cular bergschrund, it may do so in extreme summers, or it may have done so in the past, when the glacier was thinner, the bergschrund more open, and the climate different. Moreover, nivation must have alternated with glacial scour, fluvial erosion and mass wastage in most cirques.

(4) In keeping with a statistical approach to bergschrund temperatures, we must analyse the slopes of cirque headwalls and beds in a far more rigorous manner. The methods of Strahler[11] were prominent in Battle's notes and conversation in 1953.

(5) "Our ultimate object as geomorphologists must be to provide a process and chronology for the various stages of corrie [cirque] development."[3]

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THE CENTRIFUGAL SEPARATION OF FREE WATER FROM MELTING SNOW

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IN the course of recent investigations into the precise measurement of ice melt at an ablating snow surface, it was found that the amount of ice melted during a given period often failed to correspond with the ablation (surface wastage) for the same period. Obtaining a quantitative relationship between ice melt and surface wastage over short time intervals required a method for rapid measurement of free water content in the surface snow layers. Calorimetry was tried and found unsatisfactory by reason of its slowness and the requirement of precise thermometry difficult to meet in the field. A review of possible methods other than calorimetry lead to the conclusion that physical separation of the liquid and solid phases of water in snow by centrifuging seemed most likely to meet field requirements. Although other methods have been discussed in the literature (summarized in part by Halliday[1]), only recently has a centrifugal method been described by Oura and Kinosita[2] of Japan. Unfortunately their work is not available in English translation. To gain direct information on use of their method, an experimental snow centrifuge has been constructed and tested.

The instrument was designed to be light in weight and entirely hand operated. This required a simple centrifuge, operating at slow speeds and with a long radius of revolution. On the lower left in Fig. 1 (p. 763) is shown the frame for supporting the snow sample and the detachable glass vial in which the extracted water is collected. Snow is collected in a standard 500 cc. stainless steel sample tube, shown in the upper part of the figure, and the tube is inserted in the centrifuge frame. A sieve prevents snow grains from descending into the vial with the melt water. At the right is the hardwood handle with bearing, which is attached to the frame by a two-meter length of cord. The frame is insulated with a thick sponge rubber pad to prevent snow melt by heat transfer from the air during operation. The entire unit, less the sample tube, weighs 600 gm.

This snow centrifuge was tested on the Blue Glacier in the Olympic Mountains of Washington State, and operation was found reasonably satisfactory. To carry out a test for free water content, three or four hundred cubic centimeters of snow were collected in the chilled sample tube, which was immediately placed in the frame and whirled at the end of the two-meter cord for about one minute. One revolution per second was about the maximum that could be achieved without exhausting the operator. Little additional free water was extracted after fifty revolutions. Weighing the snow sample and extracted water concluded the test, which altogether required about three minutes. Snow or firn loosely scooped up in the sample tube gave best results. Firn collected as an undisturbed core in the sample tube was less satisfactory, particularly when ice layers obstructed the passage of melt water during centrifuging.

There are two principal sources of error in measuring free water content of snow with a centrifuge; one being increase of free water in the sample by snow melt during centrifuging, and the other retention of water on the snow particles by surface tension. The snow can be reasonably well insulated against heat transfer from the air, hence the only significant source of heat for melting should be the steel sample tube. This source can be kept small by chilling the tube before using, but in practice is difficult to eliminate entirely.

Retention of water by surface tension may be large with the low acceleration developed by this simple, hand-operated device. An attempt was made to estimate indirectly the quantity of free water thus retained in the snow after centrifuging. About four hundred cubic centimeters of thoroughly wetted twenty-thirty mesh standard quartz sand (grain size 0·5–1·0 mm.) were placed in the instrument, and the surplus water removed by centrifuging. Results showed that about 15·0 gm. of water remained in the sand. The test was repeated with very fine screened gravel of mixed mineral content (grain size 2–4 mm.). In this case about 14·0 gm. of water were retained after centrifuging. More water added to the wet sand or gravel was almost all removed by additional centrifuging. If a like quantity of water is retained by snow samples of similar grain size, then this source of error is serious, and may obscure any errors due to melting. Fifteen grams represents more water than often was extracted by centrifuging from the firn (grain size 2–4 mm., density 0·5–0·6 gm/cm.^{3}) used in the tests.

There is some evidence that less water may be retained by snow or firn than by sand or gravel. The variations of free water content in the surface layer of summer firn on a cloudless day, as measured with this test instrument, are given in Fig. 2 (p. 771). When the first sample was collected at 06.00 hr., the snow was frozen hard, with the nocturnal crust about 15 cm. thick. As successive samples were taken, the amount of free water extracted gradually increased, culminating in a sudden rise between 10.00 and 11.00 hr., when a distinct change in the appearance of the snow surface was noted. In the afternoon, the amount of free water obtained decreased rapidly until the last observation at 17.45 hr., when a crust began to form on the snow surface.

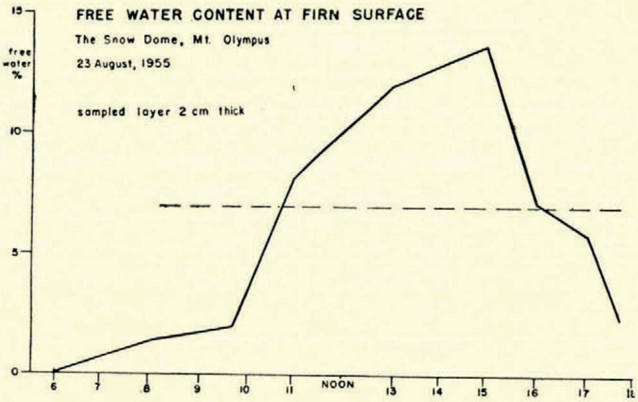

Fig. 2

The curve shown in Fig. 2 is not the one which would be expected if any large quantity of water were retained in the snow by surface tension. In the early morning and late afternoon, when the quantity of free water present in the snow fell below the critical amount retained, no water would be extracted by centrifuging, and the gradual rise in free water content from the zero value of the frozen crust would not be noted. If, for instance, the amount of water retained were equal to that found for sand and gravel, approximately the part of the curve in Fig. 2 shown above the dashed line would be obtained. As this was not the case, the error due to water retained after centrifuging apparently is lower with snow than with sand or gravel, though the evidence is not conclusive.

It is possible that in actual field operation the two principal sources of error, being of opposite sign, may tend to cancel.

Though sufficient data have not been obtained with this test instrument to warrant additional conclusions at this time, the centrifugal method of measuring free water in melting snow does merit further attention. Simplicity of the equipment and rapidity of operation commend the method to the field worker. More tests are planned, but this preliminary discussion is presented here in the hope of stimulating wider interest in the method.

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REVIEWS

REALMS OF WATER. P. H. Kuenen. London, Cleaver-Hume Press Ltd.; New York, John Wiley and Sons, Inc. 1955. 327 pages, 16 plates, 190 text-figures. Price 35 shillings.

The plan of this book is lucid. It follows the movements of water in inanimate Nature which begin with the evaporation of water from the seas and end with its return thereto by river discharge—the hydrological cycle. The scheme is worked out in five long chapters, the first two treating water in the oceans and in the atmosphere and the remaining three dealing with land waters in the solid state, in the ground and flowing over the land surface. A short introductory chapter on the circulation of water in all its forms about the Earth and on the properties of water is brilliantly written.

Fig. 6. Air photograph of Austerdalsbreen, showing the form of the valley, and the approximate positions of profiles D, E, F and G

Photograph by Widerøe's Flyveselskap og Polarfly A/S, Oslo

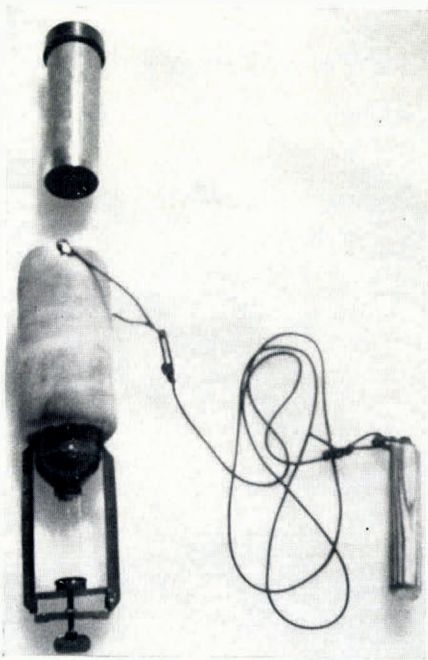

Fig. 1. Centrifuge for separating water from melting snow (see E. R. LaChapelle, p. 769)

Fig. 4. Summit of morainic arc of Litle Jiek'kevarribreen (see R. W. Galloway, p. 730)

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