CHAPTER 2

Snow and Avalanches

I HAVE often been asked what it feels like to be caught in a big avalanche. Neither I nor anyone else of record can top the ordeal of Matthias Zdarsky of Austria, although Einar Myllyla's experience in the 1965 disaster at Leduc Camp, British Columbia, described in Chapter 9, rates a close second. Zdarsky was a pioneer of avalanche research and skiing. As a soldier in World War I, on the Austro-Italian front in 1916, he was one of the victims in history's greatest avalanche disaster. Zdarsky had practically every bone in his body broken, yet he lived to ski again.

This is how it felt to me:

Three things happened simultaneously. I heard my partner call, "Watch it!" I heard the slab sound, a soft, menacing "whoosh." The snow in front of my skis humped up, like a blanket sliding off a tilted table. As a matter of fact that's what it was, a blanket of snow a quarter of a mile long, two hundred feet wide, and three feet deep—an avalanche, at the very moment of release.

I snatched a look over one shoulder. I remember thinking, You'll play hell getting out of this one, Atwater. The whole mountain was coming at me, or, at a rough estimate, a thousand tons of it.

The place was Lone Pine Gully at Alta, Utah. The time was about 0900 hours on a January morning of 1951, the Winter of the Bad Snow. There had been a two-day blizzard with thirty-eight inches of snowfall. Hans Jungster, my partner, and I were out checking the slopes before we turned the skiers loose. In these early days of avalanche control in the Western Hemisphere, our only means was to ski the slopes ourselves. If they didn't slide with us, presumably they wouldn't with anyone else. In the light of present knowledge and technique it was pretty crude; we should both have been killed long since.

Our method of avalanche busting on skis was to work in pairs. We would approach the avalanche path as high as we could get. (In the case of Lone Pine, on that day, this was about two thirds of the way to the top, bad business in itself. We should have been at the top. But in those days the lifts at Alta didn't go that high. We'd have had to climb. That would have taken several hours, and the powderhounds were waiting.) While one man took his cut at the slidepath, his partner watched from a secure position, under a rock, behind a tree. From a secure position, in turn, the first man would watch while his partner took a cut, going farther down. Thus, in leapfrog fashion, the team would carve the slidepath. No one has yet invented a faster way of opening up a ski area after a storm. It is still used, and very effectively.

In this case, Hans was a new and inexperienced partner. (He was, in fact, the first assistant snow ranger in the history of the Forest Service; prior to 1951 I had played this game alone.) He came onto the slope before I was off it. Our combined weight, plus the cutting action of our skis, was enough to trigger the avalanche. All of which was academic at the moment. Lone Pine was ripe. That's what we were being paid to find out.

As it happened, that day I was on a new pair of skis. I'd already found out that they were too stiff up front for deep snow. Instead of planing up, they wanted to dive. I doubt that it made any difference. Lone Pine is a steep chute, concave in profile, bounded by ridges, so an avalanche is limited to the gully itself. It discharges at right angles into Corkscrew, a favorite run at Alta after a slide from Lone Pine has filled its V-shaped, boulder-strewn bottom with snow. That's why Hans and I were skiing Lone Pine. Mustn't have an avalanche hanging over a ski run.

It was a soft-slab avalanche, which means that the whole gully had turned loose at once. I was a chip floating on a torrent of snow. But my ski tips were only yards from the edge of it, a boundary sharply defined by a crack that opened all the way round, like a self-powered zipper. I was already moving at speed myself on a downhill traverse toward my anchor point on the ridge. Now if those skis would only plane—

When a soft-slab avalanche breaks loose it crumbles internally, losing all its cohesion and flotation. I simply fell through it until my skis hit the hard base of old snow underneath. Now the snow along the wall of the gully began to curl back toward the main current, taking me with it. I was knee deep in boiling snow, then waist deep, then neck deep. Through ankles and knees I felt my skis drift onto the fall line. But I was still erect, still on top of them. The books tell you, *If you're caught in an avalanche, try to ski out of it.* With mine trapped under six feet of snow I wasn't skiing out of anything. I wondered what was going to happen when it came time to make that right-angle turn into Corkscrew.

Very fast and very suddenly I made two forward somersaults, like a pair of pants in a dryer. At the end of each revolution the avalanche smashed me hard against the base. It was like a man swinging a sack full of ice against a rock to break it into smaller pieces. Fortunately I took both shocks on the derriere, not on some more vulnerable spot. There was no pain, just a jolt that wrenched a grunt out of me each time. At this moment, the avalanche had taken my skis off for me and in so doing had spared my life, by giving up the leverage with which it could twist me into a pretzel. I didn't know my skis were gone and I don't remember the turn into Corkscrew. I was all the way under by then.

If my memories of this avalanche seem to be rather clear and detailed, it was a memorable occasion. I was a trained observer. In my few years at Alta as a professional avalanche hunter I'd done a lot of thinking about this moment. I was thinking now and fighting for my life. However, my principal sensation was one of wild excitement.

Under the snow there was utter darkness instead of that radiance of sun and snow which is never so bright as directly after a storm. It was a churning, twisting darkness in which I was wrestled about as if by a million hands. I began to black out, a darkness that comes from within.

Suddenly I was on the surface again, in sunlight. I spat a wad of snow out of my mouth and took a deep breath. I thought, So that's why avalanche victims are always found with their mouths full of snow. You're fighting like a demon, mouth wide open to get more air, and the avalanche stuffs it with snow. I remembered another piece of advice in the books: *Cover your mouth and nose.* The next time I surfaced I got two breaths.

It happened several times: on top, take a breath, swim for the shore; underneath, cover up, curl into a ball. This seemed to go on for a long time, and I was beginning to black out again. Then I felt the snow cataract begin to slow down and squeeze.

At the mouth of Corkscrew the slope widens out and becomes gentle. The avalanehe had swept me onto this slope. The squeezing was the result of the slowdown, with snow still pressing from behind. Whether from instinct or a last flicker of reason, I gave a tremendous heave, and the avalanche spat me onto the surface like a seed out of a grapefruit.

I lay there dazed, getting my wind back. I felt exhausted. Presently Hans came cruising out of Corkscrew. He was quartering the slide path like a bird dog, looking for any sign of me. I think the last thing he expected was to find me reclining in the snow as if in an armchair.

We said the usual things: are you hurt; I don't think so, bruised a little maybe; you'd better have a doc check you out; probably I better had. I wasn't to know it for several hours, but I was already black and blue from the waist down.

Hans said, "What'll we do about the skiers?"

From the lift terminal they were gaping at us.

I said, "Might as well let them have Corkscrew. Ought to be safe now."

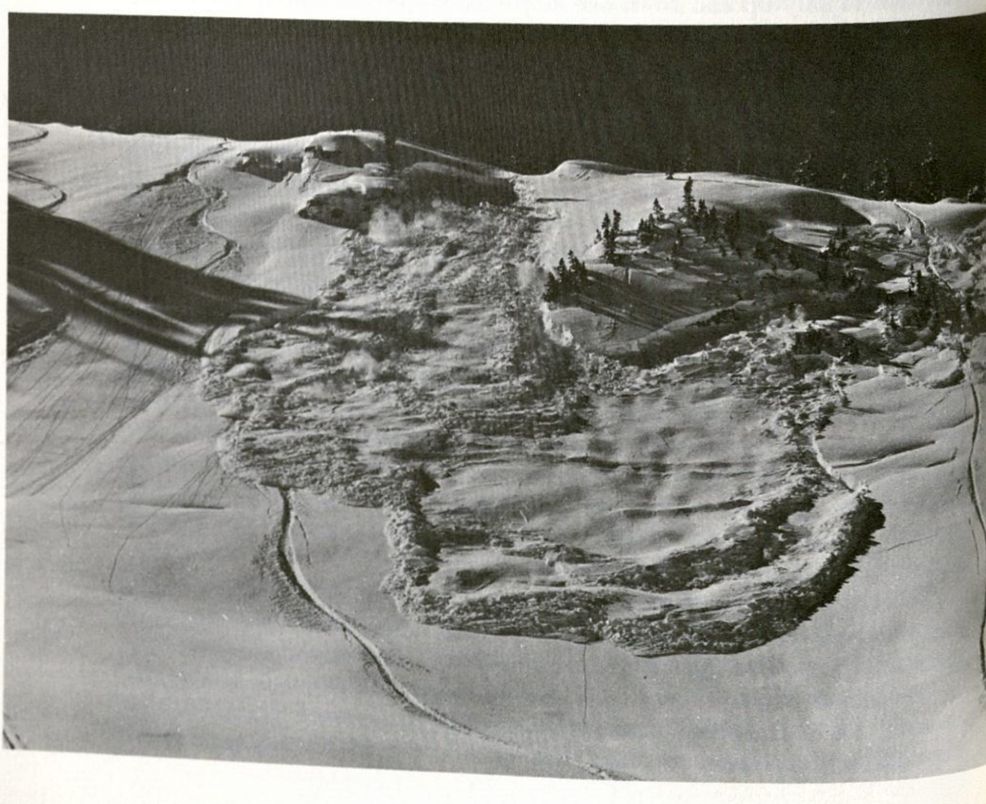
I began to paw around in the snow for the skis I thought were still clamped to my boots. On one boot there was nothing. On the other there was a piece of splintered hickory exactly the length of the sole. We found the other pieces in May when the snow melted.

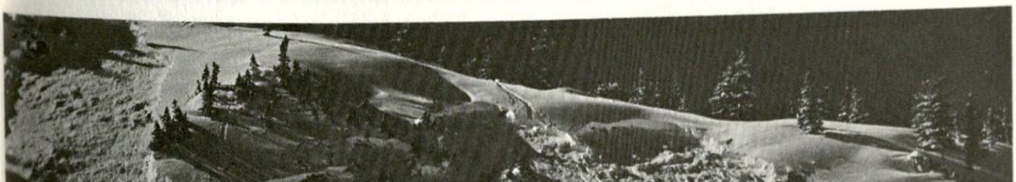
They were lousy skis anyway—wouldn't plane.

The avalanche is an elemental force with no mind or will of its own and is not actually laying for anybody, although one can get the opposite impression. There was, for instance, the party in Canada on a spring tour. They skied happily up and down one slope all afternoon. Then, on the last run, just as the sun went down, the avalanche erupted and killed most of them. Present were all the earmarks of calculated malevolence, a cat-and-mouse game. But an avalanche technician would explain that they must have been skiing on a hard slab over depth hoar. They gradually weakened the slab by their weight and by carving it with their skis. The slab was already under tension from settlement and creep. Under the sudden drop in temperature that always comes at sundown in the high mountains, the slab began to contract. This increased the tension just enough to cause the fracture. It is a classic example of the straw breaking the camel's back; in technical language, a delayed-action, falling-temperature release. At a different time and in a different place, another of the exact same breed missed me by a matter of yards and seconds during the winter of the Hundred-Year Storm in Chile in 1965.

I don't propose to go very far into technicalities. The general reader wouldn't be interested in all the theories; many of them are contradictory, for our understanding of snow and avalanches is still far from complete. The more serious reader will find that the literature is extensive. There is a selected bibliography at the end of this book.

The basic formula is simple: All it takes to produce an avalanche is enough snow on a steep-enough slope. Things immediately become more complicated when one asks, How much and how steep are enough? I have seen avalanches in six inches of snow and on slopes as shallow as 15 degrees. However, this is exceptional in both cases. The majority of avalanches big enough to be interesting originate on slopes in the 25-to-40-degree range.





Avalanche sequence. Ed LaChapelle trapped on Peruvian Ridge. Note his progress (beginning upper left in first photo) as he rides the avalanche down the slope. *Photos by Fred Lindholm.*

By "interesting" I mean dangerous to life or property or both. This element of danger lends to avalanche research a special fascination and urgency.

As for the most favorable angles, it would seem that the steeper the slope the more likely the avalanche. This is just the point. On the very steepest slopes, from 45 degrees to vertical, snow can hardly cling at all. It slides almost continuously during storms, seldom building up to menacing proportions. In the trade we call this *sluffing*. Every avalanche patrolman is glad to see the tracks of those small avalanches after a storm. They mean that the snow is getting rid of its overloads and internal tensions, all part of the natural process of stabilization. It is when those slopes of the mid-range stare back at him with an unruffled and enigmatic eye that the avalanche hunter wheels out his artillery.

Under certain conditions, snow will cling to the high-angle slopes. Wind is the governing factor. By blowing against a mountainside it serves as a trowel. Or, coming from the opposite direction, it builds cornices, those impressive drifts that take the form of a breaking wave. This brings us to the nature of snow itself.

Snow means different things to different people. To a small boy it is an inexhaustible supply of ammunition; when he makes a snowball he is utilizing two of snow's special qualities: cohesion and compaction. To the merchant, it is an unmitigated nuisance to be scraped off his sidewalk; in a big city, snow can be a minor disaster that halts all forms of transportation, tears down power and telephone lines, and costs millions of dollars to get rid of. To the hydrologist it is the perfect form of water storage; requiring no costly dams, it collects the moisture of an entire winter and releases that moisture gradually through the summer; without it the snow-fed rivers of the West would alternate between raging flood and blistering desert and life as we know it would be impossible. To the skier, snow is an ideal sliding surface for a pair of steel and plastic slivers attached to his feet, a combination that has reversed man's age-old dread of winter; the mountains, avoided in the snow season by our forefathers, have become the playground of millions. Thus the nature of snow depends somewhat upon the eye of the beholder.

Lying on a mountainside, snow looks so innocent, so bland, and to the uneducated eye so unchanging, yet the avalanche hunter knows it to be the most changeable substance on earth. From the moment the first molecule of water vapor floating around in the atmosphere condenses around some minute particle of dust, snow never really stops changing until it becomes water again, flows down to the sea, and begins the cycle all over. The life of a snow crystal can be shorter than a butterfly's, for it may melt on the way down and fall to earth as rain. On the other hand, the life of a snow crystal may be measured in centuries if it happens to become part of a glacier. Be it for moments or eras, the nature of snow is that it never entirely stops changing. This is not, of course, a unique property. Everything is changing in its own way and at its own pace. But it is a very important property in connection with avalanches.

As it tumbles down out of the clouds, many things happen to a snow crystal. It grows bigger as more water vapor condenses upon the original particle. It may melt partially or entirely and refreeze in a different form. It brushes other crystals in its random flight. These collisions often cement two or more crystals together into flakes, or, buffeted by the wind, they may grind each other into smaller fragments. These are some of the reasons why snow comes in such a bewildering variety of shapes and sizes.

The classic form of a snow crystal is the six-pointed star. But people who make a study of snow recognize ten different classifications and six different forms within each class: stars, plates, columns, needles, pellets, fragments. No two snow crystals are ever thought to be identical. It is a little hard to believe that among their innumerable legions there never have been or ever will be two crystals exactly alike. Obviously it is one of the mysteries of snow that will never be solved. I'm not even sure that we know the why of the *six*-pointed star. A more interesting riddle is why snow stays peacefully on the slope one day and avalanches violently the next. To this one we have some, though by no means all, of the answers.

When a snow crystal reaches earth it ceases to be a free agent and becomes part of the snow cover. The process of change—the technical word is *metamorphism*—continues but at a slower pace and in a different manner. Surprising things are happening as the snow cover lies on alpine meadow and talus slope, festooning the trees, softening the outlines of boulder and gully. Beneath that enigmatic surface, three principal forces are at work: pressure, temperature, and gravity.

Wind pressure sculptures snow, carving it into drifts and cornices, scouring it away in one place, depositing it in another, altering it in the process, generally by grinding it into smaller particles and compacting it. And the snow's own weight exerts pressure upon itself that causes radical changes within the snow cover.

Temperature acts as a sort of governor. When it goes up, the actions and reactions of snow are stimulated. Low temperatures slow everything down. Thus rising temperature may hasten the onset of an avalanche cycle. At least it is then over and done with. Falling temperatures may prolong a hazardous situation (or a stable one). Temperature is applied to snow in a variety of ways. Some heat from the earth filters up into it constantly; the sun shines upon it from above; wind blows upon it, subtracting or adding heat; rain seeps through it. An obvious thing to remember is that snow never goes above freezing: 32 degrees Fahrenheit, 0 degrees Centigrade. If it does it ceases to be snow.

Gravity does one thing and one only: it pulls, straight down. Again the reaction is complex. But the sum total of these principal forces, and lesser ones too, is that the snow cover is never in a state of repose. It is continually being pushed, pulled, pressed, bent, warmed, chilled, ventilated, churned. The way snow reacts to all this disturbance, so little of which is visible to the casual observer, depends upon the nature of snow itself.

The nature of snow is a controversial subject among technicians and scientists in the trade; there are so many things about it we don't understand. I once had a very lively argument with the head of the Swiss Avalanche Institute, Dr. Marcel de Quervain, on the nature of just one kind of snow—slab. Slab avalanches are accepted as the type most dangerous to life. My contention was that there are two kinds of slab, soft and hard, and that soft slab is a special kind of snow. Dr. de Quervain's position was that they are the same kind of snow differing only in the degree of hardness due to age and wind packing. Now Dr. de Quervain is one of the most noted snow scientists in the world, and I can't rate myself higher than a reasonably competent technician. Nevertheless, after ten years of personal contact with the soft-slab avalanche I thought I knew something about it. I don't recall that either of us convinced the other, but we both acquired some new ideas.

Upon one characteristic of snow, probably all observers can agree without reservation: it is the most recalcitrant substance on earth, particularly when one tries to study it. Snow seems averse to being studied. When it is poked or disturbed or manhandled in any way, it changes quicker than a chameleon, from one kind of snow to another, leaving the observer baffled. An incredible amount of work and ingenuity have gone into equipment and techniques for studying snow in its natural state. We have persuaded it to reveal some of its secrets.

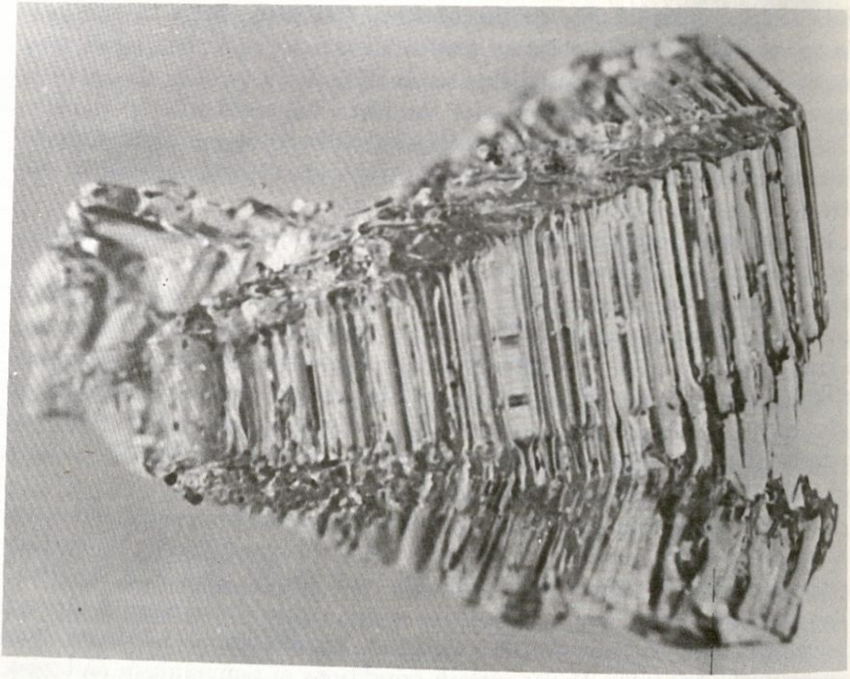
Snow is classed as a *visco-plastic*—that is, it has the ability to flow, like some liquids, and to stretch or compress without losing its structure, like some solids. Any substance that can behave simultaneously like a liquid and a solid is unusual, to say the least. The cohesion—adherence or sticking together—between one particle of snow and another, one layer and another, or between snow and the ground has the widest range in nature. This cohesion depends primarily upon two factors: *interlocking* between the arms of the snow crystals and *sintering*, or cementing. Some snow has no cohesion at all and will dribble down a slope like sand. At the other end of the scale, snow can be so firmly cemented that it has almost the consistency of stone.

The catalogue could go on through heat conductivity, which is very low; heat of fusion, which is very high; reflectivity, which is very unusual in that snow responds to some types of radiation as if it were white and to others as if it were black; and various others. All of them have a part in the reaction of snow to the forces playing upon it. But this is not a technical treatise. What I have tried to demonstrate is that snow is a highly complex material. To me the mystery has never been that it avalanches but that it usually stays on the mountain so well. To put it very simply, if at any time or place the force of gravity pulling downhill is greater than the cohesion holding snow together, the result is an avalanche. Thus within the snow cover on a mountainside there is a continual struggle between these forces, an invisible tug of war with the snow cover as the rope.

There are some oddities about snow that are interesting in themselves and important as avalanche factors. If it is mechanically disturbed in any manner—by the wind or by a skier, for instance—snow goes through a process we call *age hardening.* This means that its cohesion increases for a considerable period of time after the disturbance has ceased. The process is similar, but certainly not identical, to the way a piece of red-hot iron grows harder as it cools. No one knows the why of age hardening, but it is a stabilizing effect. The avalanche patrolman uses it every day as he cuts up a field of new-fallen snow with his skis.

The normal reaction of snow to pressure-temperature-gravity is known as *destructive metamorphism.* This means that the snow breaks down into smaller and simpler forms, more densely and firmly cemented together. Thus the snow cover tends to become more stable the longer it lies on the ground. But, in one of the weirdest manifestations of snow, this process can be reversed. Under certain conditions of temperature and snow depth, and these conditions are common in many parts of the Americas as well as Europe, *constructive metamorphism* takes place. Instead of larger particles becoming smaller and more densely packed, small particles grow larger and more loosely packed. This transformation is another of the mysteries of snow that are not completely understood. We do know that instead of melting and refreezing, which is the normal process of change, the snow crystals *sublimate;* they turn into water vapor instead of water and then recondense.

The product of constructive metamorphism in snow is depth hoar, the eeriest stuff on any mountain. We may not understand exactly how it is made, but we do know what conditions are favorable to it and we can detect it, even concealed at the bottom of the snow cover. The avalanche hunter recognizes it as one of his most dangerous enemies. Those coarse, rounded lumps of ice have no cohesion whatever. Since they generally appear at ground level, it is like having a layer of ball bearings under the snow cover. Just as ominously, depth hoar shrinks away from the normal snow above, the only situation in snow mechanics where settlement is not a stabilizing factor. In effect, depth hoar rots out the underside of a snow pack and leaves it hanging there, supported only around the edges, like a roof. All too often, the roof eventually collapses. Since depth-hoar avalanches involve the entire snow cover, they are the biggest and most



A depth-hoar crystal, greatly enlarged. *A. R. M. Stillman.*

destructive of all, the dreaded *Schneebrett Grundlawine* of Europe and the climax avalanche of the Americas. I have a personal hostility toward them because one of them in Colorado put me in the hospital.

The worst thing about depth hoar is that the rotting process goes on unseen and unheard for days, weeks, and months. The weight of the snow cover increases storm by storm, gravity relentlessly pulling down on it. Eventually a point is reached where the cohesion of an enormous mass of snow is so close to the breaking point that even an inch of snowfall or a loud sound or the slicing action of a pair of skis triggers the avalanche. No man, given existing knowledge and equipment, can foresee exactly when that moment will arrive.

If you pick up a handful of snow, it is very light in comparison to denser materials such as dirt and rock. But its weight is one of the most important elements in the nature of snow. The water content of snow varies almost as much as the cohesion, from as little as 5 per cent density in very dry new-fallen snow to as much as 50 per cent density in old, heavily compacted snow. The weight of snow is always calculated in terms of the water it contains. Thus it would take twenty inches of snow of 5 per cent density to make one inch of water, while it would take only two inches of snow of 50 per cent density.

The weight of any volume of snow is, therefore, the product of its depth times its density in terms of water, which weighs 62.4 pounds per cubic foot, or 5.2 pounds for a layer a foot square and one inch deep. A little simple arithmetic proves that the weight of snow is no minor detail. In a place like Squaw Valley, California, or the Rio Blanco, Chile, snowfall amounts to about four hundred inches per winter. Having measured it, storm by storm, over a period of years, I know that the density averages 10 per cent. Thus the snowfall of an average winter in these places contains forty inches of water. Multiply by the factor of 5.2, and it comes out that the snow cover can weigh over two hundred pounds per square foot. Piled on top of a man, it would be a crushing burden of close to a ton. Multiply pounds per square foot by the thousands of square miles of snow in the mountains, and the figures become astronomical. As a practical matter, the sheer weight of snow can crush buildings, snap telephone and power cables, break trees, bend steel towers. A moderate amount on top of a man caught in an avalanche can press on him so hard that he is unable to breathe and dies almost instantly. The rapid accumulation of weight during a storm, by overcoming the cohesion of snow lying on a slope, triggers more avalanches than all the other primary causes put together.

To the person caught in one, it matters little what kind of avalanche it is. However, anyone should know something about the different types of avalanche, because the type is so often the clue to the why. It turns out to be extraordinarily difficult to give accurate descriptions of avalanches. They come in every conceivable size, shape, and length; they may involve anything from a few cubic feet of powder snow to a monster like the Huascarán avalanche in the Peruvian Andes in 1962, which was estimated to contain over three million cubic yards of glacier ice and snow when it started.

An avalanche may be composed of one kind of snow, as when only a single layer slides. On the other hand it may be a mixture, if several layers slide. If an avalanche travels a considerable distance, particularly if it is squeezed into a ravine, the heat of friction may alter the snow from dry at the start to wet at the finish. It may travel at a moderate pace, which even a man on foot can outrun, or at speeds measured above two hundred miles per hour.

Dry-snow avalanches move the fastest. At maximum speed, part of the snow is apt to spring into the air and move in the form of a cloud. One of the most awe-inspiring sights in the mountains is an air-borne avalanche racing down a slope. It is more than just impressive; that cloud can be lethal and destructive beyond its boundaries. The cloud is actually

A dry-snow avalanche, with snow dust boiling from the terrific speed of the snow mass underneath. *Photo by E. LaChapelle.*

a globe of heavy gas, traveling at high speed. Thus it displaces enormous quantities of air, creating winds of hurricane force around it. On a small scale, you get the same buffeting effect when you pass a big van in a light car.

There is a group of summer home owners at Echo Lake in California who know what the blast from an air-borne avalanche can do. In February, 1950, several houses in this community were destroyed. No one saw this avalanche, for it came during a storm and the houses were empty. Fortunately for the owners, one member of the group was an attorney and a skier who had an interest in avalanches. He noticed that some of the houses had not been touched by avalanche snow that had moved along the ground; they looked as if they'd been blown apart rather than crushed. From his description and photographs it was obvious to me that air blast was the destroying force. Although the houses were not insured against avalanche damage, they were insured against wind damage. Through the alertness of this one man, the victims were able to collect on their insurance.

Researchers need a system of classification and description so that the record of their observations will make sense not only to them but also to others. Thus many workers in all parts of the world can compare notes and pool their knowledge. Avalanche literature is full of names and terms, some of them centuries old. Many are contradictory, inaccurate, or have only local usage. In 1965, the avalanche scientists of the world met in Davos, Switzerland. One item that received much attention was a system of classifying and describing avalanches that could be applied universally. As usual in this controversial field, the scientists couldn't agree and no system was officially adopted. However, Doctors de Quervain and Haefeli of Switzerland proposed one that is in general use.

There are two basic classifications: loose-snow avalanches and slab-snow avalanches, according to the manner of release. A loose-snow avalanche begins at a point and expands on the way downslope. A slab avalanche begins on a front and en masse. It is this characteristic of total release that makes slab avalanches more dangerous. In either classification, an avalanche is further described: it slid on other snow or penetrated to the ground; contained dry, damp, or wet snow; ran in a channel, such

The path of a large wet-snow avalanche, showing characteristic grooves and deposited snow boulders. *U.S. Forest Service photo.*

as a gully, or on the open slope; flowed along the ground or was airborne.

The de Quervain-Haefeli system does not include size or speed, probably because it is very difficult to determine either accurately. At what point, for instance, do you measure the size of an avalanche (not to mention how)? Where it started? Where it finished? In terms of distance traveled, area covered, mass? In the Americas we have solved this problem, to our own satisfaction at least, by classifying avalanches as to size in terms of their threat to life and property. Thus a small avalanche is harmless; a medium avalanche is capable of injuring or killing a man; a large avalanche is dangerous to both life and property; a major avalanche is extra large, unusually big in every dimension. We also have a separate classification (Class 5) for what we call climax avalanches, those that involve most or all of the snow cover and are the outcome of changes taking place over a considerable period of time, in contrast to the avalanche involving snow of a single storm only. The description of avalanches is important, because only by matching the type of avalanche with the conditions that produced it can we advance our knowledge of what the dangerous conditions are. The method of avalanche hazard forecasting that was developed at Alta, Utah, and is in use throughout the Americas is the result of years of such observations.

Regardless of its classification, no avalanche erupts spontaneously and mysteriously. Something has to pull the trigger: an event, a force, a change, a combination—something has to give the final nudge. Here at last, one would think, is a fairly simple relationship between cause and effect. If this were true, avalanche researchers would be close to an a-plus-b-equals-avalanche formula. The fact is that, like everything else about snow and avalanches, the triggering mechanism is highly complex. One of the favorite sports among professionals when airing their theories and honing their minds against each other is to argue which trigger was primary and which secondary or nonoperative in any given avalanche. There's the rub. There are many triggers, probably including some that haven't been identified as yet. They vary from overloading at the surface, which can be seen and measured, to the nibbling of depth hoar at the underside, which proceeds in secret. They work in combination and not infrequently at cross purposes.

As an example, consider shearing. I once wrote a technical paper advancing the theory that shearing is the only trigger, applied in a variety of ways. Shearing is *one* trigger, certainly: the slicing action of a pair of skis or a snow block falling off a cornice. But overloading is also involved: the weight of the man wearing those skis or of that snow block. Remember that the slab in Lone Pine Gully held up as long as I was alone on it. It took the combined weight and shearing of two of us to pull the trigger. Is there any point in arguing, or possibility of determining, which was the primary trigger? As for my theory, I threw my paper into the wastebasket when I realized that for the most part shearing is the effect rather than the cause, the act of breaking apart, be it a handful of crystals in a loose-snow avalanche release or countless millions in a slab release.

The commonest triggers are overloading, temperature, constructive metamorphism, shearing, and vibration. I have already mentioned overloading as the most frequent applier of that final nudge, which is not to say that it is simple. Consider a layer of new-fallen snow. If the weight increases more rapidly than the stabilizing forces can increase cohesion, the snow will shear and there will be a surface avalanche. On the other hand, the new layer may be stable in itself but the additional weight can cause the collapse of some weak layer within the snow cover. Again, once an avalanche begins to move, it exerts a shearing force that can lead to successive penetrations all the way down the mountain. Midwinter rain adds weight to the snow cover more rapidly than snowfall. Two other triggers are also involved, temperature and lubrication. Rain adds heat to the snow cover, which reduces cohesion. If it encounters a dense layer as it percolates downward and flows on that layer, it also acts as a lubricant. But heat and weight also promote settlement, which is a stabilizing factor.

The most obvious manner in which temperature acts as a trigger is by its melting action, which weakens cohesion. But it also works by means of another heat effect, which is most often seen in hard-slab–depth-hoar situations. Hard slab is the least plastic form of snow. When there is a rapid change of temperature in either direction, the snow must respond by expanding or contracting, and that may cause the slab to shear. Remember the Canadian skiers, taken by the avalanche just at sundown? The Olympic ski stars, Buddy Werner of the U.S.A. and Barbi Henniberger of Germany, were killed by a similar avalanche in the morning, when the temperature was rising. To a professional, this tragedy is twofold: that these two talented young people were killed and that no one heeded warnings that the Avalanche Institute had been broadcasting for days.

Constructive metamorphism may be the most secretive trigger, as it works away in the dark to produce depth hoar. But its effect is simply to weaken the snow cover at its most vulnerable point, the underside, where it should be most stable and have its firmest anchorage.

Vibration is a special form of shearing, applied as a sound or shock wave. There are a few authentic cases—my colleague Dick Stillman recorded one—where the snow cover was in such precarious balance that a shout triggered an avalanche. In my personal experience are two cases of avalanches released at a distance seemingly from the vibration of skis moving over a hard surface, transmitted somehow to a very tender slab. Since the skiers were on almost level ground and the snow under them neither avalanched nor cracked, there is no other apparent explanation.

In avalanche blasting, secondary releases at considerable distances, up to a mile in my own experience, from the impact point are commonplace. This is the effect of the shock wave transmitted through the air. These effects are possible only when the snow is at the point of avalanching anyway and any trigger would do the job.

Thus vibration is the most useful weapon in the avalanche hunter's arsenal. By means of explosives he applies a trigger more sudden and severe than anything in nature, forcing the snow to give him a definite answer, yes or no, at a time and place of his choosing.

In order to predict accurately the natural occurrence of an avalanche, a technician would have to know two things: the cohesion of the snow and the operative triggers. Theoretically it is not an insoluble problem. Devices have been invented to measure the cohesion factor of snow. Some of the triggers at least are not too difficult to observe, and others would yield to modern technology. Practically, time is the limiting factor. The snow cover is not a homogeneous mass. It is made up of a number of layers, each of a different character that is changing from day to day, even from hour to hour. Moreover, the character of the snow pack differs from slope to slope and exposure to exposure. By the time an observer can do the necessary sampling on even one slope, the situation has already changed. As for the triggers, their influence also varies with time and shifts in the weather pattern such as wind, temperature, snowfall intensity, and type. All of them are unpredictable variables.

A dramatic illustration came from an experiment I was carrying out to monitor temperature during a storm. It is well known in the trade that any rapid change, up or down, is a danger signal. What I wanted my sensitive telethermometer to tell me was how rapidly and widely the temperature shifts during a Sierra blizzard. Right in the middle of the storm, there was a sudden drop that lasted only a few minutes. It coincided exactly with a general avalanche cycle, the only one produced by that storm. It could have been pure happenstance. Or that trace on the recording chart of my thermometer may be a picture of a primary avalanche trigger at work.

How difficult it is to calculate the interplay between the character of the snow and the effect of the triggers was forcefully demonstrated to me early on the morning of Armistice Day, 1949, at Alta. I lay there in the mouth of Schuss Gully buried to the neck in an avalanche, thinking that this was an ironical way of celebrating the end of World War I. I was in no particular trouble except that I was so wound up in my skis that if I struggled I was sure my knees would dislocate. There would be a ski patrolman along in a minute to dig me out. My mental condition was something else.

The avalanche that embraced me so fondly came from one of my test plots. Every avalanche patrolman has them scattered about his area.

They are so steep that they will avalanche if any slope will, but too short to hurt him—he hopes. They are a rapid and very practical method of checking snow conditions. That was the trouble. The violent reaction of the test plot informed me that an overnight storm had fooled me completely. I had ordered no restrictions before I went out to cruise the area. Some of those powderhounds on the lift would inevitably head for the big slopes—Rustler, Corkscrew, Lone Pine.

Buck Sasaki came slashing down Schuss Gully brandishing a scoop shovel. "Don't you ever get tired of this?" he demanded.

I said, "Hump yourself down to the terminal. Stop the lift. Pass the word to the patrol that everything is closed outside the minimum hazard area. Tell them to track anyone who headed for Corkscrew and Rustler, but they're not to go in there themselves."

Without a word, Buck dropped his shovel and pointed his skis straight downhill. As he went I heard off to one side a familiar hissing, slithering sound. Waving its snow banners a hundred feet in the air, an avalanche tore down the face of Rustler. Automatically I catalogued it: delayed-action soft slab, rising-temperature release, new snow only, large.

Other patrolmen came and dug me out. It had all happened so fast that not many skiers could have made it onto the hill. At the lift terminal I asked the manager to get out his counterfoils and check the serial numbers against the passes issued to the skiers. Then I went up top.

I cruised off toward Corkscrew. At the edge of that winding gully several ski patrolmen were gloomily staring at the tracks in the bottom. Farther down they vanished under a rough heap of avalanche snow. Some of them came out the other side, but did *all* of them? Crisscrossing each other as ski tracks do, it was impossible to be certain.

I sent the patrolmen to make the hasty search—that is, to look for pieces of equipment or even a piece of a skier sticking out of the rubble. I went to the lift to break out the probes. There the manager greeted me with the welcome news that all skiers were accounted for.

The only hope, it seems to me, is some sophisticated device, yet to be invented, that will lie there on an avalanche slope continuously spying upon and recording the ever-changing kaleidoscope of forces within the snow cover.