoked for pothole erosion

The concept of pothole origin by water action, (either rivers or water tumbling down crevasses in a hypothetical ice sheet) invokes vortices or eddies in the current. The vortices are said to have drilled down into hard rock at the stream bed, making potholes.

This is discredited by the presence of intersecting holes, that are present in most areas where potholes occur. The wall of one pothole opens into another. Neither intersecting potholes nor partial potholes in the cliffs can be explained by the action of vortices. A rotary current would not be maintained, once part of a pothole wall is breached, where it opens into a neighboring hole.

Any circulation in a system of two or more intersecting holes immediately ceases, because the angular momentum of the fluid gets dissipated. Since the fluid is no longer completely contained by the wall of a pothole, the current flow takes a tangential course, where the wall of the container is missing. So the momentum and rotational energy gets dispersed, and rotation cannot be maintained. Therefore, the idea of vortices drilling the intersecting potholes must be flawed.

The conventional tale about the origin of potholes is easily discredited. What process formed the potholes? The theory of *in situ* rock disintegration can be applied here. The potholes can be explained by the mechanism of rock disintegration, a pressure related process that penetrated vertically downwards, in conditions which no longer exist. Conditions for pothole formation involved release of vertical stress as overburden was rapidly eroded away by fast currents.

The process of rock disintegration may form a canyon where a series of linked or intersecting potholes developed along a joint. When the unconsolidated fill is eroded, the partial potholes remain in the sides of the canyon. There are some examples of this Rockwood. Other examples occur at Watkins Glen, NY, Wisconsin Dells, Wisconsin, and at Maligne Canyon, near Jasper, Alberta.

Maligne Canyon potholes

The potholes that form the Maligne Canyon are several hundred feet in vertical extent, and the canyon walls are in places only a few feet apart. Its formation was described by B.R. MacKay in an old issue of Canadian Geographical Journal:

> The cutting of this canyon began at the close of the Glacial Period, and was caused by the river being diverted from its preglacial channel by the deposition of glacial drift, and thus forced to follow a new course which led along joint planes and over the rock wall of Athabasca River. This resulted in a waterfall and the development of potholes by the churning action of large boulders carried by the stream. During the succeeding centuries pot-hole after pot-hole was formed, enlarged, cut away, and the waterfall migrated slowly upstream, leaving behind a deep gorge.

What seems to be left unexplained in the various explanations I have seen is how the agent of erosion, whatever it is, "knows" how to drill cylindrical holes into the rock, that have a shape that is continuous from the top to bottom. How do the rotating boulders and/or vortices and/or acidic solutions and/or glacial waterfalls determine the appropriate diameter, and precisely where the center of curvature should be, to make bottom part line up with the hole at the top?

In the *in situ* disintegration theory there is no need to invoke magic, as the form of the holes was determined by adjustments of pore fluid pressure in the rock as the overburden was eroded away in former catastrophic conditions. The rock probably partly disintegrated in the vicinity of a joint, and the weaker rock was more easily eroded, leaving the pothole forms in the remaining rock.

Composition of the drift

The drift contains many boulders are rounded, and it has been commonly supposed that the only effective means for rounding stones is by abrasion. This was assumed by Louis Agassiz, the Swiss scientist who developed the theory of the ice age as an explanation for the drift phenomena. Agassiz adopted the then current diluvial interpretation of the drift, that its stratified material was deposited in a fluvial environment, but said the streams were meltwater streams from glaciers.

However, another mechanism for the formation of rounded boulders is by concretionary development. Along the Ontario shore of Lake Huron there is a shale known as the Kettle Point formation, famous for its remarkable concretions, that can be found eroding out of the rock. They are spherical balls of limestone, varying in size up to about 1 m diameter. Many of these concretions have a radial structure inside.

The big concretions of limestone at Kettle Point are embedded in a shale. The shale has been eroded by wave action and the limestone concretions, which are more resistant to weathering than shale, are exposed along the shore.

An interesting feature at Kettle Point is the amount of compaction that has occurred in the shale. Shrinkage due to compaction has caused the bedding of the shale to drape around the big concretions, which remain roughly spherical. The concretions evidently formed before the shale was completely compacted.

There are many concretions in the drift in southern Ontario, and boulders in the drift often exhibit concretions either inside, or on their surfaces. In my *in situ* disintegration theory, the rounded boulders of the drift are concretionary. This explains the many examples of concretions within drift boulders. A glacial environment is incompatible with the observation of concretions in the drift, as these are generally composed of material far too soft to have survived glacial transport, and there is little chance concretions could have formed in existing conditions in the locations where they occur.

What is it that distinguishes between a boulder that has a concretionary origin, and one that has another origin? Geologic dogma originating with James Hutton more than two centuries ago says the drift boulders and pebbles were rounded by abrasion during transport in streams, or by being rolled by waves on a beach, or by glacial action, etc. But there are exposures of the drift in Ontario where a majority of the boulders examined by the writer had concentric structure, which appears to be a good indication of their concretionary origin. Furthermore, internal features such as concentric structure and internal concretions in the boulders are not well explained by invoking glacial action. How could the alleged former glacial environment account for the concentric structure within many of the boulders?

Concretionary processes during disintegration can account for the great variety of rock texture and trace minerals in boulders of the drift. These account for the varied appearance of many drift boulders, whereas generally only a limited number of bedrock formations may be available in the supposed path of the hypothetical glacier, far too few to account for the varieties of rocks that occur in the drift.

Radiating crystals, concentric structure, internal concretions, and concretions on the surfaces of boulders in the drift would discredit a glacial interpretation.

The following is a link to a report on a study of the lithology of the drift in Ontario near the Shield boundary:

http://www.erudit.org/erudit/gpq/v51n01/cogley/cogley.html

J. G. Cogley et al., Allochthonous sediment in till near a lithological boundary in Central Ontario, *Géographie physique et Quaternaire,* 1997, vol. 51, n° 1, p. 0-0, 5

From the Abstract:

> .. "Clast counts, and measurements of carbonate abundance in the sand fraction, show that little of the till covering a portion of central Ontario was carried across the boundary between Precambrian rocks (up-ice) and Palaeozoic limestone (down-ice). Seven eighths of the pebble fraction is local, from within ~2-5 km of the site of deposition" ...

If seven-eighths of the material in the drift is local, claims about ice transporting huge volumes of debris for great distances may be exaggerated. However if the stones in the drift were not rounded during transport over great distances, some other effective means for them to obtain their rounded form is needed, such as an *in situ* disintegration process which operated in the past, in conditions which no longer exist, a process which is not observed in nature at the present time.

Cross strata and the disintegration theory

The disintegration theory provides an explanation for patterns of cross strata in the drift. Sediment accumulation is a bottom-up process. The disintegration theory says the patterns of cross strata typically present in the drift sands and gravels are not sedimentary in origin, but formed by a top-down disintegration process. This may have involved crystallization. Successive surfaces of rock were converted to sand in a pressure-related disintegration process during former catastrophic conditions.

This interpretation of the cross strata of the drift leads to new explanations for land forms which typically occur in areas where drift is present, such as caves, drumlins, eskers, rogen moraines, etc. There are also possible applications in the origin of fjords, certain types of mountain valleys, and lake basins.

Disintegration can account for the formation of drift in valleys and troughs, that were then subject to erosion by fast currents retreating from uplifted areas as former submerged lands rose out of the sea. The currents eroded drift sand and gravel, rather than hard rock, so deep valleys, fjords and lake basins were excavated, perhaps in a short span of time.

In the disintegration theory, cross strata might be expected in drift in various odd places, whereas the pattern would be quite unexpected in those locations if it was caused by fast currents in a sedimentary environment. For example, it might be present in the drift that is present in caves. Since caves are highly restricted areas, the patterns of cross strata in some of the sandy layers of cave fill might be anomalous.

Also, cross strata might be present in the drift of potholes that have not been excavated. Reports of investigations of pothole contents in the nineteenth century sometimes included drawings that showed patterns of cross strata in their contents. The problem here is explaining how a suitable current could exist within a pothole while it was filling up with sand and boulders. These are questions that would probably reward further investigation.

Exposures of cross strata in the drift are generally associated with abundant pebbles. This is true in the drift within kames and eskers for example, and often in drumlins. The cross strata in these exposures exhibit very smooth curves. In kames and eskers there is often an anticlinal structure near the sides, which is attributed to expansion of the drift in the disintegration theory. Where drift was thrust up in due to lateral pressure, there was slumping along the sides, causing the anticlinal structure.

The drift generally exhibits concave upwards sets of sandy strata, which form distinctive patterns. These have been previously interpreted as sedimentary in origin. However, there are some notable problems with the interpretation of the cross strata in the drift as sedimentary.

Cross strata is usually organized to some extent into patterns of individual groups of laminations called sets. These sets tend to have smooth, concave upwards lower boundaries. The direction of layering in sets varies. In one set, strata may be inclined one way, in adjacent sets the strata can be inclined in other directions, perhaps having opposite slope. This makes for a very confused interpretation, if one tries to imagine what sedimentary environment could have caused this.

If we try to relate the direction of inclination of cross strata to other indicators of current direction, this is likely to be futile, and produces contradictory results. One possible way to determine current direction in sediments is by looking at streamline effects, such as ridges on the lee side of pebbles, parallel to current direction. These are called "current shadows." Orientation of current shadows in sediments corresponds to the slope of cross strata, and both are caused by currents.

This does not seem to occur in the cross strata of the drift, as evidence for current shadows appears to be missing.

In a fluvial interpretation, the smoothness of the patterns of cross strata in sets where pebbles are present is anomalous, as the presence of pebbles on the stream bed would produce turbulence in the currents, that would destroy the smooth layers. There would be "bumpiness" in the sandy strata where pebbles are present, because of lee-side current shadows and stoss-side horseshoe-shaped troughs where currents eroded the sand from around the obstacle. These would destroy the smoothness and distinctness of the cross strata, if it was formed in an environment of fast current flow.

Besides new insights that the disintegration theory provides for the origin of land forms, the theory also has potential value to miners and prospectors. If drift formed in place, and was not transported over great distances by ice, there are obviously practical applications of the theory, in the development of new techniques for mineral exploration.

On the *in situ* disintegration mechanism

Rocks and sediments that were disintegrated may have contained a mix of various components that were relatively stable in conditions of deep burial, but in changed conditions when the sediment was unloaded, due perhaps to rapid erosion of overburden, some of the components separated from the mix, causing the sediment to disintegrate. Gibbs' phase rule probably has an application in this problem.

As a possible example, rocks consisting of hydrated minerals formed at depth might become unstable at lower pressure, releasing water. The effect might be to cause disintegration or recrystallization at the low pressure surface.

Disintegration or crystallization of the rock in successive layers would form patterns of non-sedimentary stratification as the disintegration surface (or front) progressed downwards.

Observations by the writer indicated there was a need for a completely new explanation of certain forms of cross strata. Where drift gravels and sands occur with distinct patterns of cross strata, a vertical section exposed with both boulders and sandy strata has smooth curves of cross strata with embedded boulders. There is no indication of stoss side troughs or lee side ridges or current shadows.

The patterns of laminations of the cross strata are smooth curves, whether pebbles and boulders were present, or not. But, a little thought indicates there is a problem. If the cross strata was formed by deposition from rapid currents, why are no current shadows present around the boulders? Why is the cross strata not bumpy, because of current shadows associated with other nearby pebbles and boulders? It was to solve this and other similar problems that the theory of *in situ* disintegration was developed.

In this interpretation, the cross laminations in the sandy materials affected by this process represent former surfaces of the rock, that became disintegrated successively in thin layers. The successive surfaces or laminations record the progress of the disintegration process as it penetrated downwards.

Comparison with sedimentary cross strata

Louis Agassiz, who is credited with establishing the glacial theory in the nineteenth century, said: "study nature, not books." Following that advice led to the observations which discredit the glacial theory.

In the freshly exposed drift of southern Ontario, many of the rounded stones have smooth surfaces; however, at the beaches on the shores of the Great Lakes where the stones eroded from the drift are being rolled and tumbled by the waves, the surfaces of similar stones are found to be pitted and rough, no doubt as a result of countless impacts with other stones as they were rolled by the waves. So the tumbling action of the waves apparently destroys the original polished, smooth surfaces of the stones derived from the drift.

In my disintegration theory this has a good explanation; the smooth surfaces of the rounded pebbles and boulders of the drift are not due to abrasion or transport, but they were surfaces formed chemically during the disintegration of the rock.

None of the rounded stones found in fresh exposures of the drift are abraded and chipped like the pebbles and stones one encounters at the beach. However a minority of the stones in the drift are found to be striated, and scratched. Geologists usually attribute these scratches to transport in a glacier. In my theory these scratches have occurred during movements within the drift as disintegration occurred, because of expansion effects. As the drift formed by *in situ* disintegration, the lateral effect of expansion could cause several meters of displacement over the subsurface causing the stones at the interface to be scratched and striated. Disintegration may subsequently progress to deeper levels. These expansion effects can also account for the mounds and ridges in the drift, called kames and eskers.

Since the striations occur on surfaces of boulders already rounded and smooth, these stones evidently were not rounded and smoothed during transport in the ice, or in meltwater streams after the ice melted. [Yet the whole point of invoking former Ice Ages is to explain the features of the drift, including the origin of these rounded stones. If the stones were already rounded prior to glaciation, what need is there for a glacial era?]

Conventional geologic dogma says that the sand of the drift has been derived from the abrasive action of the stones tumbling against one another during transport, the process which also is supposed to have rounded the stones, but this isn't necessarily so, because these abrasive processes do not produce sand. The material generated is much finer than the sand of the drift, and different in character. It is called rock flour. Also the abrasive action of existing glaciers generally does not produce sand like that found in the drift, but rock flour. This fine powder is what makes the streams which flow from the existing glaciers milky in color.

Many of the sand particles in the drift are fragile and probably would not have survived transport in a fluvial environment. Also it is common to find large, fragile, disintegrated boulders in the drift, that discredit the idea of transport in streams or in a glacial environment. How could boulders of granite or gneiss so fragile, they can be crumbled in one's hand, have survived any tumbling process intact? How could these boulders have been carried vast distance in the base of an ice sheet? It defies common sense.

The features of the drift mentioned above support my *in situ* disintegration theory of the drift, (a process that occurred in former catastrophic conditions, but which is not seen in nature today), rather than a glacial interpretation.

In the exposures of cross strata of undisturbed, freshly exposed sandy drift gravels the laminations are often more distinct than the cross strata of stream deposits. When some of the same distinctly laminated sand is re-deposited in the bed of a stream, or in a flume experiment, the strata produced is much less distinct, and the inclined laminations of ripples are not nearly as smooth. Perhaps it is because of the indistinct patterns of sedimentary laminations that the stoss and lee effects around pebbles in sediments are often not noticed, but I have produced some of these stoss and lee patterns around pebbles in flume experiments.

Why is it that modern sedimentary cross strata are not as distinct, or as smooth, as ancient cross strata of the drift? In the drift, where the strata is well preserved and very distinct these directional effects should be evident on the stoss and lee sides of embedded pebbles, if the material was indeed of sedimentary origin. It should be easy to determine the direction of current flow from them, however it is not, because the lee side ridges in the cross strata of the drift are missing. In my interpretation, it is because the cross strata of the drift has a different origin, a non-sedimentary one.