Submarine Mass Flow Deposition of Pre-Pleistocene Ice-Age Deposits

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ABSTRACT

Pre-Pleistocene "ice ages," which are based on till-like rocks, challenge the Genesis Flood as the origin of sedimentary rocks. The first postulated ancient ice age was based on a misinterpretation of a fanglomerate in England. The till-like layers exhibit several features that are contrary to recent or Pleistocene glaciation. Since 1950, mass flow has been shown to not only duplicate the till-like fabric of the rock, but also mimic many "glacial diagnostic" features. The best example of a pre-Pleistocene "ice age," the late Paleozoic Dwyka "tillite" from South Africa, will be evaluated. Submarine mass flow during the Genesis Flood is a more likely explanation for pre-Pleistocene "ice ages."

INTRODUCTION

Mainstream scientists continually challenge Flood geology and the short time scale of earth history deduced from a straightforward reading of Genesis [47]. They believe many phenomena from the rocks contradict the creation-flood model. One of these phenomena is ice ages. They maintain that each Pleistocene ice age took about 100,000 years, and there were from 15 to about 30 of them in regular succession. A model for the Pleistocene or post-Flood Ice Age, lasting about 700 years, has been developed within the creation-flood model [30-32]. The key to this vast difference in time is the catastrophe of the Genesis Flood.

Deposits from the post-Flood Ice Age cover the surface of the earth and are thin and unconsolidated. These deposits lie mostly on flat terrain and show signs of being overrun and molded by ice. However, in the hard sedimentary rocks from around the earth, layers exist that superficially resemble glacial till. These layers consist of a poorly sorted mixture of rocks of all sizes embedded in a fine-grained matrix. This mixture when unconsolidated and derived from a glacier is called till. Its lithified equivalent is called tillite. When the mixture looks like till, but its origin is uncertain, it is called a diamictite, or sometimes a mixtite. Striated and faceted stones, abraded bedrock surfaces, and rocks in varve-like sediments are noted in some of these layers of hard rock. A varve is a couplet composed of a coarse lower layer followed vertically by a fine-grained layer that was deposited in a pro-glacial lake in one year. If the period of deposition is unknown, the deposit is called a rhythmite. Other glacial-like features are cited as proof that the till-like layers represent deposits left over from ancient or pre-Pleistocene "ice ages."

Pre-Pleistocene "ice ages" cluster into four periods of geological time: 1) the mid Precambrian, 1.6 to 2.7 billion years ago; 2) the late Precambrian, 615-950 millions years ago; 3) the late Ordovician, 440 to 460 million years ago; and 4) the late Carboniferous and Permian, 270 to 340 million years ago [13].

Pre-Pleistocene ice ages, if they occurred, bring up a critical problem for creationists. These supposed ice ages occur in rocks that creationists consider Genesis Flood sediments. (Although there is disagreement among creationists, I will assume all Precambrian sedimentary rocks are Flood rocks.) How can ice ages occur within a one-year global flood? Strahler [47, p. 263], using the example of the late Paleozoic "ice age" in the Southern Hemisphere, challenges:

The Carboniferous tillites cannot be accepted by creationists as being of glacial origin for the obvious reason that the tillite formations are both overlain and underlain by fossiliferous strata, which are deposits of the Flood. During that great inundation, which lasted the better part of one year, there could have been no land ice formed by accumulation of snow.

Strahler is correct that there can be no ice age during the Genesis Flood. If these deposits really represent ancient ice ages, the Genesis Flood cannot be the explanation for these particular sedimentary rocks. If this is so, the uniformitarian time-scale is supported, which adds credence to their explanation for the remainder of the sedimentary rocks. Therefore, pre-Pleistocene "ice ages" directly confront the concept of a relatively young earth and the Genesis Flood as the origin of most sedimentary rocks.

HISTORICAL MISINTERPRETATION

The first ancient "ice age" was proposed by A.E. Ramsay in the mid 1850s. He claimed that a Permian ice age, based on angular, polished, and striated boulders, developed over portions of England [4, p. 92-94]. But scientists in England rejected Ramsay's assertion, claiming instead that he mistook a fanglomerate for glacial debris. Nevertheless, Ramsay's report spurred other scientists to look for and find a <u>Permian</u> "ice age" in the Southern Hemisphere. The fact that most of these "tillites" were found in the hot tropics did not bother the discoverers. This problem was later solved by plate tectonics. Permian "ice age" rocks were soon discovered at many localities in the Northern Hemisphere. It almost seemed like a worldwide Permian glaciation. At the same time, "ice ages" in all the other periods of geological time were also discovered, including the three periods of the warm Mesozoic era [4].

Scientists at the time possessed only a rudimentary understanding of recent and Pleistocene glacial processes. They knew little of alternate mechanisms for forming glacial-like features. Because of the large number of pre-Pleistocene "ice ages" during the abundant warmth of geological time, many scientists became skeptical of the concept of ancient ice ages. Alternative mechanisms were discovered. Unfortunately, the concept of ancient ice ages was too engrained into the geological paradigm for much of a change in thinking. Some "tillites" were seriously challenged and rejected. Most were not. Schermerhorn [43] challenged all late Precambrian "ice ages." His careful research fell on deaf ears. Recently, Oberbeck, Marshall, and Aggarwal [35] claim that the concept of ancient ice ages has serious geological problems and that most, if not all, "tillites" are the result of debris flows caused by large meteor impacts.

CONTRARY ICE AGE FEATURES

Despite the enthusiasm of many geologists for pre-Pleistocene "ice ages," there are many features that do not compare with modern or Pleistocene glaciers [29]. One of these is that practically all "tillites" are marine, while most recent and Pleistocene glacial debris is continental. Based on the uniformitarian principle, pre-Pleistocene diamictites were originally declared continental "tillites." Increased knowledge of both ancient diamictites and modern glaciomarine sedimentation has dispelled this interpretation. Deynoux and Trompette [6, p. 1313] state: "...almost all ancient glacial deposits are marine...and deposited in geosynclinal or other unstable belts..." The most rapid paleoenvironmental revisions occurred when marine fossils were later discovered in "continental tillite."

The three-dimensional shape of "tillites" is contrary to tills from recent and Pleistocene glaciation. The largest "tillite" is one million square kilometers in the Paraná Basin of Brazil, while the second largest is 600,000 km^2 in South Africa. The remainder are much smaller. This compares to the Antarctic ice sheet, which blankets 12.5 million km^2. Pre-Pleistocene diamictites are commonly several hundred meters to several kilometers thick. The thickest is about 5,000 meters in the late Precambrian Adelaide geosyncline of Australia and in the Miocene to early Pleistocene Yakataga Formation in southern Alaska [13]. Pleistocene and recent continental tills are very thin in comparison. Pleistocene tills range from an average of about 30 meters thick near the periphery of the ancient Laurentide ice sheet to a rough average of 5 meters thick over interior Canada [11, p. 150]. Therefore, pre-Pleistocene diamictites are one hundred times thicker and cover less than one-tenth the geographical area of Pleistocene glacial debris. This lack of correspondence to recent or Pleistocene glaciation points to another mechanism, besides glacial ice, for the deposition of pre-Pleistocene diamictites.

Glaciotectonic or ice-push structures are deformed, sheared, and thrusted bedrock or basal till caused by a sliding glacier. Recognition of these features in Pleistocene glacial deposits was slow, but now glaciotectonic features are common in both Pleistocene and recent glacial debris. The shapes of these structures are sometimes distinct, such as a horseshoe-shaped hill surrounding an upflow depression. Small composite ridges, less than 100 meters high, are the most common tectonic landforms very likely pushed up by the Pleistocene ice sheets. Glaciotectonic ridges are forming today in many glaciated areas, for instance at the edge of several glaciers in Iceland.

When we turn to pre-Pleistocene diamictites, glaciotectonic structures are rarely if ever described. Flint [12, p. 125] states: "There is no obvious reason these ice-thrust structures, observed rather commonly in connection with Quaternary glaciation, should not occur in pre-Quaternary rocks." This indicates that "tillites" not only are marine, but they were also not deposited at the grounding line of a marine ice shelf. Thus, pre-Pleistocene diamictite would have to be formed almost exclusively by debris dropped from icebergs.

However, there is no indication, or at best very few claimed occurrences, of iceberg marks in pre-Pleistocene diamictites. An iceberg in shallow water will often slide, strike, or deform the bottom, usually in random fashion [48, 49, p. 248]. Iceberg drag marks are commonly observed on the ocean bottom in presently cold climates, for instance as deep as 500 meters around Antarctica [2]. They are admittedly not observed in ancient diamictites:

> Although iceberg plough and furrow marks have been widely reported from the floor of modern lakes and oceans...structures caused by the grounding and subsequent in situ decay of icebergs do not appear to have been observed in ancient sequences [49, p. 248].

Therefore, neither continental nor iceberg glaciotectonic features are observed in pre-Pleistocene diamictites. This strongly contrasts to modern and Quaternary glacial environments.

A fourth contrary feature of ancient glaciations is that many are closely associated with limestones and dolomites that indicate warm water. Dolomite especially requires a very warm environment. This association is the rule in late Precambrian "tillites." Anderson [1, p. 17] states:

> The diamictite-carbonate association is especially common in late Precambrian sequences and is, in fact, the rule rather than the exception for those rocks which have been interpreted as being of glacial-marine origin.

Frakes [13, p. 88] concurs: "Indeed, if mixtites were not known from the late Precambrian, the proportion of shelf carbonates could be taken as evidence for widespread and continuously warm climates." Very thick accumulations of carbonate rocks, measured in kilometers, predominate throughout the mid and late Precambrian, and continue into the Paleozoic.

Ice ages are not expected in the tropics at low altitude, although ice caps do top the highest mountains at present. However, the late Precambrian "ice age" faces this dilemma. Many of these "ice ages" are found near the current equator, and they are supposedly glaciomarine diamictites. No matter how the continents are rearranged by plate tectonics and paleomagnetism, many of the diamictites still fall within low paleolatitude [43, p. 674]. Frakes [13, p. 90] states: "...paleomagnetic investigations have already shown, rather startlingly, that an abundance of Late Precambrian glacial strata were deposited in relatively low paleolatitudes." The above two considerations for late Precambrian "tillites" should eliminate them as serious contenders for an "ice age."

SUBMARINE MASS FLOW

Is there another process that can account for pre-Pleistocene "ice ages"? For many years, no other process was seriously considered, so glaciation was accepted by default. In the 1950s and 1960s, earth scientists discovered that mass flow can duplicate the till-like character of diamictites. As a result, some "tillites" were reinterpreted as mass flow products, while others were seriously challenged [5, 43]. Mass flow products include at least four types, but their classification varies somewhat according to the particular author. In regard to pre-Pleistocene diamictites, debris flows and turbidity currents are the most relevant.

Debris flows manifest many important properties of pre-Pleistocene "tillites." They form a jumble of rocks of various sizes mixed within a fine-grained matrix. This fabric cannot be distinguished from glacial till. Debris flows also have the ability to transport surprisingly large boulders in laminar or non-turbulent flow [22, p. 434; 18, p. 776]. Submarine debris flows can flow long distances over nearly flat terrain. They are generated from submarine slumps or landslides on bottom slopes as low as one to three degrees [9, p. 204]. The sediments can continue traversing slopes as low as one degree or less [9, p. 189]. Therefore, submarine debris flows "freeze" on nearly flat terrain, which is one of the criteria that is sometimes employed to claim a glacial derivation for the diamictite.

A turbidity current is an underwater flow of sediment supported mainly by fluid turbulence. It usually flows swiftly down the bottom of a subaqueous slope, spreads out, and is deposited on a nearly flat bottom. A turbidity current rapidly traverses long distances. The indurated equivalent of a turbidity current deposit is called a turbidite. They likely form a significant portion of the earth's sedimentary rocks. Turbidites are most often characterized by a particular vertical sequence, which grades upward from coarse sediment, usually gravel or sand, into fine laminated silt and clay. If the turbidite lies on the ocean bottom long enough, a layer of biogenic sediments are deposited on top. The entire sequence of a turbidite is rarely found in full in the rock record. Geologists recognize two end members of turbidites with gradations between. The first is the proximal turbidite, deposited near the sediment source, and containing a thick basal layer of gravel. The second end member is the distal turbidite, deposited far from the source and containing very little coarse material. It normally alternates between a thin layer of fine sand or silt and a thin layer of clay or fine silt. This sequence can be repeated numerous times in one turbidite. Distal turbidites can mimic glacial varves, especially since each sublayer can sometimes alternate dark and light colors.

Unfortunately, this new information on mass flow did not persuade geologists to change their interpretation of most "tillites." They simply recognized that mass flow deposits are common within "tillites." To distinguish between a glacial or a mass flow derivation, geologists have employed three main diagnostic criteria for a tillite: 1) striated and faceted clasts, 2) abraded pavements, and 3) dropstone varvites [17, p. 17]. Varvites are assumed to be the lithified equivalent of varves. Dropstones are clasts that are larger than the layers and, therefore, are assumed to be dropped by icebergs. When any of these criteria, especially the latter two, are found in a diamictite it is almost automatically labelled a tillite. However, there is a large body of data available that shows these "diagnostic" characteristics can be formed by mass movement and tectonics.

THE LATE PALEOZOIC DWYKA "TILLITE" IN SOUTH AFRICA

The late Paleozoic "ice age" in South Africa is considered the best ancient glaciation [7, p. 1290]. The diamictite is called the Dwyka "tillite" and covers large areas of southern Africa (Figure 1). The Dwyka "tillite" outcrops around the Karoo Basin of South Africa and, based on numerous boreholes, is mostly continuous below the post-Dwyka sediments in the Karoo Basin. In the Kalahari Basin, the Dwyka "tillite" outcrops in the west and continues eastward underground. The Dwyka "tillite" in just the Karoo Basin occupies an area of 600,000 km^2, about the size of the state of Texas. Beautifully striated, grooved, and polished bedrock below the "tillite" are abundantly displayed in some outcrops. Not only that, what are interpreted to be special glacial marks occasionally embellish these pavements, such as chattermarks, crescentic gouges, nailhead striations, and roches moutonnées [60, p. 75]. U-shaped valleys, two boulder pavements, dropstone varvites, and faceted and striated clasts are also found in the Dwyka "tillite." Because of all these glacial "diagnostic" features, the evidence for a late Paleozoic glaciation in southern Africa appears impressive.
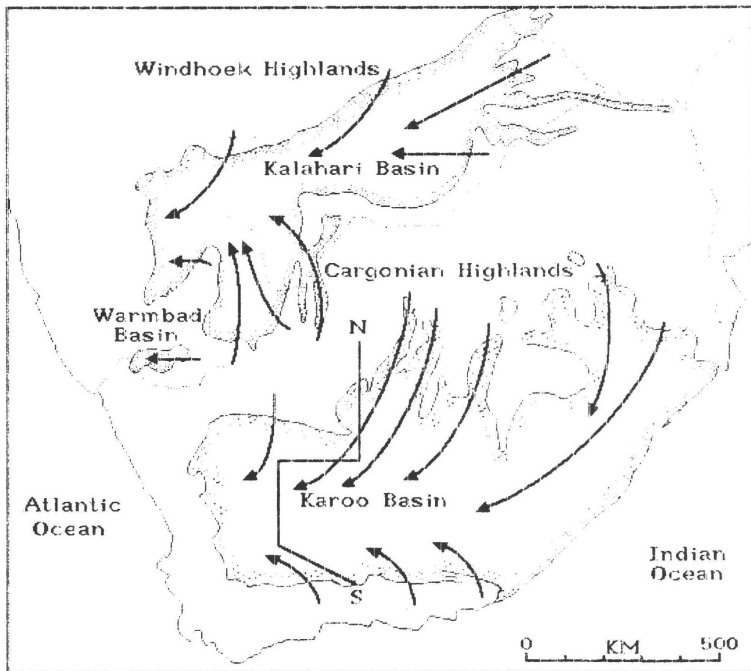

Figure 1. Map of southern Africa showing the basins that contain the Dwyka "tillite." Surrounding highlands and the flow directions of the diamictite also shown [53]. North-south line in the western Karoo Basin is cross section line for Figure 2.

The Dwyka Group in the Karoo Basin can be divided from north to south into three macrofacies: 1) the highland, 2) the valley/inlet, and 3) the southern platform (Figure 2). The most important distinctions between the northern two macrofacies are that the highland is mostly brecciated basement rock and conglomerate while the valley/inlet macrofacies is composed of mostly waterlain rocks of various sorts. These northern two macrofacies are generally thin, but of variable thickness, depending upon the relief of the Precambrian crystalline and sedimentary rocks. The diamictite fills paleovalleys and thins on ridges. The southern platform macrofacies is filled mostly with massive diamictite up to a maximum depth of 800 meters. The lower and upper boundary of the Dwyka Group slopes

southward.

Because of the many striated pavements, early geologists automatically assumed the Dwyka "tillite" was a lithified continental till. By 1970, geologists realized this interpretation was based on little more than the striated pavements. Further information, mostly after 1985, has shown that the Dwyka "tillite" is mostly, if not totally, a marine diamictite with ubiquitous evidence for mass flow [15, 50, 56]. Marine microfossils have been retrieved from the interbedded mudrocks [54]. In addition, arthropod trackways and fish trails in turbidites of likely marine origin have been discovered in many outcrops of the Dwyka Group [61, p. 36]. Even the thick beds of massive diamictite in the platform macrofacies (Figure 2) are now considered the result of submarine mass flow [15]. Although Visser once believed 90% of the formation was a continental "tillite" [52], he now concludes that deposition was predominantly from a marine ice sheet. Summarizing just the geochemical data, Visser [54, p. 383] states: "All samples from the platform facies association plot in the glacial marine field, as well as all the samples, except for one, from the valley facies association..."
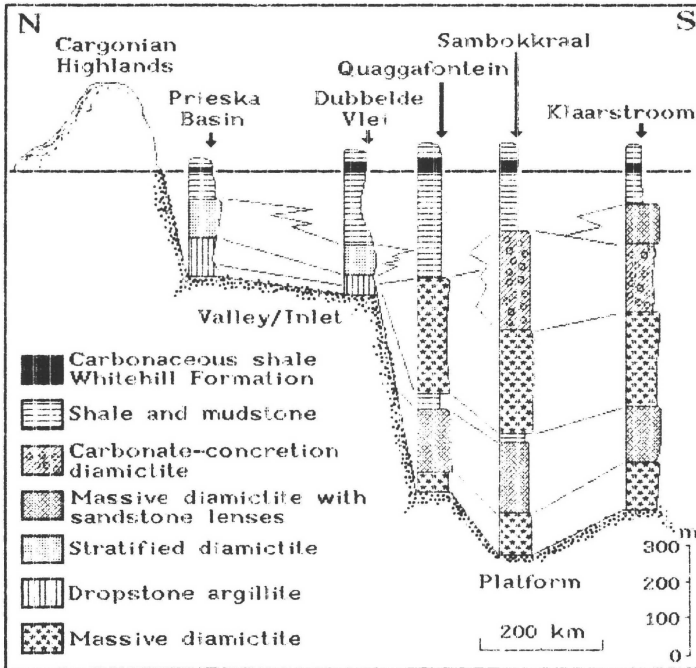

Figure 2. General north-south cross section through the Dwyka "tillite" of the Karoo Basin showing the relief of the basin floor and the lithostratigraphic units. The Whitehill Formation forms a distinctive white band that was used as a datum [53].

An unusual feature of the Dwyka "tillite" is that it thins and pinches out against basement highs; the "ice sheet" or "ice shelf" never planed down locally irregular topography. Visser [52, p. 669] writes: "In all the basins the glacial deposits either thin or pinch out against basement highs where they are overlapped by shales of the Ecca Group." Some of these high areas are tall and thin, like spires. For an "ice age" that lasted 50 million years, one would suppose that tall pinnacles would be planed down in that amount of time. Except for isolated patches in depressions, the Dwyka "tillite" also does not cover broad highlands, such as the Cargonian and Windhoek Highlands (Figure 1). These highlands are located where a thick ice sheet supposedly developed and spread out into the surrounding marine basins [53, p. 128]. One would expect substantial signs of terrestrial glacial activity on these highlands, but little or no evidence has been discovered.

These observations not only speak against a continental glaciation, but also against a marine glaciation. Debris dropped from icebergs is expected to mantle both topographic lows and highs. The fact that the Dwyka diamictite pinches out on basement highs is more consistent with large submarine mass flow. Submarine mass flow will deposit debris mainly in low areas. The debris will pinch out on these highs, or sometimes it will overtop higher elevation if the flow is strong enough. There are also no, or extremely few, claimed iceberg drag marks or

glaciotectonic features in the Dwyka "tillite." The diamictite itself does not differ from a nonglacial diamictite from Portugal [43, p. 675,676]. Therefore, the above observations are much more in accord with a mass flow origin than a glacial origin. Here is where the glacial diagnostic criteria are invoked to claim that the Dwyka diamictite was deposited during an ancient ice age. We will examine the three main glacial criteria as applied to the Dwyka "tillite."

The first criterion is striated and faceted clasts. Facets are flattened faces on a rock due presumably to abrasion. They are rare in the Dwyka Group, but locally abundant [60, p. 75]. For instance, 50% of the rocks in a particular bouldery diamictite were striated [59, p. 40]. However, it is well known among stratigraphers that mass movement can also striate and facet rocks. Schermerhorn [44, p. 253] reports: "...nonglacial sedimentary and tectonic processes produce pseudoglacial striated and faceted clasts." Even silt and fine sand grains can striate clasts. For example silt and fine sand in an Australian mudflow scratched a little less than one-half the pebbles [62]. This mudflow deposit also resembled the texture of a nearby late Precambrian "tillite." Judson and Barks [23, p. 377] summarize evidence for macrostriations due to mass movement: "Mass movement of material has long been known as an effective process of striating rock." As for faceted clasts, Frakes [13, p. 82] considers them as even less reliable than striae as a criterion for glaciation because of their diversity of origins. The number of striated and faceted clasts varies considerably in mass movement strata, as well as in recent and Pleistocene glacial deposits. So, the occurrence of locally abundant abraded clasts in the Dwyka Formation is not a significant criterion for judging its derivation.

Dropstone varvites is a second diagnostic property used to claim the Dwyka diamictite is a tillite. This is based on the superficial resemblance of these structures to recent and Pleistocene "varves." However, this criterion has serious difficulties. One main problem is that the one-year period for each varve couplet from recent and Pleistocene rhythmites is very difficult to prove. How then can it be applied to pre-Pleistocene varve-like sediments? Although modern-day varves do form in some lakes adjacent to glaciers, they form in many non-glacial lakes as well. Moreover, recent evidence indicates that many varve-like couplets can form within one year in both glacial and nonglacial environments [33, 34]. For instance, Lambert and Hsü [24] report that 300 to 360 varve-like couplets formed in 160 years in Lake Walensee, Switzerland. The number and thickness of each couplet varied with the location, so correlation from place to place would be difficult. The extra-annual couplets likely formed by turbidity underflows caused by either melting snow or runoff into the lake after heavy rain storms. Pickrill and Irwin [38] analyzed rhythmic sediments from a deep glacier-fed lake in New Zealand. They had to depend on ^{210}Pb dating to ascertain the annual sedimentation rate, since each couplet looked similar. They found an average of three couplets per year and surmised that the extra two couplets were deposited by floods and slumps. In another instance, Wood [63] describes three varve-like couplets laid down in a new reservoir. They were formed by three peak river inflows caused by light showers within a two week period! Smith, Phillips, and Powell [45] discovered that large diurnal variation in glacial meltwater, combined with semi-diurnal tides (especially the large spring tides) form two rhythmite couplets a day in small bays of Muir Inlet!. Each couplet averages half a centimeter thick, and the sequence superficially looks like varves [25, p. 115].

As stated in the previous section, distal turbidites can mimic varves. Crowell [5, p. 1005] states: "Sandstone and mud sequences laid down by turbidity currents far removed from a glacial environment may be easily confused with varved sequences..." Therefore, turbidity currents are the likely mechanism for pre-Pleistocene varve-like sediments, which would have been deposited rapidly. In fact one of the best and most studied examples of an ancient dropstone varvite is now considered to be a turbidite [27]. This was the primary criterion for defining the mid Precambrian Gowganda "glaciation" in Ontario, Canada.

We have shown that turbidites can mimic the fine layering of dropstone "varvites." However, how do the stones become embedded within these fine layers, if they are not dropped from icebergs into real varves? It would be a happenstance to have a stone fall from an iceberg at just the right time as a turbidity current was freezing. So, the question of how the stones were emplaced determines the origin of the fine-grained layers.

Recent evidence shows that turbidity currents can emplace stones of various sizes within their fine-grained upper portion. Cobbles and boulders have been observed "floating" in the finer grained rhythmites above the turbidite traction carpet. Postma, Nemec, and Kleinspehn [39, p. 47,49] report:

> Many turbidites appear to contain floating megaclasts...Reported examples include the deposits of inferred high-density turbidity currents that contain isolated, floating megaclast up to a few decimetres or even a few metres in their longest dimension...

Pre-Pleistocene dropstones within rhythmites are small and often isolated. They rarely pierce the bed. Usually, the stone slightly depresses the bed. This simple bending is usually offered as evidence for a dropped stone. However, simple bending of beds around a stone can occur by compaction after lateral emplacement and is not diagnostic of a dropstone. Thomas and Connell [49, p. 245] state: "Thus, clasts which show either symmetric or basally asymmetric bending of laminae around them cannot be regarded as diagnostic of drop."

Comparisons with modern and inferred Pleistocene dropstones also show that stones in ancient rhythmites were likely not dropped. Glacial dropstones often cluster in mounds, caused by the overturning of debris-laden icebergs [8, 36]. Except for one possible case, no iceberg dump structure is known from any pre-Pleistocene varve-like

sequence. Isolated dropstones often disrupt the bed as they strike the bottom. The amount of disruption depends upon the size, the shape, the axial orientation of the clast as it strikes the bottom, the sediment strength, and the depth of the water. Usually, the kinetic energy of falling particles reaches a maximum in a short distance. If a clast strikes vertically, it will sink into the sediment about two-thirds its length. Therefore, dropped clasts should normally rupture the sediment. From sediment cores taken from Cambridge Fjord, northern Baffin Island, Gilbert [14, p. 115] observed that small stones only slightly disturbed the sediments. But stones larger than about 8 millimeters mixed the fine sediments, obliterating the laminations. So even small stones can break the bedding. The fact that very few dropstones pierce the bedding favors lateral emplacement of the clasts.

In the Dwyka Group, "dropstone varvites" are often described, but are patchy and thin [16, p. 133]. As in other "tillites," the clasts are small and isolated [52, p. 677]. The rhythmites often display properties very unlike true varves. For instance, in northern Natal the varve colors are opposite to those of Pleistocene or recent "varves" [51]. Visser and Kingsley [58, p. 75] report that the rhythmites in the Virginia Valley display no lithological difference between the light and dark bands, except the light-colored bands are more highly indurated. Sometimes there is no grading at all within each layer [59, p. 41,42]. Therefore, rhythmites with outsized stones in the Dwyka diamictite are very likely not dropstones in ancient varves.

The many striated, grooved, and polished bedrock is the third and most significant diagnostic criterion for the Dwyka "tillite." Of all the "tillites" from around the world, the Dwyka has by far the largest number of abraded pavements. More than 100 localities, some with multiple striated pavements, are known. Abraded pavements are mostly etched on hard igneous rock in the northern and eastern Dwyka Group. However, in the southwest and east some abraded pavements are grooves within the diamictite. The best striated pavements are etched and polished on lava rocks at the Nooitgedacht farm, northwest of Kimberley, South Africa, which is now a national monument in honor of the late Paleozoic "glaciation." Visser and Loock [59, p. 38] state that 24 abraded pavements occur in just this one area.

How can a marine ice sheet can cause these abraded pavements, especially since there are few if any glaciotectonic features? This suggests another mechanism. Is mass flow up to the task? Although glaciers commonly abrade hard igneous rocks, mass movement also can striate, groove, and polish bedrock [5, p 1005; 17, p. 14; 43, p. 622]. In addition, mass movement can duplicate most, if not all, of the special features of abraded pavements. For instance, a debris flow from a flash flood striated a three square meter igneous boulder embedded solidly within alluvial gravel [21]. The resulting striae were in crossing sets, indistinguishable from "glacial" striae. Some of the striated pavements below the Dwyka "tillite" are as small as the top of this boulder. Grooves in soft sediment in the western Karoo Basin were said to be "...undoubtedly the finest examples of glacial pavements and striae yet discovered in the southwestern Cape..." [41]. However, the grooves also show delicate features that would be very difficult to preserve, if carved by an overriding ice sheet [55, p. 242]. Savage [42, p. 307] questions: "How these were protected from further ice action until buried beneath a subsequent deposit of tillite is difficult to envisage." The ice sheet likely would have torn up the soft sediments. Ice, meltwater, or further sedimentation should have obliterated the delicate features. The more valid explanation for the grooved surfaces within the Dwyka "tillite" is that a rapidly-moving debris flow carved them. After carving, the debris covered up and protected the delicate sedimentary features.

Chattermarks, crescentic gouges, and nailhead striae on the abraded pavements are actually rare [60, p. 75]. It is likely that mass movement and tectonics can duplicate such features. Crescentic cracks and nailhead striations are imprinted on a late Precambrian pavement in Brazil that Frakes [13, p. 79] insists was caused by mass flow. Oberbeck, Marshall, and Aggarwal [35, p. 11] state that, besides abraded pavements, possible nailhead striations on rocks were observed from the Ries impact crater in Germany. They also see no theoretical reason why debris flows cannot produce chattermarks and crescentic gouges. Petit [37] reports crescentic fractures, similar to glacially caused fractures, and nailhead-like striae on fault surfaces. There is no theoretical reason why mass movement cannot duplicate these features of abraded pavements. A large debris flow rapidly scoring a surface is little different from a glacier inching its way along.

Boulder beds are widely distributed within the Dwyka Formation, but only two boulder pavements are known, and they are small [57]. A boulder pavement is a layer of boulders in a diamictite in which the top has been sheared off by some moving medium. The origin of boulder pavements during the Pleistocene ice age is not well known [3]. New theories propose that they are formed by deforming glacial till below the ice, similar to a debris flow. Clark [3, p. 531] states: "Mechanics and rheologies of deforming subglacial sediment are fundamentally similar to those of debris flows." Thus, boulder pavements within pre-Pleistocene diamictites and from true glacial deposits may be formed by debris flows.

Roches moutonnées are considered a glacial diagnostic feature of abraded pavements. These are elliptical-shaped mounds or hills that have a gentle incline where the ice moved up the protuberance on the stoss side, and are usually broken or sharply sheared off on the lee side. Superb roches moutonnées are claimed at the Nooitgedacht farm near Kimberley, but, except for one, these forms are not roches moutonnées at all. Visser and Loock [59, p. 38,39] inform us:

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The basement outcrops consist of polished and striated dome-like rock knobs (length:width ratio = 1) with fairly steep (up to 35^0) stoss-sides and gentle leesides mostly covered by glacial debris...The glacial erosion features therefore do not comply to the definition of roche [sic] moutonnées...and can best be defined as drumlinoid complexes with a rock nucleus and a tail of glaciated debris.

The above features are not close to *roches moutonnées*. Lee-side plucking features are also rare. Since the authors are committed to the glacial hypothesis, they claimed the features are drumlinoid complexes, but they admit this interpretation is <u>inferred</u> [59, p. 42]. These drumlinoid complexes are likely the "drumlins" that Flint [12, p. 124] claims exist near Kimberley, South Africa. Due to the variable shape of these lava knobs, it seems more reasonable that a debris flow overran, striated, and polished them with only a slight change in their shape. It is also reasonable that a debris flow would leave debris on the downflow side of these obstructions. A glacier, on the other hand, would have either planed the knobs off or streamlined them into either *roches moutonnées* or rock drumlins.

U-shaped valleys occur in the valley/inlet macrofacies. However, these U-shaped valleys are not diagnostic either; mass movement also forms U-shaped valleys [22, p. 537-539, 565-570]. A further look at the stratigraphy of these U-shaped valleys shows they were eroded across a steep east northeastward trending paleoscarp, 300 to 500 m high, which still exists today. This is shown in the highland and valley/inlet macrofacies on Figure 2. Near the Virginia Valley in the northern Karoo Basin, the paleoscarp is 1000 meters high [58, p. 71]. The paleoscarp consists of soft Precambrian sedimentary rocks that could have been eroded rapidly by mass flow, especially if not completely consolidated. The eroded valleys started as faults [58]. Thus, mass movement could carve out U-shaped valleys rapidly by following the trend of these faults.

LARGE SUBMARINE MASS MOVEMENT DURING THE GENESIS FLOOD

We have discussed characteristics of the Dwyka diamictite that are inconsistent with the glacial interpretation but favorable to a mass movement process. Mass movement is also able to duplicate the special diagnostic features of the diamictite. Therefore, the evidence points more toward a submarine mass flow origin of the Dwyka diamictite than a glacial origin. Two other "tillites" are considered excellent examples of ancient "ice ages." These are the mid Precambrian Gowganda "glaciation" in Ontario, Canada, and the late Ordovician "ice age" in the Sahara Desert. However, the main diagnostic feature for the former, dropstone "varvites," is now considered a turbidite with embedded stones [28]. The latter "ice age" has many equivocal features that are crudely similar to features in recent glaciers and in the post-Flood ice age. However, the most significant feature is a striated and grooved surface that outcrops over hundreds of square kilometers. Rhodes Fairbridge [10, p. 271] states: "Of course, the rock pavement is the supreme criterion [for recognizing an ancient glaciation]." The problem with this feature is that the striations and grooves are in the same direction. No known glacier can striate and groove in the same direction over such a large area on soft sandstone with no glaciotectonic features. However, mass flow commonly forms parallel striations and grooves. Therefore, submarine mass flow is a much more likely explanation for the above three "tillites," as well as other "tillites" that contain fewer "diagnostic" features.

The Dwyka diamictite in the Karoo Basin alone is 600,000 km^2 in extent. The striated and grooved pavement in the Sahara Desert is parallel over hundreds of square kilometers. No modern submarine mass flow products are anywhere near this size. Based on the uniformitarian principle, present mass movement cannot account for them. Therefore the agent that caused the submarine mass flows that deposited diamictites must have operated on a scale and extent requiring at least regional catastrophic events.

The Genesis Flood provides a unique model to explain large-scale submarine mass movement. The Bible describes the Genesis Flood as a worldwide tectonic and hydrological catastrophe lasting about one year. This worldwide catastrophe would have quickly accumulated thick sediments over broad areas. Some of these sediments would either slump off unstable slopes or slide downhill from stable slopes due to tectonic accelerations, orogeny, or other processes occurring during that awesome event.

These landslides would likely travel rapidly over large distances and deposit thick diamictite. Recent subaerial landslides of large size, for some unknown reason, move rapidly and travel extraordinarily far. Melosh [27, p. 41] states:

> However, there is a class of very large landslides, or, technically, rock avalanches, that do not obey normal rules relating the total vertical drop to the distance of forward horizontal travel. These avalanches travel extraordinarily far for their vertical fall and are even capable of climbing slopes and topping ridges in their paths.

Most significantly, it is only large slides that are highly mobile [26, p. 161]. Thus, mass movements during the Flood would flow rapidly and continue moving across low slopes for large distances. No steep slope would likely be found in the immediate vicinity. Lack of a nearby steep slope is one of the main reasons why a mass flow origin for diamictites around the North Atlantic is rejected by Spencer [46, p. 216]. However, this would be expected during the Genesis Flood.

In the Dwyka diamictite, fairly large "U-shaped valleys" at the edge of the Cargonian Highlands (the valley macrofacies) could be rapidly excavated by headward erosion during mass movement, especially in soft, partially

consolidated sediment. Flow directions, based mainly on directional measurements on striated bedrock, are shown on Figure 1 for southern Africa. (The flow direction in the southern portion of the Karoo Basin is questionable because it is based only on "exotic" clasts thought to originate from Antarctica.) They indicate the diamictite was sloughed off the Cargonian and Windhoek Highlands and into the basins [53, p. 128]. This is as expected from a large mass movement process in which a huge mass of sediments slides off the highlands. It also explains why diamictite is not found on the highlands, except in small basins, and pinches out against pinnacles and broad highs within the valley/inlet and platform areas.

Rapid mass movement would produce grooves and striations on the sediments below. This mechanism would account for the large-scale parallel grooves in scattered outcrops covering hundreds of square miles below the Ordovician diamictite of the central Sahara Desert [10]. Parallel grooves are normally considered a product of mass movement, but because of the large area that the grooves cover in the Sahara, geologists dismissed mass movement in favor of glaciation. Catastrophic mass movement during the Genesis Flood is the only feasible mechanism to account for them.

Striated and faceted clasts, of course, would be expected in catastrophic mass movement. Large turbidites would often be associated with these debris flows, since subaqueous debris flows sometimes change into turbidity currents [18]. The debris flows would also be a source of outsized clasts for the turbidites, and the deposit would resemble dropstone varvites. Some stones could even be dropstones, but dropped from floating logs or kelp. The Genesis Flood would explain why most, if not all, ancient "ice age" sediments are marine. There would be no trouble accounting for the presence of warmth indicators, like extensive limestones or dolomites, adjacent to diamictites.

The Genesis Flood provides an adequate mechanism for the deposition of large diamictites covering areas the size of Texas and lying on nearly flat terrain. Many glacial-like structures would be formed. The Genesis Flood very likely is the only reasonable explanation for these diamictites. Pre-Pleistocene "ice ages" need not be invoked.

ACKNOWLEDGEMENTS

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