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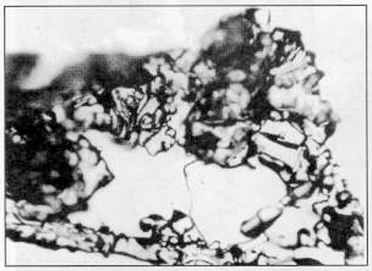
Of Wet Snow, Slush & Snowballs

By Samuel C. Colbeck



"... dry snow and wet snow ... even have different colors and surface textures. And, of course, wet snow is great for making snowballs, while dry snow is not!"

Figure 1. A wet snowflake. How many of these have you seen on Christmas cards?

As surely as snowflakes fly in wintertime, the white mantle they leave on the landscape eventually melts away into the ground or into babbling brooks that carry its moisture back toward the ocean from whence it came.

Indeed, many people think of snow cover as just a solid form of water waiting to melt. As I described in my last article, however, there is more to it than meets the naked eye.

In the subfreezing cold of midwinter, snow that blankets the ground is usually of a loose dry composition with or without crusty layers. Far from being just a compacted mass of broken snowflakes, dry snow has a structure that undergoes a rapid metamorphosis into new crystalline forms and shapes.

In the thaw season, dry snow becomes wet. Its crystalline makeup then changes dramatically, and along with it, the physical properties of the snow. As any skier knows, dry snow and wet snow are very different materials. They even have different colors and surface textures. And, of course, wet snow is great for making snowballs, while dry snow is not!

My purpose here is to take a close look at wet snow and its unique crystalline structure that makes it different from other forms of snow. And I'll touch on some of its mysteries, too.

For example, something that has always amazed me about fresh, wet snow is that it can be sticky, yet also extremely slippery. Falling wet snow (Figure 1) sometimes adheres with a vengeance to trees and power lines. In Japan, wet snowstorms occasionally result in such large snow accretions on power lines that mile after mile of wire and supporting poles collapse under the weight, like so many toppled dominoes. Yet, these same storms can coat highways with snow so slippery it causes serious traffic problems.

Then there is slush a variety of wet snow that is not particularly slippery but one that can splash around almost like a liquid, as when we drive through it on a highway. Slush is a water-logged version of wet snow that forms when melt water is unable to drain away - a very different thing indeed than freely draining wet snow. Let's look at slush first.

Slushy Snow

A slushy layer of snow results when rain or melt water percolates downward from the snow surface but can't penetrate an icy layer or the ground surface beneath. Because of its low binding strength, slush that forms in hilly terrain can sometimes pose a hazard by releasing wet snow avalanches. These avalanches can occur even on very gentle slopes where, though they are unable to gather much speed, the great mass of slush sometimes involved can make them very destructive. Figure 2 shows the kind of poorly bonded masses of well-rounded ice crystals that make up slush and are responsible for its fluid-like properties.

The ice crystals in slush are relatively large, having grown very rapidly by a process of cannibalism. The process is similar to the one responsible for grain growth in dry snow, and even to one that occurs in metals.

In dry snow (see the February 1994 Avalanche Review) the pores or spaces separating the ice crystals - are occupied by moist air. Crystal growth is driven by differences of water vapor pressure in the pores in the vicinity of crystalline particles which have dissimilar temperatures or curvatures. The rate of crystal growth is limited by the rate that the water vapor can diffuse across the pores from the smaller particles to the larger ones.

The situation in slush, however, is different because the pores between the ice crystals are occupied by liquid water rather than air. Crystal growth in slush is driven not by water vapor diffusion, but rather by thermal diffusion - in other words, by the flow of heat from crystalline particles that are growing (and becoming slightly warmer through the absorption of the latent heat of fusion) to the particles that are shrinking (and becoming slightly cooler by supplying latent heat). The rate of crystal growth is limited by the rate at which heat can flow between particles through the waterfilled pores. Let's look more closely at the situation from the viewpoint of an individual particle. Locally, the heat flow to or from the particle is determined by the melting temperature of the particle. The melting temperature, in turn, depends on the size of the particle: the smaller it is, the lower its melting temperature.

So, with sufficient heat available from the pore water to allow melting, the small particles are the first to succumb. The smaller they get as they melt, the faster they shrink until when they are reduced to a small fraction of their original size-they disappear almost instantaneously. It is interesting to note that, in dry snow, it is likewise the small particles that selectively disappear in that case owing to their higher vapor pressure rather than to their lower melting temperature.

In only a few days after weather conditions favor the formation of slush, the mean particle size typically increases to a diameter approaching onemillimeter. As the smaller particles in slush are removed from the population by selective melting, the larger particles are able to grow at a compensating rate. The overall amount of ice in the slushy mass remains essentially the same, but now it is divided among a much smaller total number of (relatively large) crystals.

As the ice crystals grow and their numbers decrease, slushy snow typically maintains a low bonding strength because the crystals are rounded and only weakly coupled. In other forms of wet snow the crystals can bond together more strongly.

More than a century ago, the English physicist, Michael Faraday, performed experiments with ice crystals. He found that two such crystals held in contact with one another in water would bond together in much the same way as the crystals in freely draining, wet snow. Given the difference between the individual crystals in slush, shown in Figure 2, and the tightly bonded clusters in freely draining wet snow (shown in Figure 3), I find it difficult to reconcile Faraday's observation with the very different behavior of slush. To me, that's another mystery of wet snow!

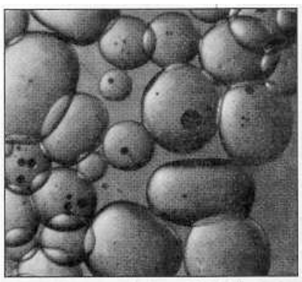


Figure 2. Slushy snow seen through crossed Polaroid filters, leaving only the ice crystals visible. Such crystals are typically 0.5 to 1.0 mm in diameter.

Freely Draining Wet Snow

When melt water is free to drain through snow, the result is a form of snow much less dense than slush, with a considerably smaller liquid water content. In no case, however, does wet snow drain below a liquid content of about 3%. That much water can be held against the pull of gravity by capillary attraction along the boundaries of the snow grains, which tend to group into grain clusters. Additional water that may be present slowly migrates downward from one grain cluster to another.

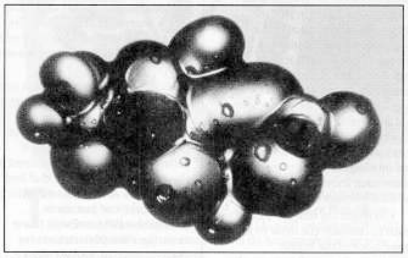


Figure 3. A tightly bonded cluster of well-rounded, single crystals in freely draining wet snow.

Now let's take a closer look at the photograph of a typical grain cluster (Figure 3). Wherever two grains (the individual, well-rounded crystals visible in Figure 3) come into mutual contact, a grain boundary develops. Liquid adheres through capillary effects to these boundary recesses.

More liquid water is held in the interior of clusters at three-grain junctions, or veins. A close-up view of such a junction is shown in Figure 4. This type of liquid-filled juncture is also commonly found in "rotting" lake ice, as well as in metals near their melting temperatures. But those materials lack the open structure and high porosity of snow.

Although each individual cluster found in wet snow is a dense and tightly packed mass of ice, the clusters themselves are only loosely packed together and are surrounded by large air-filled pores (see Figure 5). This is why wet snow usually has a high permeability, and a density of only one-half to one-third that of solid ice.

Effects of Melt-Freeze Cycling

In my earlier article, I described two mechanisms at work in dry snow that result in continual recrystallization. In wet snow, there are also two mechanisms leading to recrystallization. One is the selective growth process that favors the larger crystals, already described. The other involves melt-freeze cycling.

An important consequence of the process of meltfreeze recrystallization has to do with problems related to water pollution and acid rain. Most impurities that reach the snow surface-either in the original precipitation or added later by "dry deposition" will reside on the surfaces of the ice crystals. When a polluted snow cover is first wetted, the impurities that are water soluble are quickly dissolved by the infiltrating water. For this reason, in areas subject to acid precipitation the first fraction of the snow cover to melt during a thaw tends to produce runoff into streams and lakes that is especially high in acidity.

Such sudden acid flushes from melting snow can be bad news for aquatic life. At first glance it would seem to be a simple matter to predict when they will occur, based on routine weather forecast information. But such predictions are complicated by the fact that many areas susceptible to this kind of environmental damage are those in which the normal range of temperature and other conditions is favorable to frequent cycles of melting and refreezing. These cycles, in turn, tend to change the distinctive grain clusters discussed earlier into the kind of amorphous ice particles shown in Figure 6.

One result of this process is to redistribute the impurities in the snow and to change the pattern of acid flushes.

The larger the number of meltfreeze cycles, the more the clusters are rounded and the less distinct the individual crystals in them become. On the other hand, given enough time between melt-freeze cycles, the clusters tend to return once again to their original form. That is because the geometric configuration shown in Figure 3 is the equilibrium cluster shape in an air-water-ice crystal mixture, nature returns to it when given the opportunity. Heat provided by solar radiation, able to penetrate the snow in sunny conditions, can greatly accelerate this reversal process.

Since some refreezing will have had a chance to occur in most wet snow covers, the snow will usually consist of a mixture of the two different cluster shapes I have just described. The collection of ice crystals from a wet snow cover, shown in Figure 7, is an example of what the competing forces of solar radiation and melt-freeze cycling can fashion. Both well-rounded single crystals and large amorphous aggregates of multiple crystals are visible.

Between this article on wet snow and my earlier one on dry snow, I have discussed the most basic types of crystals to be found in snow but by no means all of those that can and do exist. For example, many special crystalline forms are created at the surface of a snow cover. When these are buried by subsequent snowstorms they retain at least traces of their special features. Icy layers are often formed in a snow cover, too, such as those formed from crusts due to wind or sunshine, and later buried.

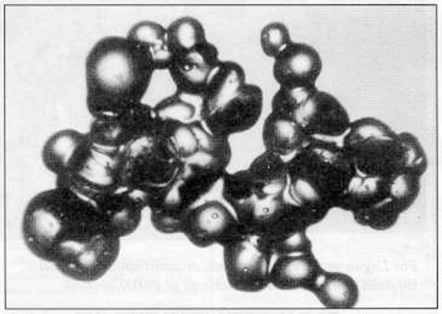


Figure 5. Interconnected groups of grain clusters found in wet snow. The ample spaces between the clusters account for the typically open, porous structure of wet snow.

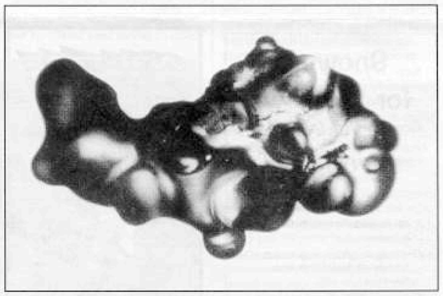


Figure 6. An ice particle in wet snow of the kind commonly found after a number of melt-freeze cycles.

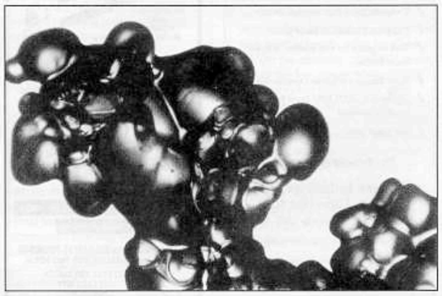


Figure 7. Many particles in a wet snow cover are hybrids, consisting of both well-defined single crystals and amorphous collections of multiple crystals.

If we look closely at any blanket of snow, there are many things of interest we might discover about it. I've looked at the variety of crystals in snow. But I've left out many things about their role in giving snow some of its wide range of characteristics that are part of our experience. Why, indeed, do cold, dry snow and slush both make poor snowballs?

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