THE DEVELOPMENT OF SNOW AND GLACIER RESEARCH IN SWITZERLAND

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Abstract. The evolution of snow and glacier research in Switzerland is outlined. The settling, creep, viscosity and slipping of the snow cover are discussed in detail and the relationship of these comparatively simple processes to the more complex movements in a glacier are described. The importance of further research in glacier physics in connection with the crystallographic and mechanical properties of ice is stressed; certain preliminary laboratory experiments and some subjects for further research in the field are suggested. The Great Aletsch Glacier is recommended for this owing to the proximity of the Jungfraujoch Research Institute and facilities for transport by the Jungfraujoch Railway.

Zusammenfassung. Die Entwicklung der Schnee- und Gletscherforschung in der Schweiz wird erörtert. Das Setzen, Kriechen und Gleiten sowie die Zähigkeit der Schneedecke werden ausführlich beschrieben, und der Zusammenhang zwischen diesen verhältnismässig einfachen Vorgängen und den mehr verwickelten Bewegungen im Innern des Gletschers wird erläutert. Es wird betont, dass weitere Untersuchungen der physikalischen Eigenschaften des Eises im Gletscher, besonders auf dem Gebiet der Kristallographie und der Mechanik, von grösster Wichtigkeit sind. Gewisse Vorversuche im Laboratorium und einige weitere Forschungsarbeiten im Gletscher werden vorgeschlagen. Für den letzteren Zweck sei der Grosser Aletschgletscher besonders gut gelegen.

I. Introduction

The brilliant light of the great Alpine glaciers, which appeals from afar to the men who live in the lowlands and arouses the enthusiasm of all lovers of nature, has made Switzerland the cradle of the science of snow and glaciers. J. J. Scheuchzer (1672–1733) and M. A. Cappeler (1685–1769) may be regarded as its founders. In his *Beschreibung der Naturgeschichte des Schweizerlandes* Scheuchzer discussed not only avalanches, glaciers and icebergs, but also the problems of the growth and crevassing of glaciers. Cappeler, a doctor from Lucerne, conceived the beginnings of an ice crystallography as well as a theory of glacier motion which is admirable for its advanced ideas and its recognition of fundamentals.[1]

Glaciology, which went through its classical period during the nineteenth century, owes much to the formation of the Schweizerische Naturforschende Gesellschaft (S.N.G.) in 1815. The daring conception of the Great Ice Age, first fully clarified through the work of J. Venetz, soon became established in the minds of the scientific world, with the result that general attention was drawn to the properties of ice as a rock. By discovering the granular, polycrystalline structure of glacier ice, Hugi recognised the connexion between snow and ice. Regelation owes its discovery to the interest which the transformation of snow into glacier ice aroused in the minds of certain eminent physicists, notably Tyndall, Thomson, Emden and Helmholtz. The fundamental work on the glacier grain and the temperature conditions in glaciers by Hagenbach-Bischoff and Forel was followed by the first accurate observations on glacier motion by Agassiz and his collaborators (1841–46). The Glacier Commission of the S.N.G. continued these researches on the Rhône Glacier under the direction of P. L. Mercanton [2]; later they were supplemented by the investigations of the Zürich Glacier Commission on the Claridenfirn.[12] The connecting link between glaciology and geology was established by Heim, the author of the first text-book of glaciology (published in 1885), who showed the analogy between the behaviour of glaciers and that of earth slides.

Modern snow and glacier research is characterized by the predominance of practical aims. It started at the beginning of the present century with the foundation of an International Glacier Commission, which, with the help of American scientists, was soon to be supplemented by a Snow

Commission. In Switzerland the most important object was the prevention of avalanches. Whole villages had often been overrun and loss of life was increasing as a result of the growing winter traffic. The first Swiss Chief Inspector of Forestry, J. Coaz, devoted his life to this great aim.[3] The Swiss Forestry Law of 1876 was designed to preserve protective forests, the most effective cover against avalanches. However, the preliminary researches of Paulcke, Welzenbach, Hess, Eugster, Oechslin, Campell and Seligman led to the recognition that practical knowledge alone does not suffice to solve the problem of avalanches and to develop effective protection against them. In order that the problem might be investigated further the Swiss Commission for Snow and Avalanche Research * was founded. Under its guidance and through its collaboration with various research institutes of the E.T.H. a new basis was laid for the science of snow and avalanches. The newly gained knowledge was put to practical test by being made available to Swiss mountain troops during the Second World War.[4(a, b)] This helped to show the practical importance of the new science and facilitated the recent replacement of the first primitive snow laboratory, on the Weissfluhjoch near Davos, by a new research institute equipped with an up-to-date refrigerating plant. This institute was built under the auspices of the Snow and Avalanche Commission and works under the direction of the Swiss Forestry Department (1943). Snow and avalanche research has thus been given an ideal base which supplements the research station on the Jungfraujoch, where most glacier research is now centred.[25] The foundation of a department of hydrology at the Institute of Hydraulics and Soil Mechanics † of the E.T.H. ensures that the work of O. Lütschg [29] will be continued, and that sufficient attention will be given to the hydrological aspects of snow and glacier research.

II. Recent Problems and Results

There are many problems relating to snow, firn and ice. Of these, certain connexions between the behaviour of the snow cover and that of glaciers have been chosen for discussion in this article, mainly with a view to considering the mechanism of flow. This should provide a general picture of the problem and serve as a supplement to Niggli's thermodynamic and crystallographic treatment of the subject elsewhere.

When dealing with snow and ice one finds that the terms liquid and solid acquire a purely relative meaning, since the snow cover, although composed of crystalline elements, behaves in a way which resembles a liquid rather than a crystalline solid.[5, 6] At the temperatures prevailing in nature the yield strength of the snow cover is so low that the smallest sustained force is sufficient to produce continuous creep. Snow is, therefore, an excellent example of Maxwell's conditions of perfect plasticity. Snow also conforms to the law of linear proportionality between shear stress and velocity gradient, which Newton showed to be a characteristic property of viscous liquids, at least approximately and within certain limits of stress. This surprising "fluidity" of snow, which is after all a solid, is caused by metamorphosis of the snow grains themselves. This metamorphosis exercises a dominant influence on all processes which extend over long periods of time and leads to certain deviations of the properties of snow from those of normal viscous liquids. Such deviations are conditioned by the changing shape of the crystals and the resulting compressibility of the snow, and also by the change with time in density and viscosity which that compressibility causes.

1. *Creep and Sliding*

The plasticity of the natural snow cover finds its expression in settling and creep, both of which

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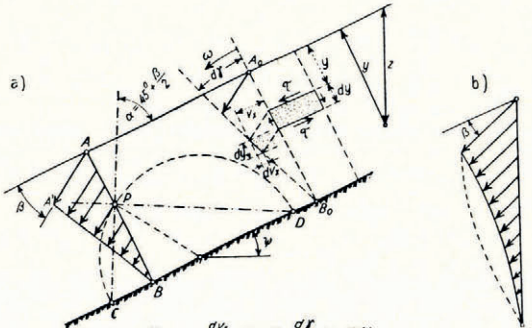
* Schweizerische Schnee- und Lawinenforschungskommission.

† Versuchsanstalt für Wasser- und Erdbau.

properties are dependent on temperature. Since creep is of fundamental importance for the understanding of both avalanche formation and glacier flow, it will be discussed in some detail below.

In the simplest case of a snow layer which undergoes creep accompanied by an increase in density on an inclined plane, straight lines remain straight and merely rotate about a point at their base. Assuming that the snow layer does not slide on its base, a movement of this type would result in a triangular creep profile with a linear velocity distribution in accordance with Fig. 1 (*a*) below. Such a profile has a constant velocity gradient. On the other hand, the shear stress in a small area which is parallel to the surface of the snow layer increases as a linear function of depth (provided the density is uniform). The velocity gradient would thus also have to increase, since, according to Newton, the velocity gradient is proportional to the shear stress, provided the viscosity remains constant. It follows that the existence of a triangular creep profile can only be reconciled with Newton's fundamental equation if the viscosity is not constant, but increases with depth in proportion to the shear stress.[6]



$$\tau = \mu \cdot \frac{dv_t}{dy} = \mu \cdot \frac{d\gamma}{dt} = \mu \cdot \omega$$

$$\omega = \frac{\tau}{\mu} = \frac{y \cdot \gamma_s \cdot \sin\psi}{y \cdot \mu_1} = \frac{d\gamma}{dt}$$

$$= \frac{\gamma_s \cdot \sin\psi}{\mu_1}$$

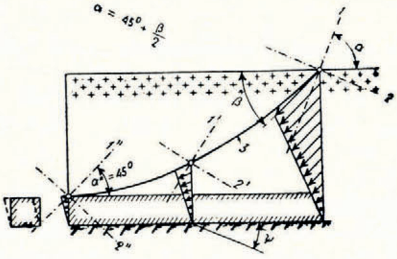


Fig. 1 (a). *Triangular creep profile of a plane-parallel, compressible layer (angle of inclination* ψ*). Linear rise of viscosity from* A *towards* B. *Construction of the directions of the principal stresses* P–C *and* P–D. *Approximate calculation of angular velocity* ω *of a straight line* A_0–B_0 *about its base* B_0. μ_1*-viscosity at distance 1 from the surface of the layer.* γ_s*-mean density of material*
(b) *Plain line: creep profile, if viscosity increases as a power (square, cube, etc.) of the depth. Dotted line: parabolic creep profile at constant viscosity*

Fig. 2. Creep curve (3)
β = *angle of creep*
1, 1', 1'' = *directions of first principal stress*
2, 2', 2'' = *directions of second principal stress*

The angular velocity of ω, with which the normal to the snow surface *A–B* rotates about its base, can be calculated from Fig. 1. It is proportional to the mean density γ_s of the snow and the sine of the angle of inclination ψ, and inversely proportional to the viscosity μ of the material at unit distance from the surface of the layer.

The creep profiles which were measured in the actual snow cover agree to a first approximation with the prototype of creep motion pictured in Fig. 1 (*a*).[6] Seeing that the temperature generally rises from the snow surface towards the ground, the increase of viscosity with depth which can be deduced from the linear velocity gradient may seem surprising. Its explanation can be found in the strong influence which crystal size has on viscosity. Crystal size increases with depth and seems to cause a considerable rise in the viscosity of the lower snow layers. In midwinter the creep profile is frequently of the type shown in Fig. 1 (*b*). This deviates markedly from the triangular shape and indicates that the viscosity does not rise as the first, but as a higher, power of depth under the snow surface.

Despite these deviations of the observed creep profiles from the ideal triangle, the latter was used as a first approximation because it led to simple and clear relations between the direction of creep, the angle of creep β and the stress distribution. Fig. 1 (*a*) shows that in this case the directions of the principal stresses *P–D* and *P–C* can easily be constructed.

The construction is based on the fact that the right angle *ABC*, being a peripheral angle in a semicircle, does not change if *P* is shifted by a small amount in the direction v. In the case of an ideal plastic body the absence of angular change depends on the absence of shear stresses in the directions concerned, *i.e.* these directions have to coincide with the directions of the principal stresses.

Creep cannot be a stationary process, since snow increases in density as a result of its metamorphosis. Continued observation shows in fact that a given point in the snow does not move along a straight line, but along a slightly concave curve resembling a hyperbola. This is called the creep curve (see Fig. 2, p. 194). At the apex of this curve (representing the completion of the metamorphosis of snow into non-porous ice) the direction of creep is parallel to the base of the slope, because ice may in this connexion be regarded as incompressible ($\beta=0$). It does not matter here that this non-porous state cannot in fact be reached at temperatures below freezing point, but needs for its attainment the presence of the liquid phase. It is noteworthy, on the other hand, that the relationship between creep and the state of stress mentioned above indicates a change of stress according to a definite law, which, unfortunately, cannot be discussed here (metamorphosis of stresses [7, 8]). It may, however, be worth mentioning that in the final state (ice) the first principal stress is not vertical but inclined at 45° to the surface of the ice layer. Its magnitude can be calculated from the equation

$$\beta=0 : \sigma_1=\gamma_e\, z[1+\sin\psi(\cos\psi-\sin\psi)]$$

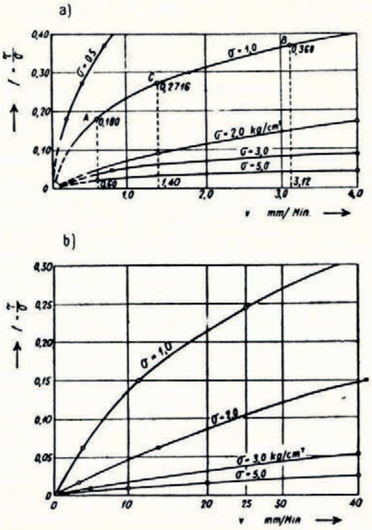
where z is the depth under the surface of the snow layer, γ_e the density of ice, and ψ the angle of inclination of the layer. Hence the maximum principal stress in a "creeping" ice layer of infinite extent not only depends on the height z of the reference point but also on the angle of inclination. It should also be noted that the entire process of deformation, which consists in shearing and compression, goes on at a decreasing rate, since the viscosity of the material rises as a result of the increasing density.

The process of creep which has been described above must be regarded as a special case, because it is continuous in space and involves no sliding on the base. In general it occurs in combination with a discontinuous form of movement which is called slipping. This is of the greatest importance both for the stability of the snow cover and for glacier flow. It involves a plane of discontinuity which can become a thrust plane. Under certain conditions of temperature, roughness and pressure, slow slipping between the snow cover and the ground is liable to take place. The glacier on the other hand may slip on its base and in addition contain internal planes of discontinuity acting as thrust planes.

There is a close resemblance between these two superficially very different forms of movement, *i.e.* continuous shear or flow on the one hand and discontinuous slipping on the other. This may be due to the fact that in each case displacements occur in similar boundary layers. In the last resort shear may be regarded as the end effect of a multitude of small slipping movements which are predominantly *inter*-crystalline in snow and firn, but include *intra*-crystalline *gliding* in the case of ice [11(a, b)]. Figs. 3 and 4 (p. 196) show the experimental results obtained during the sliding of snow on a perfect plane of discontinuity (a glass plate) and give a glimpse of the relationships which hold in such a case. In Fig. 3 the friction rises with increasing velocity of sliding at constant pressure σ. This indicates that Newton's law of friction is approximately obeyed within the sliding layer. At 0° C. the proportionality between friction and velocity of sliding is practically perfect, which shows that a film of liquid is transmitting the pressure within the range of pressures investigated (1–5 kg./cm.^{2}). The marked reductions of the specific friction τ with increasing pressure σ may seem a surprising result. On the other hand, Fig. 4 shows that, at a given inclination of the slip plane, the velocity of sliding increases with the weight of the sliding body. These results may be summed up by stating that the velocity of sliding depends upon the following five factors: the nature of the sliding materials, the roughness and inclination of the plane of sliding, temperature and pressure. A relatively small rise of pressure or of temperature sometimes produces a comparatively large increase in the velocity of sliding.

2. *Application of Glacier Flow*

It will be useful to begin by pointing out some general relations between creep and slip in a snow cover on the one hand, and the more complex movements taking place in a glacier on the other. For this purpose four idealized velocity profiles have been drawn showing how the behaviour of a cover of snow changes into that of a glacier (Fig. 5, p. 197). Fig. 5 (*a*) is the profile obtained in a snow cover in which creep in the form of a shearing movement and slip over the base (*e.g.* a grassy slope) take place at the same time. In this case the viscosity is assumed to rise as a linear function of depth under the snow surface. At constant viscosity the parabolic curvature of the velocity profile shown in Fig. 5 (*b*) is obtained. A similar profile, but with greater curvature, would be found if the viscosity of the material decreased with depth instead of increasing.



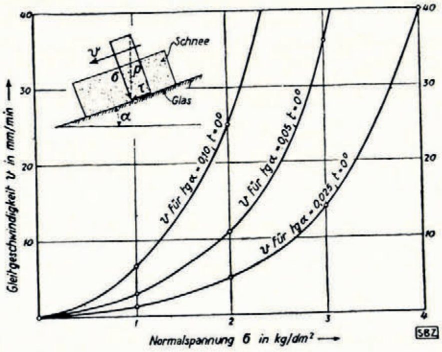
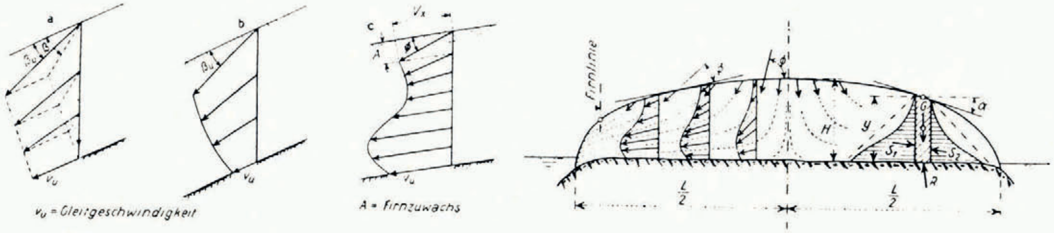


Fig. 3. Sliding of snow on glass. Friction f as a function of velocity of sliding, pressure and temperature [6]
(a) *Mean temperature* = −7°
(b) *Mean temperature* = 0°

Fig. 4. Sliding of snow on glass. Sliding velocity as a function of pressure σ at constant temperature (0°) *and different inclinations* (α) *of sliding plane* [6]

The velocity distribution along a vertical line through a glacier is influenced by a variety of additional factors. In the first place this is no longer a problem confined to a plane, but one in space where the conditions prevailing at the margins have to be taken into account. Moreover the presence of internal thrust planes, which are rarely observed in a snow cover except after fracture (avalanches), cannot be excluded in glaciers, where they are liable to produce a discontinuous velocity distribution. To-day, the co-existence of creep, *i.e.* plastic flow and slipping on the base as well as along internal thrust planes, may be regarded as an established fact. Hence the conflict between the schools of von Engeln and Chamberlin no longer exists. The investigations of Perutz and Seligman [32] have shown that in the firn region slipping along large-scale thrust planes may be regarded as exceptional, whereas it definitely occurs in the glacier tongue. The formation of thrust planes is facilitated by the presence of water. Interglacial overthrusts on a very large scale have been observed in the case of abnormal glacier variations.[9, 10]

Within a glacier profile the mechanical properties of the crystalline aggregate vary within very wide limits. In the firn region, for instance, there will be imbedded between the fluid superficial snow layers and the highly plastic ice at great depths, a stratum of ice which carries a relatively small load and therefore tends to behave as a rigid zone. If either lateral friction or tension from the upward slopes (anchoring at the upper margin of the firn region or within a spherical segment) exercise a drag on the movement of this stratum, the profiles indicated diagramatically in Figs. 5 (*c*) and 5 (*d*) may result.[7, 31*b*] Such profiles, no matter what their special form, suggest a connexion with Finsterwalder's theory of glacier flow, because the mean angle of creep β of an annual layer becomes identical with the angle ϕ which a streamline encloses with a surface as it submerges. The tangent of this angle is equal to the ratio of the thickness of the annual firn accumulation A to the annual velocity V_x.



(*a*) (*b*) (*c*) (*d*)

Fig. 5 (a, b, c). *Comparison of different velocity profiles.* V_u=*velocity of sliding.* A=*thickness of layer corresponding to firn accumulation*
(d) *Velocity profile in an ice cap.* Cf. *Koechlin* [31*b*]

In assuming that the viscosity of ice decreases as a function of depth below the glacier surface in accordance with Streiff-Becker's observations,[12(*a, b, c, d*)] it was argued that the water, which is in equilibrium with ice at the pressure melting point and which tends to concentrate at the crystal boundaries, exercises a strong influence on the viscosity of the two-phase system notwithstanding the very small amount of water actually present. According to the laws of thermodynamics the fraction of water in the ice increases in proportion to the pressure.[17] This probably results in a greater participation of the liquid phase in the transfer of pressure and hence in a reduction of the viscosity of the entire system at great depth. There may thus be a critical hydrostatic pressure (at the pressure melting point) beyond which macroscopic cavities in a glacier would no longer exist, unless they were filled with a liquid or a gas of appropriate pressure. Thus the conception of a limiting level between "open" and "closed" ice arises which may be important for the internal movement of water in a glacier, since below the limiting level large water veins would have to be replaced by inter-crystalline capillaries through which the melt water would have to seep. In those parts of a glacier where the critical pressure is reached (a depth of several hundred metres of ice may be needed for this), the melt water which pours in from above may move mostly in channels which lie close above the limiting level.

So far as its mechanical properties are concerned, therefore, the "closed" ice at great depth would have to be regarded as a saturated two-phase system of small permeability. In such a system the inter-crystalline water reduces internal friction and leads to hydrodynamic phenomena of the type observed in clays saturated with water and subjected to pressure.[13, 14]

3. *Special Experiments*

Further research on the viscosity of glacier ice is of fundamental importance for the study both of glacier flow and glacial erosion. Thus according to Carol the formation of *roches moutonnées* can be readily explained on the basis of the reduction of viscosity through pressure.[15] On the up-stream side of a hump on the glacier bed the erosive power of the rock debris imbedded in the ice is small, because it is not gripped sufficiently firmly by the plastic ice. That is to say it "floats" in the ice. The tendency of glaciers to accentuate the existing contours of the landscape, both on a small and on a large scale, which is so striking a feature of glacial erosion, may be attributed to the same cause. Therefore one of the most important preliminary studies of future glacier research will be concerned with the crystallographic and mechanical properties of ice, especially its viscosity as a function of pressure and temperature. For this purpose the following three experiments are indicated (see Fig. 6).

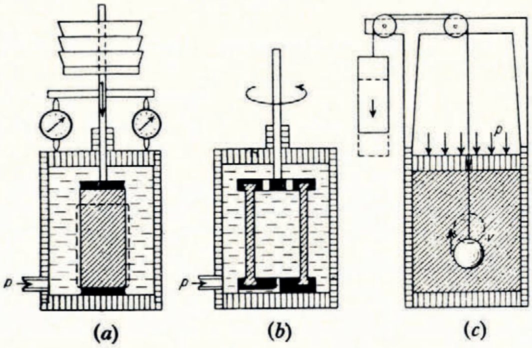


Fig. 6. Apparatus for measuring the viscosity of ice subjected to hydrostatic pressure
(a) *Compression of solid cylinder which is free to expand laterally*
(b) *Torsion of hollow cylinder*
(c) *Motion of sphere driven by a known force*
Under conditions (a) *and* (b) *the ice sample may have to be protected from the surrounding liquid by a rubber skin*

(*a*) Uniaxial compression of a solid cylinder subjected to variable hydrostatic pressure, in which case the viscosity can be computed from the compressibility, as in clays.

(*b*) Torsion of a hollow cylinder subjected to variable hydrostatic pressure. A similar device but without external pressure is now being developed both in soil, and in snow, mechanics.

(*c*) Determination of the velocity of a sphere pressed through ice which can be subjected to a variable hydrostatic pressure. In this case the viscosity can be calculated from Stokes law.

The third experiment should give valuable results, especially as regards the rate of sinking of rock debris in highly plastic ice. In all these experiments the temperature will have to be carefully controlled, the most important temperature range naturally being the pressure melting point of ice, *i.e.* the temperature range existing in the interior of a glacier. These experiments should be carried out primarily with actual glacier ice; the occurrence of any crystallographic changes should be observed.

The best method of studying changes in crystal texture is the investigation of stressed strips of ice between crossed nicols. This method was used by Winterhalter,[11a] on the suggestion of the present author (1937), and it has shown that relatively small sustained stresses, no matter whether tensile or compressive, suffice to produce a continuous process of deformation. The rate of deformation is slower the further the temperature is lowered from the melting point.[10] When this method has been further developed the effect of pure shear stresses, instead of that of uniaxial tension, might be investigated. As in snow mechanics, the velocities of deformation at unit stress (kg./cm.^{2}) observed in compression, tension and shearing might then be used as plasticity figures (a_1, a_2 and a_3), which would make it possible to calculate the corresponding viscosities.[25]

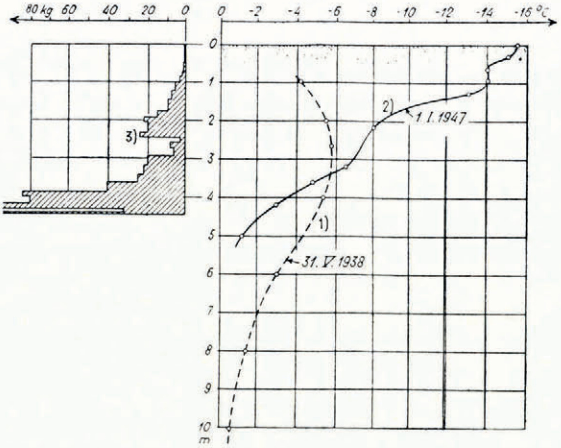


Fig. 7. Temperature determinations in the firn region (Jungfraufirn)
(1) *Summer temperature as a function of depth according to Hughes and Seligman* [20] *determined* 31.5.1938
(2) *Winter temperature, determined* 1.1.1947
(3) *Dynamic resistance of displacement of a pointed rod of 2 cm.*^{2} *cross section (driving resistance profile* 1.1.1947)

The sensitivity of the viscosity of ice to variations of pressure and temperature is the cause of seasonal variations in the velocity of flow of the glacier surface. Recent measurements confirmed Blümke and Finsterwalder's observations on the Hintereisferner that the lower part of the glacier has its greatest velocity in summer, whereas the upper part flows fastest in winter.[16, 17] In 1942 the determination of the velocity of a point on the Jungfraufirn at 3350 m. showed a winter velocity which was about twice as great as that in summer.[18] Further work on these seasonal variations is still needed, yet it seems improbable that the increased winter velocity is due only to the additional weight of the new snow cover. It appears more probable that we are dealing with the combined effects of pressure and temperature. In this connection it is instructive to compare two temperature profiles, one measured in mid-winter (1 January 1946) and the other at the beginning of summer (31 May 1938) by Hughes and Seligman [19, 20] (see Fig. 7, above). This comparison shows that the insulating effect of the winter snow cover "dams up" the flow of heat from the earth, so that the 0° C. isotherm comes to lie nearer to the snow surface than in spring.

This process can also be explained on the basis of the phase shift undergone by the winter cold wave as it penetrates below the glacier surface. Hence there should come a time in the course of the winter when various influences, especially the great weight of the new snow cover and the prevailing temperature conditions, combine to produce the maximum seasonal velocity in the firn regions.

III. Conclusion

All problems relating to the snow cover are being intensively studied at the Swiss Federal Institute for Snow and Avalanche Research * not only from the point of view of avalanche defence but also for the purpose of establishing the fundamental scientific laws which govern the behaviour of snow and ice in general.[24, 25, 26] These results and the experience gained in the study of snow can now be applied to glacier research and to snow mechanics, where they may be further developed.[27] It would be most profitable to co-ordinate the knowledge gained in all these different subjects and to apply it to one individual glacier in such a way that the results of laboratory research, theoretical work and field observations can be woven together to give a coherent picture. This would lead to an understanding of the functional significance of individual phenomena in the behaviour of a glacier as a whole.[7]

The Great Aletsch Glacier seems to us to offer the most attractive field for research. As early as 1869 its greatest velocity (in the Konkordia profile) had been determined as 0·505 m. per day (Grad and Dupré). To-day the research station on the Jungfraujoch, which lies at the source of the Great Aletsch Glacier, is easily accessible by railway and offers an ideal base for studying glaciological phenomena in their natural sequence. Seligman and his collaborators were the first to make use of this Station for glacier research and to recognize its full potentialities.[30] To-day it is becoming an important centre of glaciological research. In addition to the crystallographic studies of the Geotechnical Commission (Winterhalter), continuous observations of snow falls, firn accumulation and glacier flow have been carried on since 1940. These observations had originated in a study of avalanche formation in the firn region (Roch, Kasser, Haefeli). One of the special objects of these long-term observations, which have been planned for the decade 1940–50, is the testing of Streiff-Becker's theory in two closed profiles, one of them above the firn line (Jungfraufirm contour 3000 m.) and the other below (Konkordia Hut, contour 2800 m.).[21, 22, 23(a, b)] For this purpose it is planned to carry out photogrammetric work as well as seismic soundings. The latter are designed to supplement the echo soundings of Mothes, which showed a maximum depth of about 800 m., and to carry the seismic measurements across a suspected rock barrier under the ice below the Konkordia Platz. The results of this work may also have an interesting bearing on problems of glacier erosion. Fundamentally there is the possibility that the distribution of velocity in the interior of the glacier might be studied by determining the position of metallic floats with the aid of geophysical methods. The use of electrical resistance thermometers should provide an improved picture of the temperature conditions in the firn region.[28] Financial support for these projects is provided through the generosity of the Swiss Alpine Club, the Swiss Commission for Snow and Avalanche Research and especially from the Glacier Commission of the S.N.G., where our plans were first studied and conceived.

We know that the research now begun on the Great Aletsch Glacier represents no more than the nucleus of further endeavours designed to gain a fuller knowledge of the intricate life of a glacier. I hope that it will lead to a free interchange of knowledge and to collaboration between people of different nations who are united by the common bond which the love of nature provides. It seems as though the Glacier knows how to preserve its secrets, and will only reveal them to those who seek them by experimental research, rather than by speculative thinking.

MS. received 31 *January* 1947

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