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PROCESSES ACTING TO PRODUCE GLACIAL DETRITUS

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Abstract

The traditional view of attrition and abrasion as the major agents producing glacial debris is considered in the light of recent work by engineering geologists and geomorphologists. The decomposition of certain rock types when affected by frost action leads to the concept of rock deterioration within the body of the glacier. It seems that differing rock types with varying responses to low temperature conditions would produce a heterogeneous mixture of particle size such as is usually termed glacial till. Observations in recent work on rock stability emphasise the importance of clay minerals and their mode of occurrence. It is considered that a detailed study of the stability of rocks forming the source region of a glacier should give considerable insight into the nature of the till produced.

It is generally acknowledged that the processes acting at the base of a glacier are imperfectly understood. This fact has not deterred geophysicists and geomorphologists from theorising about the character of these processes but the link between the processes and the deposits produced has been neglected. Recent work in both engineering geology and geomorphology has provided a great deal of new material which gives a firmer basis for theorising about the nature of processes acting subglacially.

Bed rock is obviously a major contributor to the detritus produced by glacial action and geomorphology is beginning to focus its attention on this. Both Yatsu (1966) and St. Onge (1968) have recently produced work demonstrating the considerable influence of bedrock on topography. This work in both cases emphasizes the important role of clay minerals in rock decomposition. Investigations of this type enable one to see more clearly the processes implied by Flint (1957, p. 76) who states "It is obvious that the grinding up of bedrock into fine particles is an important element in glacial erosion." His preceding statement "Abrasion, the scour of rock by rock, is evident not only in the striated, polished and fluted surfaces common to most glaciated regions, but also in the large quantities of fine sand and silt, 'rock flour' visible in the streams that drain living glaciers . . ." gives some indication of the complexities involved in accounting for the internal mechanism of the glacier. Obviously abrasion cannot easily be observed in the subglacial environment. Equally, the existence of rock flour in the meltwater of the proglacial area is not itself sufficient evidence that abrasion is the creator of the material.

Recent research by engineering geologists has produced results which seem to offer the key to a greater understanding of the processes of till formation. These are well summarised in a paper by St. Onge (1968) who is primarily concerned with nivation landforms. Many of his points are pertinent to a consideration of the processes producing glacial detritus. Carol's (1947) concept of *frost wedging* acting beneath a glacier loosening rock enabling it to become frozen into the glacier and carried with it, seems to be valid.

St. Onge's (1968) summary of the action of frost-cycles is particularly pertinent: He states " . . . both field observations and laboratory studies indicate that mechanical weathering due to frost is not a very effective process in a dry rock unit. Mechanical weathering, like its companion process, chemical weathering requires water to be an important factor in landscape evolution." Gjessing (1956) and Theakstone (1956) state that the subglacial environment is one in which supplies of water are available. Therefore physical and chemical weathering processes can operate. Details of the physical weathering process have been provided by Lliboutry (1965) and St. Onge (1968). The detritus so produced varies with the rock type. Experiments have been undertaken to determine the nature of the detritus and it is usually found to be coarse and angular. Sandstones frequently disintegrate to sand and shales to a silt.

Continuous subglacial frost action could therefore produce a deposit which compares closely with the sandy or silty material typical of many areas of glacial deposition. At this point there seems to be a need to investigate the presence of the clay materials frequently found as glacial deposits.

Geological research into the nature of water and ice in the pores of carbonate rocks led Dunn & Hudec (1966) to the conclusion that frost action as traditionally conceived was not responsible for the disintegration of certain rock specimens. Their work was designed to investigate the "soundness" of rock for engineering purposes. Taking samples of rock which were known to be "sound" or "unsound" they designed a cold D.T.A. apparatus which was able to detect the freezing of water contained in a rock sample. After a series of experiments it was found that the "sound" rocks were those in which 50-100% of the contained water froze at temperatures from —7°C to —10°C and no further freezing could be detected at temperatures down to —20°C. The "unsound" rocks were those in which less than 50% of the contained water froze at temperatures as low as —40°C. In eleven of these fourteen samples of "unsound" rock no freezing whatsoever was detected. Obviously in these cases expansion of water on freezing was not the cause of the rock being "unsound" (i.e. disintegrating under freeze-thaw conditions). Further examination of some of these rock samples showed that they were of unusual structure. The samples in which magnesium carbonate has replaced calcium carbonate were found, on inspection, to consist of crystals of magnesium carbonate surrounded by a film of clay. This clay was the impurity from the rock which had been excluded by the magnesium carbonate crystals as they grew.

The clay surface thus presented is one onto which water molecules are adsorbed. Water at low temperatures becomes ordered water in which the individual molecules take on a particular orientation. The molecules, so oriented, are polar molecules carrying a negative charge on the oxygen atom and positive charges on the hydrogen atoms at the other extremity of the molecule. Where pore spaces in the rock are large this dipole has little effect as it projects from the clay surface into the mass of water filling the pore space. Water of such quantity is known as bulk water. Where the space is much more restricted, i.e. pores are five microns or less in size, then a different situation exists. In these circumstances the layer of ordered water at the clay surface is rigid and, as there is a similar surface on the opposite wall of the pore space, a similar layer of water exists there. This results in a situation where the dipoles are attracted to the wall of the pore space but the charges on their free ends repel each other at the centre of the pore space. As the temperature is lowered the alignment of the molecules becomes more rigid hence the repulsive force becomes greater but the *water does not freeze*. Variations in this force accompany temperature changes and it is these forces which appear to be instrumental in the rock disintegration. Dunn & Hudec have effectively demonstrated this by using the highly polar liquid formamide to produce similar results after a small number of temperature cycles (Anon. 1966).

Although the experimental evidence of Dunn & Hudec referred to carbonate rocks, the same processes would act given the presence of clay in minute fissures within most rock types. The conditions at the base of a glacier are such that the polarity of water would be greatly enhanced. Carol's (1947) hypothesis of glacial action in these conditions is worthy of some re-examination.

The postulated disintegration of bedrock by frost action could, in the case of carbonate rocks, be attributable to the ordered water decomposition described above. Such material once incorporated into the glacier results in the fragments being exposed to the optimum conditions for breakdown. Surrounded by ice they have the low temperatures which lead to the breakdown of the rock by ordered water and hence fine fragments would be produced not by abrasion but by rock disintegration. Clays of different types would, of course, be likely to behave differently. The classical distinction between swelling and non-swelling clays highlights the importance of the interactions between water and clays. The polar effect of water at low temperatures as suggested by Dunn and Hudec further complicates the role of water in clay-water systems (Brown, 1965; Van Olphen, 1963). Presumably the polar mechanism of Dunn and Hudec would increase the very large pressures which have been observed at temperatures above freezing by wetting compacted swelling clays (Grim, 1962 pp. 247-251). Moreover, as Dumbleton and West (1966) have pointed out, the type of mineral present is likely to affect the plasticity of a clay and this again is likely to be a significant factor in the behaviour of disintegrated rock material beneath and within glacial ice.

It would seem that in such studies of clay-water systems we have a basis for a greater understanding of the processes of glacial action. Certainly the possibility that rock fragments can be weathered within the ice lends greater credibility to the glacial origin of deposits known as boulder clay. A random distribution of fragments in the ice mass all weathering at different rates gives a deposit, on melting, which is a heterogeneous mixture of particle-size. In such circumstances the ultimate control would be the bedrock of the area and its susceptibility to disintegration by the wetting of the contained clay minerals, and the disruptive force of ordered water at low temperature. To use Dunn and Hudec's (1966) terms an area of "sound" bedrock would presumably yield a stony or gravelly till. An area of "unsound" bedrock would presumably yield a silty-clay till.

It is particularly pertinent to note that recent research into the nature of stylolites demonstrated them to be a more widespread phenomenon than was previously thought. The existence of clay minerals near or within the stylolite seams would indicate that the processes outlined above could be active in rocks which have well developed stylolite systems. Park and Schot (1968) list a wide range of rock types in which stylolites have been observed and it seems that they occur in almost all rocks. In such circumstances these rocks would be susceptible to decomposition processes which would exploit stylolite bands and result in rock disintegration. The dimensions of stylolites would seem to invite the presence of adsorbed water and it would be surprising if the clay minerals present remained unaffected by the presence of this water in the subglacial environment — when it would, presumably, become ordered.

Thus the determination of the "soundness" of bedrock should certainly become an important item in the evaluation of till genesis. From a study of the source region, if sufficiently exhaustive geological examinations are conducted, it should be possible to predict the "till" which would result from glacial action. Further study of clay minerals should permit an assessment of the history of the till by comparing its present character with the prediction. Such research, if rigorously conducted at all stages should meet the requirements outlined in Yatsu's work for a more rigorous and scientific geomorphology (Yatsu 1966, p. 2).

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