by adding wire loops. (A series of loops of varying lengths is needed.) (2) Next transfer the mineral to the lower pan. It will lose weight, so the counterpoise is moved toward the fulcrum until balance is restored. The specific gravity is then indicated by the position of the counterpoise on the beam.

Accuracy.—Tried with such minerals as quartz and calcite, this balance is accurate to about two units in the second decimal place for two or three grams of material.

A Portable Balance.—A convenient balance for rough work in the field may be made of a thin strip of wood, such as a foot ruler, driving a nail through for a fulcrum. To the short arm is attached a thin cord with rubber elastic for holding the mineral. The long arm is graduated so that the specific gravity may be read off directly as previously described.

The balance upon which the above description is based was constructed by Mr. F. A. Stevens, mechanician at Stanford University.

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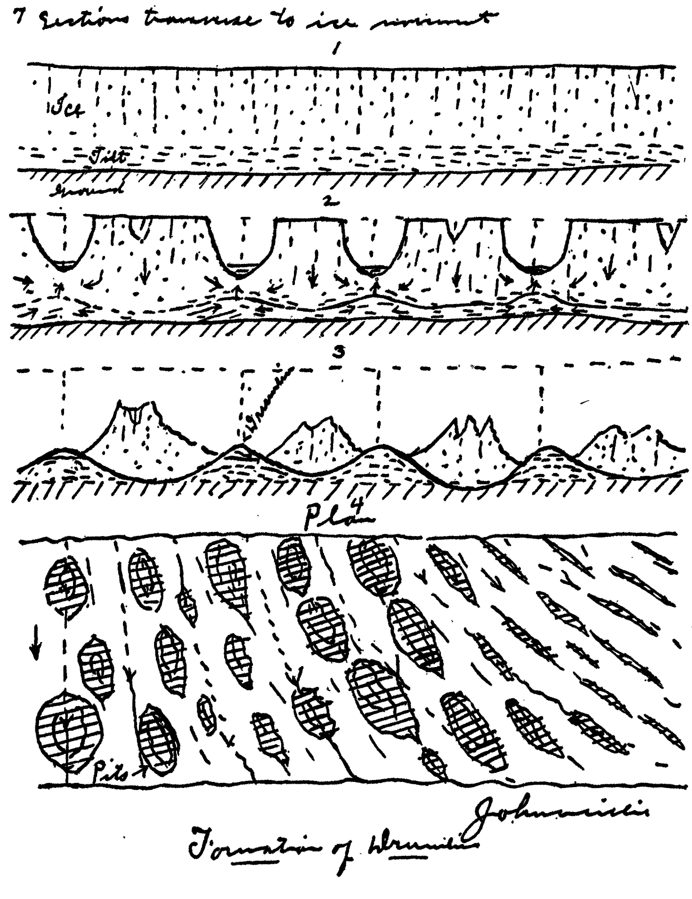
WHAT CAUSED THE DRUMLINS?

To the Editor of Science: The following is a concise outline of a theory offered as an explanation of the process of formation of the peculiar smooth-contoured hills and ridges called *drumlins* and their allied topographic forms that occur in certain localities within the areas of the earth's surface formerly occupied by the ice sheet, notably in central New York, in southern Wisconsin, in portions of New England and of Canada, and in Ireland. These features of the surface have been the subject of much study and speculation and of a variety of theories, but so far as I can ascertain from available literature on the subject, the explanation here given has not heretofore been proposed.

During the period of dissolution of the ice covering certain glaciated areas, commonly called the period of "retreat" of the ice sheet, melting took place in the upper surface as well as on the front wall or slope. Owing to the strains in the ice mass produced by the forces that caused and attended the general advance of the sheet its internal structure had become such as to modify the process of melting from the upper surface. Before melting began there had been formed in the ice a system of vertical and parallel cleavage planes and fissures and the general direction of these conformed to the direction of the ice movement, owing to the forces above referred to. The assumed difference between a general ice sheet on a nearly horizontal surface and an individual glacier with a steeper descent in respect to cleavage is here to be noted. Changes of temperature with the changes of season may have had something to do with this structure. During the melting process the upper part of the ice sheet became deeply pitted or honey-combed on a somewhat gigantic scale because of the fissures and cleavage planes, and the pits were more or less elongated horizontally in the direction of these fissures and planes. As the melting proceeded on the internal surfaces of the pits, enlarging them, of course, the earthy matter in the upper parts of the ice, including stones, boulders, sand and gravel, dropped to the bottom of the pits and this material was thus subjected to a certain amount of water action and washing while the water drained away. With the enlargement and deepening of the pits and the removal of water the areas of ground ice and land surface beneath the pits were relieved of a large portion of the vertical pressure which the full thickness of the ice sheet had produced, while between the pits this pressure remained nearly the same as before melting started. The consequence was that a slow movement or flow of bottom ice towards the pits and an upheaval in the bottoms of the latter took place, and this lateral and concentering and upward ice flow at the bottom would, of course, carry with it the "till" material which was located principally in the lower portions of the glacial sheet, and a certain amount of the underlying material as well. There may have been periods during which the general melting was checked, due to seasonal changes of temperature or other causes, while the above concentering ice flow at the bottom continued. Meanwhile the general advance of the remains of the ice sheet had not entirely ceased and this movement exerted a modifying influence in producing the surface forms that eventually resulted. Finally, as the ice faded away and the water drained off the englacial matter was quietly laid down in the smoothly rounded hills and ridges with intervening plane or hollowed surfaces that constitute the hitherto mysterious drumlin topography.



The forms of these surface features are doubtless attributable in some degree and in certain localities to the direct action of overmoving ice, either during formation or subsequently, but it seems probable that the gathering up of the drumlin material while in and under the ice by the movements described, and what may be termed its precipitation as the ice and water disappeared by melting and slow drainage respectively, were the principal formative causes. If the drumlin area was subsequently again covered by ice, this was probably of moderate thickness and was formed largely in place by accumulation of local snow fall in excess of the rate of melting, with a limited forward movement of the sheet; the effect on the surface being like laying down a heavy blanket over it and then dragging the blanket forward, rather than like pushing over the area a thick ice sheet with a definite front edge.

The original forms of the drumlins appear to have been remarkably preserved since the ice period by the conditions of soil and climate favorable to a protecting covering of vegetation, and by a texture and composition of the material that are adapted to the absorption of water falling on the surface and to effective subsurface drainage, so that there has been little change by surface erosion or washing.

The forms of surface produced in any particular locality would, of course, be effected by a variety of conditions, such as the original topography and surface material of the drumlin area, the thickness of the ice sheet, the rate of its movement, and the nature, amount and location in the mass of the ice of the englacial material; the rate of melting and its degree of regularity and continuity, and the direction of the general movement of the ice sheet and the direction of the prevailing winds, since these would affect the action of the sun and atmosphere on the shape of the pitting in the ice. The rate at which the water was drained away would be a factor, too, as would also be the general climatic conditions during the melting period.

Besides offering a "workable hypothesis" as to the causes of the drumlin forms and their orientation, the above theory appears to explain many observed details that it has been heretofore difficult to account for satisfactorily. Among these may be mentioned the occurrence of the drumlins generally on approximately flat and level areas, the approximation roughly to uniformity in height in any given locality or group, and the nearer approximation to uniformity of spacing transversely to the direction of ice movement than parallel thereto where the drumlins are closely clustered; the internal composition of the drumlins, which is usually a compact till material with occasionally layers or strata of sand, gravel and boulders, these layers being usually near the top and conforming more or less closely to the curvature of the outer surface; the evidences of formation by lateral collection of local and recently deposited material; indications of lateral compression of the mass of the drumlin; the form of cross section sometimes seen which has quite flat side surfaces inclined to be hollow instead of convex and with a tendency to a sharp central ridge or apex; greater steepness of slope on one side than on the other in the drumlins of certain groups; more abrupt slopes or greater bluntness on the ends turned towards the source of the ice flow than on the other ends; the characteristic hollows between the drumlins and the troughs and hollows at their bases that are found in certain drumlin areas; and finally, what has seemed to the writer more puzzling than any other feature, *the departures from type forms;* the irregularities and variations in the shape and in the orientation of the drumlins, and their frequent close association with morainic deposits of quite different character. The variations of form are from greatly elongated slender ridges of very low relief to high hills with nearly circular horizontal contours—the "Bunker Hill" type of the Massachusetts region—and to hills only approximating to drumlins called "drumloids," while there are a few cases of drumlins elongated transversely to the direction of ice movement. Some characteristic drumlins are curved horizontally in their length, some appear to be branched or multiple, and many considerable departures in orientation from the local direction of movement of the ice sheet are to be found. These apparently abnormal shapes and positions are attributable to local peculiarities of the original land surface, and to the variations in the internal structure of the ice and in the direction of the fissures and cleavage planes. No doubt there are other causes.

As to the absence of drumlins from areas apparently favorable for their formation under the above theory, it can only be said at present that for some reason the various contributing causes were not so balanced or related as to produce the results herein described, and the ice withdrew or disappeared so as to lay down the englacial material in a sheet instead of gathering it up into drumlins. Possibly in certain areas drumlins were actually formed and subsequently washed away or otherwise destroyed.

John Millis