

HOW TO ESTIMATE AVALANCHE DANGER¹

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(Five illustrations: nos. 29-33)

IN the May, 1965, number of the *Alpine Journal*² there was an article in which an attempt was made to explain the mechanism of avalanche release. From that paper it can be seen that the mechanism may take many forms. The tourist, even if he understands the mechanism, may still wonder how he should set about estimating the danger level.

The triggering of avalanches *may* be simple, but it can be so complex that to go onto a slope, measure the strength and stresses in the snow cover—some stresses are extremely difficult to measure—and then deduce how near an avalanche is to starting would be a hopeless proposition. However, knowledge of the release mechanism does allow us to analyse which factors may augment the likelihood of an avalanche.

Let us recapitulate the causes of the start of an avalanche: they derive either from an increase in stress or from a reduction in strength. An increase in stress *may* be slow and progressive owing to the weight of a new snowfall or of rain, whereas a reduction in strength is *always* slow, caused as it is by metamorphism or a rise in temperature. These effects cause what we term a *spontaneous release*.

But the rise in stress may also be sudden, owing to the passage of a skier, the fall of a lump of snow from a tree, or a shock caused by the peripheral rupture of a slab, and this may provoke a *release by accident*.

The way for the tourist, as well as for an avalanche warning organisation, to estimate the danger consists of studying the factors which contribute to an increase in the possibilities of a release. Three of these factors are caused by meteorological influences: a *snowfall*, the *wind*, and a *change of temperature*. And the fourth is intrinsic to the snow itself: the presence in the snow cover of one, or perhaps several,

¹ M. André Roch writes: 'I should like to thank Dr. de Quervain, Director of the Federal Institute for Snow and Avalanche Research at the Weissfluhjoch, for his supervision of the preparation of this paper. Colin Fraser, author of *The Avalanche Enigma* (John Murray, 1966), a comprehensive book on the problem of avalanches, was kind enough to give most valuable help with the editing and points of translation; he should be regarded as co-author.' —EDITOR.

² *A.J.* 70. 57-68.

fragile strata. These factors are always interrelated to a lesser or greater degree.

1. *A Snowfall*

A snowfall is the main cause of avalanche activity, for its weight provokes an increase in stresses. And the strength of new snow itself is very small—only that which is brought about by the interlocking of the branching, feathery crystals, a sort of felt-like cohesion. It is estimated that, in mid-winter, 80–85 per cent of avalanches are caused by new snow (1) (2),³ but it does not follow necessarily that these conditions are the ones that most commonly endanger tourists. As we have already seen, slopes may discharge themselves by *spontaneous release* owing to a snowfall, beginning with the steep slopes first. The very steep slopes, over 45° in inclination, usually discharge themselves (sometimes repeatedly) during the storm itself. Less steep slopes are in a way more treacherous, for they need more snow before reaching a state of instability; and the enormous catastrophic avalanches happen on mountain slopes of about 30°. In addition to causing avalanches in the above way, new snow can, by falling in a lump from a tree or rock, cause a *release by accident* on the slope below.

In general, one foot of new snow, without aggravating influences such as wind or a temperature rise, will constitute the threshold of the danger level for the tourist. With two feet of new snow, the avalanches will be larger and may well endanger roads and railways. Catastrophic avalanche conditions occur when four or more feet of new snow have fallen with little or no interruption. Such amounts of new snow, accumulated on a fragile base of metamorphic snow (depth hoar), bring the worst avalanche conditions. The fragile snow foundation will collapse and either give start to avalanches or simply compact. During such periods of catastrophe, the tourist is not usually endangered, for there is too much snow for skiing or climbing.

Usually a fall of new snow, because it insulates the older layers from the cold air above and allows the relative warmth of the ground below to make itself felt, brings about a rise in temperature in these older layers. This in turn brings first a reduction in their strength, followed by settling and consolidation.

Another aspect is that the lower layers of a heavy fall of snow become very compact and form a slab within the snow cover. This internal slab may rest on a weak metamorphic layer. The triggering possibility of this slab is complex, but if a peripheral fracture occurs in it, an avalanche may be released, whereas, given the same stability, loose snow could never start. Thus, the danger of slab avalanches grows as the new snow gains in strength.

³ Figure references are to the bibliography appended to this article.



1. A THIN WALL CUT IN THE SNOW SHOWS THE STRATIFICATION OF THE SNOW COVER.

Photo: ISAR]

(No. 29)



Photo: A. Roch]

2. MEASURING THE SHEAR STRENGTH OF SURFACE HOAR IN LEAVES, WITH A FRAME OF 4 DM^2 AND A DYNAMOMETER. THESE HOAR LEAVES WILL RESIST THE PRESSURE OF THE WEIGHT OF A NEW SNOW FALL, THOUGH THEIR SHEAR RESISTANCE IS VERY SMALL.

(No. 30)



Photo: A. Roch]

3. A GENERAL AVALANCHE SITUATION DUE TO A SNOWFALL. ON ALMOST ALL SLOPES WHICH ARE STEEP ENOUGH, SLIDES OF SOFT SLAB AVALANCHES HAVE TAKEN PLACE. FROM LEFT TO RIGHT: MATTLISHORN, GAUDERGRAT AND KISTENSTEIN (IN THE PARSENN AREA).

(No. 31)



Photo: Alfred Sutter]

4. HARD SLAB AVALANCHE FROM WIND-PACKED SNOW IN THE LOETSCHENTAL. ONE SEES THAT THE SNOW WAS ACCUMULATED IRREGULARLY BY THE WIND. THE MAN IN THE PICTURE IS ALEXANDER GRAVEN.

(No. 32)

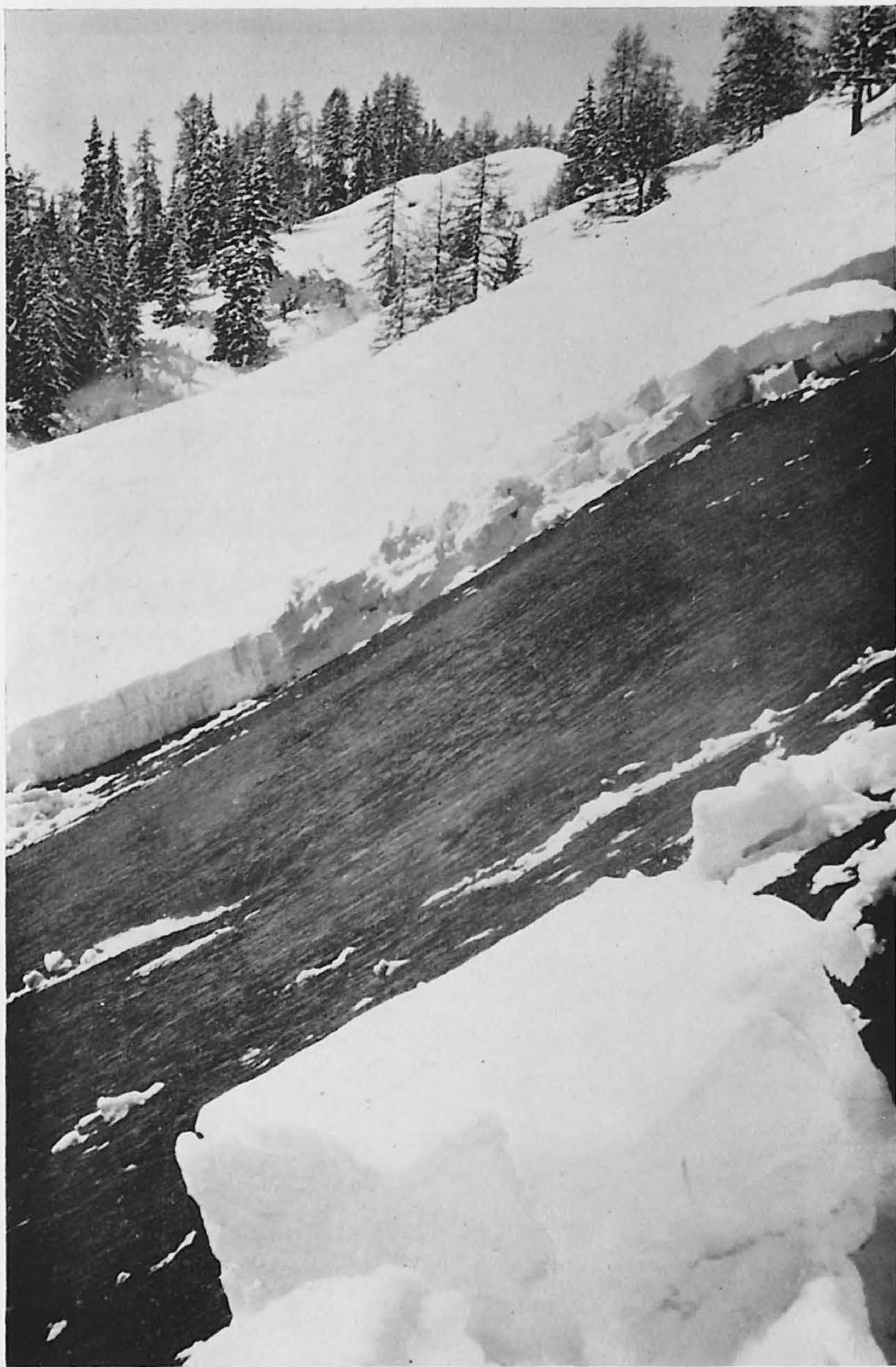


Photo: A. Roch]

5. SLAB AVALANCHE ON A SLOPE OF WET GRASS FACING SOUTH. THE RELEASE WAS CAUSED BY A RISE IN TEMPERATURE. DORFTÄLI, DAVOS.

(No. 33)

2. *The Wind*

Wilhelm Paulcke wrote that the wind is the engineer of avalanches (3). First of all, the wind amasses the snow irregularly on the mountains. With a strong air current, the slopes exposed to the wind are left almost bare, while there are large accumulations on the lee slopes. As slopes are never even and smooth, differences in thickness of snow, deposited by the wind, are tricky to detect. And also, of course, cornices may collapse.

Practically, in the field, the passage of a skier at a given point may cause no fracture, because the snow layer accumulated by the wind is thin and the inherent stability high; yet ten yards further on, he may set loose the snow in a place where, owing to the weight of a thicker snow deposit, the inherent stability is less.

And secondly, wind builds slabs. The new snow crystals are broken, rolled and brought together. After a while (several hours to a day—usually overnight) they aggregate and form a hard slab. We saw in the first paper that the harder the slab the better the possibility of its being released as an avalanche, for the shock of a peripheral fracture is greater, and better transmitted, in hard snow than in soft. From this it follows that, given the same stability in the anchorage along the underside of a slab, a peripheral fracture in a hard slab is more likely to release an avalanche than it would be in a soft slab or in loose snow.

Referring again to the difference in thickness of snow accumulated by the wind, it may be (contrary to what was said two paragraphs back) that the thinner part of the slab on a convex slope is under traction stress and will break when the skier goes by, and that ten yards further on, the slab is thicker, more resistant and will not crack.

A new snowfall without wind may not cause any danger, but the wind starting to blow after the snowfall may redistribute and compact the snow and thus cause localised hazard.

It is well known that for the tourist, slab avalanches constitute the greatest menace because of their many release possibilities and their lateral expansion. In most avalanche accidents involving tourists, the tourists themselves have set the slab in motion.

3. *The Influence of Temperature and of a Change of Temperature*

Low snow-surface temperature prevents the crystals sintering (forming bonds) and thus conserves a loose snow layer at the surface. It causes a large temperature gradient inside the snow cover and hence activates constructive metamorphism. Crystals build facets and with time the lower layers become a scaffold of depth hoar, whose crystals, in the final stage, have the shape of tiny cups. This fragile scaffold may collapse and start avalanches.

A rise in temperature brings a decrease in snow strength, and this

effect, expressed in strength units, is greater the more compact and strong the snow is in the first place; and it is also greater the closer the temperature is brought to melting point. Snow layers that get warmer become more plastic; they creep downwards faster on a slope and they become thinner on convex parts. All, or any, of these influences may cause fractures.

In spring, the snow surface melts in the sun during the day and re-freezes at night. This process tends to form *firn* snow (*névé*). This surface firnification builds a hard layer which may be supported by a weak foundation of slightly wet depth hoar. The foundation may collapse or the hard slab may break at its limits. In both cases a slab avalanche will be triggered if the slope is steep enough.

4. *The Stratification of the Snow Cover*

The presence of a fragile stratum inside the snow cover causes low stability. The stratum may collapse for any of the three reasons we have already seen: a slow increase in stress brought about by a new snowfall, a slow decrease in strength caused by metamorphism or a temperature rise, or it may collapse when there is a sudden increase of stress caused by some accident or occurrence. If there is a hard layer or an ensemble of hard layers on top of the weaker one, these higher layers can be released through any of the numerous possibilities for the triggering of slab avalanches.

It is important then to have some knowledge as to how the snow cover and its stratification are formed.

The layers that have little strength are:

(a) *The upper parts of snowfalls that remain for a long period (roughly a week or more) on the surface without melting*

The original star or needle crystals become, under the influence of destructive metamorphism, granular particles. These granules at the surface are not forced together and thus the contacts and bonds between them are minimal. After a while they will resist the pressure of a new snowfall and remain loose, forming a fragile stratum.

(b) *Surface-hoar layers*

A layer of surface hoar in the form of leaf-like crystals, needle or even small hoar-frost crystals resists the pressure of a new snowfall. The crystals do not bond together, and they constitute a very dangerous fragile stratum for the sliding of the layers above them.

(c) *Depth-hoar layers*

As already noted, constructive metamorphism in the lower layers builds a fragile stratum, and this may be the cause of low stability for

the whole winter. A thin snow cover remaining for a long period without fresh snow, say at the beginning of the winter when the snow-surface temperature may be low and the underlying terrain warm (producing a large temperature gradient), may result in all the snow being transformed into depth hoar crystals. It is for this reason that winters with little snowfall may be especially dangerous for tourists, an observation made by the well-known climber and writer F. S. Smythe (4).

(d) *Layers situated beneath an ice layer*

A surface ice layer, formed by melting and re-freezing, stops the air circulation, and this causes the formation of a very loose stratum of depth hoar beneath the ice.

(e) *Warmed-up snow layers*

The warming up of the snow cover in spring brings a general loss in strength in all the layers. This loss of strength may well cause avalanches to start, but if the layers lose their strength without avalanching, they then settle and become more compact.

The compact layers which may form slab avalanches are:

(a) *The lower layers of heavy snowfalls*

Mentioned briefly in the *snowfall* section these compact layers slow air circulation in the snow cover and this in turn checks constructive metamorphism. For this reason they remain more compressible than would layers of metamorphic granules. And later on, under the influence of more snowfalls, these compact layers are further strengthened.

(b) *Wind slab*

We have seen, in the section above on *wind*, how layers of wind slab are formed.

(c) *Hard surface layers caused by melting and regelation*

Melting and regelation of the snow surface build a hard layer or even an ice layer, which may behave like a slab. Once covered by new snow, these layers disintegrate slowly, and after two months they have lost their cohesion and become strata of large crystals. Very weak depth-hoar layers form beneath them (see earlier, section 4(d))

5. *Avalanche Forecasting*

E. La Chapelle (5), who is in charge of the avalanche safety organisation at Alta, Utah, near Salt Lake City, has analysed the method of evaluating avalanche hazard.

He has vast experience of avalanches and from this experience he defines four types of avalanches that endanger tourists in his area. We

try here to correlate his types to our explanation of the release mechanism, and for that purpose we shall change his order:

'(i) *Direct action avalanche* . . . This type falls during or within twenty-four hours after a storm and involves only the snow of that storm at the release point.'

This corresponds with our spontaneous release caused by a snowfall, but may also include slides released by the fall of a lump of snow from a tree or rock, or even by the fall of a cornice.

'(ii) *Soft Slab* . . . The constituent snow of a slab avalanche with a low degree of internal cohesion. The sliding snow breaks up into an amorphous mass and may resemble loose snow.'

Even with little internal cohesion, snow may break away as a slab avalanche if underneath it there is a stratum with even less cohesion. The soft slab may also slide on wet grass, or on a softer layer deposited during a period of the storm when there was less wind. The soft slab can occur only when there is a low degree of stability: this infers on very steep slopes, or when the slab lies on very fragile or well lubricated strata.

'(iii) *Hard Slab* . . . The constituent snow of a slab avalanche with a high degree of internal cohesion. Sliding snow usually remains in chunks or blocks.'

Lower parts of heavy snowfalls, wind-packed layers, melted and re-frozen surfaces, all can form hard slab. And we have already seen that the higher the degree of stability, the harder the slab must be for its release mechanism to be possible.

'(iv) *Climax Avalanche* . . . This type falls as a result of internal weakness within the snow cover, which may develop over a long period of time. It may be triggered by a new snowfall, but at the release point it involves snow layers deposited by more than one storm.'

If it was triggered by a new snowfall, and/or if it was the result of a general collapse in an old, fragile stratum, it could be termed a *spontaneous release*. But it could equally well be *released by an accident or occurrence*—the passage of a skier, or the shock caused by a peripheral fracture in the slab—which would break the cohesion in the fragile stratum.

Climax avalanches are difficult to forecast and may occur over a long period, as long in fact as the fragile stratum is present, although such strata can disappear as a result of collapsing and consolidating under the weight of a new snowfall; and they can also disappear if the whole snow cover warms up, settles, and compacts.

6. *Safe Conditions*

Safe conditions result when there is no weakness inside the snow cover, and this situation is most likely to prevail when the snow cover

has been formed by several major snowfalls, one to two feet in thickness, with not more than a week between them.

The surface crystals do not have time to change their shape sufficiently to resist the pressure of the next snowfall. The whole snow cover becomes compact and will only slide as a whole on wet grass or wet rock slabs, perhaps on sunny slopes during very warm periods, or in spring.

When, after this strong foundation has formed at the beginning of winter, there are only light snowfalls of less than one foot, without either wind or a major rise in temperature, conditions are ideal.

7. *What to Know*

As we have just done, La Chapelle itemises what should be known in order to forecast avalanche danger:

The stratification of the snow cover. (This shows the presence of fragile strata which may give rise to climax avalanches. We would note too the existence of hard layers, bearing in mind the release characteristics of hard slab.)

From the influence of weather the following factors must also be known:

The intensity of snowfall

The thickness of new snow

The type of fresh snow crystals

The wind velocity and its direction

The temperature of the air

The specific gravity of the new snow and its rate of settling.

Observations of what is happening in nature will complete the knowledge of the avalanche-danger level:

What kind of avalanches have already taken place?

Test skiing (an American technique in which a snow ranger dips rapidly into a short, steep slope and out again in an attempt to release an avalanche with his skis) will show what avalanches are to be expected.

The use of explosives or artillery fire will also establish what avalanches can be expected and the degree of danger.

Observation is of the greatest value because nature usually shows her hand. Experience is an important trump card, but the more experience one accumulates, the more one discovers unexpected forms of loosening of snow masses. For this reason one should never be too certain, and one should try to keep as large a safety margin as possible.

In Switzerland, an organisation to warn of avalanche danger was set up in the years just prior to World War Two. The warnings were based on measurements taken at six stations, but during the war, under military control, the scale of the organisation was increased. And it now functions with fifty measuring stations scattered throughout the Swiss Alps. An observer at each station spends about ten minutes every morning noting total snow depth, new snow depth, temperature, weather conditions, and so on, and he also gives details of any avalanches that have been seen, adding his own estimate of the danger level. He sends all this data in a line of code figures, transmitted by teleprinter, to the Institute for Snow and Avalanche Research at the Weissfluhjoch.

Every day, after the weather forecast at noon, a bulletin about the avalanche situation is broadcast over the radio. This bulletin helps ski-resorts and tourists to avoid danger, and it certainly reduces the number of avalanche accidents (the average number of victims is twenty-four per annum). Unfortunately, the situation is somewhat similar to that on the roads: the number of accidents continues to rise, despite the fact that there are many less avalanche accidents involving tourists when measured in terms of percentage of the total number of skiers.

Warning organisations of the same type exist in the Vorarlberg and the Tyrol. In France, the meteorological service is to start a warning system shortly, mainly in view of the Winter Olympics to be held at Grenoble in 1968.

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