which corresponds closely with values determined in permafrost elsewhere. From this it can be assumed that the bottom of the ice sheet is below freezing point at this point. In north Greenland the low values of τ at points in the eastern part of the traverse suggest that the bottom is at melting point, while on the western side the values approach those obtained in south Greenland, where the bottom is frozen. It is unlikely that the differences between the western and eastern ends are due to differences in the rates of accumulation of snow, and since the rate of movement is greater in the east, larger values of τ might be expected there. However, the additional movement may provide sufficient heat for the amount of melting to be significantly greater, so that the "lubrication" is more efficient in the east.

Sufficient data are not yet available for a full analysis to be made of the properties of ice and of the form of the Greenland Ice Sheet. In particular, information is required of the rates of movement of parts of the ice sheet and of conditions existing at the bottom of the ice. It is hoped that the forthcoming International Glaciological Expedition to Greenland will be able to undertake seismic refraction experiments in north Greenland, as well as the redetermination of the positions of the beacons previously erected at many points on the ice sheet.

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PRELIMINARY RESULTS OF RESEARCH ON SNOW AND AVALANCHES IN CZECHOSLOVAKIA

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ABSTRACT. This paper gives a brief account of the results so far obtained in research in Czechoslovakia on the crystallographic, stratigraphical and thermal properties of snow cover, and the use of these data in avalanche investigations. Avalanche danger is predicted by comparing the penetration resistance of snow layers, measured with a rammsonde, with resistance graphs of typical avalanche situations.

ZUSAMMENFASSUNG. Es wird ein kurzer Bericht über die Resultate gegeben, die bisher in Forschungen in der Tschechoslowakei über kristallographische, stratigraphische und thermische Eigenschaften der Schneedecke erhalten worden sind, und über die Anwendung dieser Data in Untersuchungen von Lawinen. Lawinengefahr wird durch Vergleich des Durchdringungswiderstandes von Schneeschichten, der mit einer kleinen Rammsonde gemessen wurde, mit Widerstandsdiagrammen typischer Lawinen Lagen vorausgesagt.

Introduction

The increasing number of casualties from avalanche accidents in the mountain area of Czechoslovakia, resulting from the ever increasing popularity of ski-ing and winter alpinism, induced us, several years ago, to begin systematic research into snow and avalanches. This research has been carried out within the framework of the government Mountain Service, and covers all the important mountain areas of the country, especially the sub-alpine * Krkonoše region, and the more mountainous Vysoké Tatry, a region very prone to avalanches.

Our research started on the basis of work done in other countries with a well-developed winter sports traffic, but we soon discovered that the different geographical conditions in our country, where the principal areas are sub-alpine, do not allow us to use the results of foreign research indiscriminately. We have used some fundamental measuring methods used elsewhere to test our own theories, and have devised a method for determining the danger of avalanching which is somewhat different from the Swiss method on which it is based. Using this forecasting method, we have established a network of measuring stations in the areas in which avalanches occur. Our work at present is devoted almost exclusively to the prevention of avalanche accidents, and the main task of our stations is to determine the danger of avalanches, and to warn the public in due time. Fundamental research on the physical and mechanical properties of snow cover is at present a secondary consideration. Nevertheless we are attempting to solve some fundamental problems, and believe that the results of this work may be of use in other fields such as meteorology, hydrology, crystallography and agriculture.

This paper gives a brief account of our present, mostly qualitative results, which are peculiar to the mountain areas of Czechoslovakia.

Metamorphosis of Snow

One result of the climate of the Czech sub-alpine regions is that stratigraphic changes occur rapidly in snow cover. This is very evident in Fig. 1 (p. 74), which shows the development of snow cover on a test area in Krkonoše during the winter of 1953–54. The symbols used for the different types of snow are those used in the older Swiss literature (Fig. 2, p. 75). Fig. 1 shows that powder snow is converted to firn in at most ten days and usually much less. This rapid metamorphosis forces the stations in Krkonoše to study the fundamental problems of physical properties, and in particular, the crystallographic processes in snow cover[1]. We have used the density changes of individual snow layers to indicate the course of the metamorphosis although we are aware of the danger of neglecting other criteria, such as the size and shape of the snow crystals. Despite this, we have been able to construct curves showing the metamorphosis which are close to the ideal harmonic shape which should be found if atmospheric conditions remained constant. The curves are affected by the changes in density caused by the migration of water molecules via the vapour phase resulting from variations in atmospheric temperature. The shape of the metamorphosis curves demonstrates that the rapid initial changes must be connected with the different lattice energy of dendritic crystals. If this driving force were absent the metamorphosis curve would be a straight line assuming that external conditions were constant[1]. It is our intention to study crystalline processes in snow cover so as to support this theory quantitatively.

The Soviet glaciologist Tushinskiy has also studied the theory of lattice energy and vapour migration [2, 3], and perhaps attributes too important a role to the latter process in the metamorphosis in snow. We have attempted to verify some of the experimentally unproved parts of his migration theory by measuring the air humidity at various levels in the snow cover in conditions of varying air temperature, when the migration of water molecules is greatest. These experiments will be concluded during the coming winter, and we shall return to this interesting and little-studied problem in a special article. We have also made a careful qualitative study of vapour migration, and have confirmed the existence of *fibrous firn* having a vertical texture and resulting from sublimation as described by Tushinskiy [3].

* The term sub-alpine is used in the sense of the German *Mittelgebirge*.—Ed.

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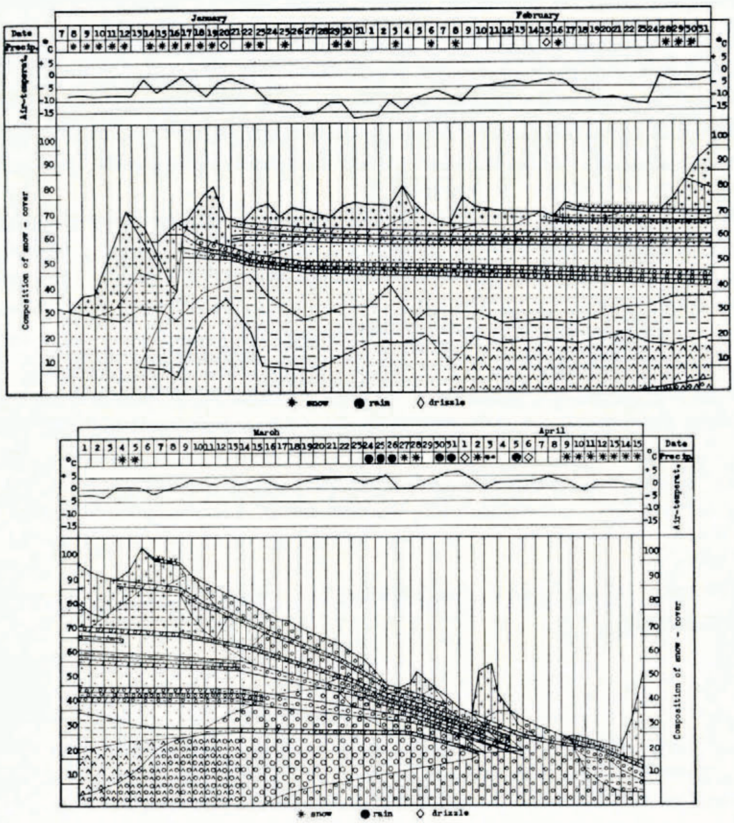

Fig. 1. *Diagram showing the thickness and nature of the snow cover during the winter of 1954 at Krkonoše, Hnědý vrch, 900 m. above sea level, on a slope of 5°. The symbols used for snow layers are explained in Fig. 2. Note the short time taken for powder snow to change character. The upper graph shows air temperature and the symbols at the top the nature of precipitation*

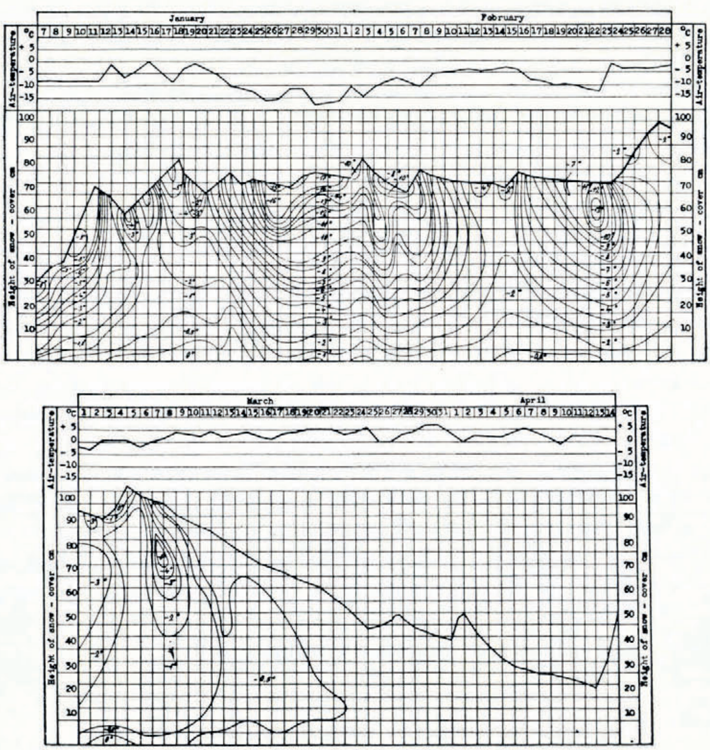

Fig. 3. *Diagram showing the variations in temperature in snow cover during the winter of 1954 at Krkonoše, Hnědý vrch. The upper graph shows air temperature, while in the lower diagram lines are drawn connecting points of equal temperature (isotherms)*

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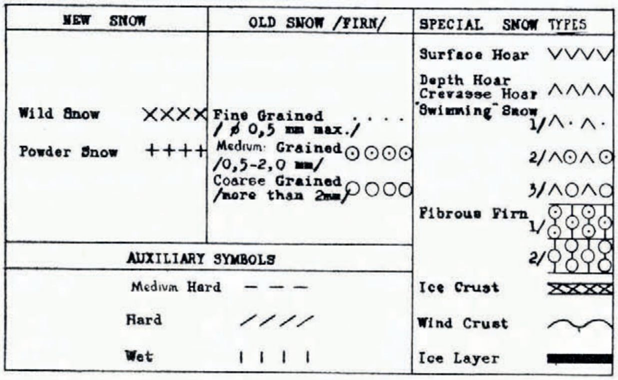
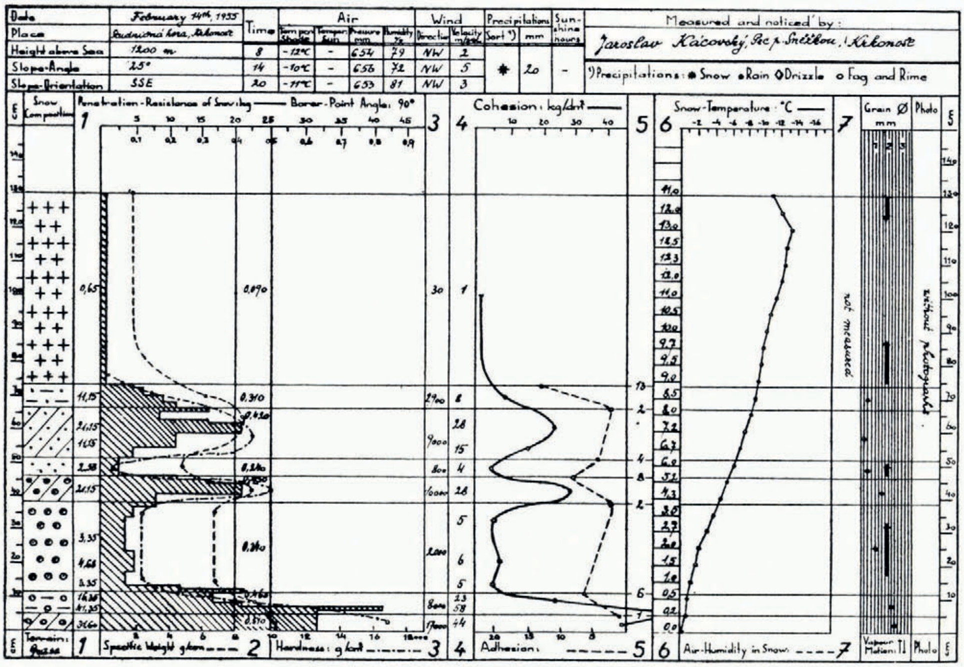


Fig. 2 (left). International snow symbols

Fig. 4 (below). Data for determining the threat of avalanches



We have also observed the formation of depth hoar photographically[1], and, although these researches are not yet complete, we cannot accept Tushinskiy's views on the formation of depth hoar by recrystallization. We consider depth hoar to be formed by a process of pure sublimation, and Tushinskiy's photographs[3] do not seem to us to be sufficient to confirm his theory.

Temperature and Density of Snow

The results we have found in measurements of temperature and density in snow cover on our sub-alpine areas are somewhat different from those found in the Alps. For example we are unable to use the Swiss ideal temperature curve because of the greater variation in weather and snow cover in our lower mountain areas. Rapid air temperature changes and the variety of snow layers with their differing thermal conductivity influence the temperature curve, which is seldom straight for the lower parts as it is in typical high mountain conditions[1]. We have followed the development of temperature in the snow cover throughout a complete winter season, and drawn isothermal curves (Fig. 3, p. 74). With these it is possible to confirm Oechslin's assertion that atmospheric humidity and wind speed influence the temperature of the upper layers of snow cover[4].

Measurement of density of snow in the Alps are only partially in agreement with our measurements. We have not found in our sub-alpine areas the extreme values of 0·01 to 0·03 for wild snow or those of 0·7 to 0·8 for coarse-grained firn. Our specific gravity measurements have ranged between 0·05 and 0·56, due to our relatively mild winter weather and the absence of summer firn fields and glaciers. In the past two years we have found the following values for snow density:

Snow Type	Density gm./cm.³ *minimum*	*maximum*	*average*
Powder snow:			
Soft	0·050	0·192	0·123
Medium	0·172	0·260	0·222
Hard	0·184	0·440	0·312
Wet	0·108	0·204	0·169
Fine-grained firn:			
Soft	0·230	0·360	0·296
Medium	0·256	0·430	0·346
Hard	0·330	0·448	0·413
Wet	0·296	0·390	0·336
Medium-grained firn:			
Soft	0·328	0·380	0·352
Medium	0·300	0·470	0·367
Hard	0·350	0·500	0·428
Wet	0·400	0·488	0·427
Coarse-grained firn:			
Soft	0·290	0·560	0·441
Medium	0·385	0·560	0·433
Hard	0·440	0·560	0·486
Wet	0·330	0·520	0·472
Other forms of snow:			
Surface hoar			0·128
"Swimming snow" (depth hoar and firn grains):			
Fine-grained	0·320	0·336	0·328
Medium-grained	0·230	0·320	0·275
Coarse-grained	0·296	0·368	0·339

These results were determined by the method described by Klein[5].

The systematic determination of snow density allows us to follow the density changes of the individual layers, and also of the snow cover as a whole, the water equivalent of which is determined from the formula

$$Z = 1000 \,.\, \Sigma_1^n s \,.\, v$$

where Z is the water equivalent of the snow cover in mm. of water, s is the density of the individual snow layer in gm./cm.³, v is the height of the snow layer in metres, and n the total number of snow layers in the snow cover.

Mechanical Properties of Snow Cover and Avalanche Protection

A serious weakness in our early work was our lack of measurements on the mechanical properties of our snow cover, for which we had to rely on the Swiss data. However, during the last winter season we introduced snow hardness measurements using the apparatus described by Klein[5], and in the coming winter we intend to start measurements of a different type. We are well aware of the necessity of knowing the adhesion and cohesion of snow in avalanche forecasting, but the Swiss literature has led us to conclude that the penetration resistance of snow determined by a conical tipped rammsonde gives a reading that is approximately proportional to the cohesion and adhesion of the snow. At first the necessity of building up the network of avalanche stations as quickly as possible, and instructing their staff, prevented us from determining these properties in the classical way, and we have now decided to make use of the Swiss conical borer as our main apparatus in these mountain stations, but to modify it to remove some of its disadvantages. We have adapted it both for station and field measurements, and have constructed a more easily transportable type of rammsonde, which, since it has an enlarged borer point, eliminates the distorting effect of the friction of snow on the stem[1].

Our method of making tests and of calculating and graphically recording the penetration resistance is much the same as with the Swiss conical borer. Apart from the rammsonde tests, our avalanche stations make regular measurements of the depth and structure of the snow cover, humidity, temperature and density of the snow, air temperature (using a thermograph), wind speed and direction, type and quantity of precipitation, duration of sunshine, etc. These data are all recorded on a form which serves both for determining the immediate avalanche situation and also as a documentary record for future research (Fig. 4, p. 75).

The avalanche danger is determined by comparing the "Daily Measurement Survey" with typical data on the structure and penetration resistance of the snow cover in known avalanche situations. If a distinct similarity is found, the avalanche station at once publishes a warning and forbids entry to those slopes on which avalanches might occur. If there is only an approximate similarity, the station measurements are extended and checked by rammsonde tests at safe places on slopes which might produce avalanches owing to their different meteorological situations such as higher wind speeds and thicker, softer or harder layers of snow at the dangerous levels[6].

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REVIEWS

LES APPLICATIONS DE L'EXPLOSION THERMONUCLÉAIRE. CAMILLE ROUGERON. Paris, Berger-Levrault, 1956. 307 pages. 18·5 cm. Fs. 600.

CHAPTER 4: "La climatologie thermonucléaire", is not without interest for glaciologists as regards the peaceful uses of nuclear energy. The views expressed seem futuristic only to those who are behind the times. The hydrogen bomb is a reality; it only needs to be tried in the attack on the cryosphere instead of the biosphere!

A hydrogen bomb of 20 megatons, as also a superbomb of 60 megatons, could be used to melt the cryosphere, so to speak, in order to use geothermal energy to ameliorate climates and make the Volga and the St. Lawrence navigable, as also the Great Lakes. The subterranean explosion of hydrogen bombs would give craters of enormous dimensions permitting the utilization of this energy. Artificial gulf streams could be created, which could change regional climates and render navigable the arctic seas. The author even envisages electric power stations constructed under the Greenland and Antarctic Ice Sheets.

A. BAUER