SURFACE FORMS OF SNOW COVER • AGING OF THE SNOW COVER • THE FORMATION OF GLACIERS • THE FORMATION OF SNOW AVALANCHES • UNDERSTANDING THE CYCLE OF SNOW

CHAPTER 27

THE CYCLE OF SNOW

Understanding the cycle of snow helps climbers anticipate changing conditions from the bottom of the mountain to the top, from morning to evening, and from day to day. While dramatic changes occur during storms, often subtle changes—caused by different exposures to sun and wind or aging processes—create significant impediments or enhancements to travel.

Snow crystals form in the atmosphere when water vapor condenses at temperatures below freezing. They form around centers of foreign matter, such as microscopic dust particles, and grow as additional atmospheric water vapor condenses onto them. Tiny water droplets also may contribute to snow crystal growth. The crystals generally are hexagonal, but variations in size and shape are almost limitless, including plates (fig. 27-1a), dendrites (fig. 27-1b and e), columns (fig. 27-1c and f), and needles (fig. 27-1d). The particular shape depends on the air temperature and the amount of water vapor available.

When a snow crystal falls through air masses of different temperatures and with different water vapor contents, snow crystals may become more complex or combine. In air that has a temperature near freezing, snow crystals stick together to become snowflakes: aggregates of individual crystals. When snow crystals fall through air that contains water droplets, the droplets freeze to the crystals, forming the rounded snow particles called *graupel* (fig. 27-1g)—soft hail. When snow crystals ascend and descend into alternating layers of above- and below-freezing clouds, layers of glaze and rime build up to form hailstones (fig. 27-1h). Sleet (fig. 27-1i) is a refrozen raindrop or melted snowflakes that have refrozen.

The density of new-fallen snow depends on weather conditions. The general rule is that the higher the temperature, the denser (heavier and wetter) the snow. However, density varies widely in the range of 20 to 32 degrees Fahrenheit (minus 6 to 0 degrees Celsius). Wind affects snow density, because high winds break up falling crystals into fragments that pack together to form dense, fine-grained snow. The stronger the wind, the denser the snow. The lowest-density (lightest and driest) snow falls under moderately cold and very calm conditions. At extremely low temperatures, new snow is fine and granular, with somewhat higher densities. The very highest densities are associated with graupel or needle crystals falling at temperatures near freezing.

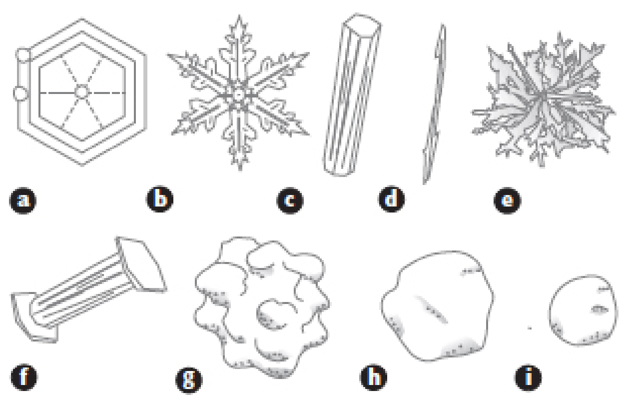

Fig. 27-1. Snow crystal forms: a, plate; b, dendrite (stellar crystal); c, column; d, needle; e, spatial dendrite (combination of feathery crystals); f, capped column; g, graupel (soft hail); h, hail (solid ice); i, sleet (icy shell, inside wet).

The amount of water (solid or liquid) in layers of snow can indicate its density. Higher water content means that more space is occupied by ice or water and less air is present, causing higher density. In new-fallen snow, water content ranges from 1 to 30 percent, sometimes even higher, with the average for mountain snowfall being 7 to 10 percent.

SURFACE FORMS OF SNOW COVER

Snow and ice undergo endless surface changes as they are affected by wind, air temperature, solar radiation, freeze-thaw cycles, and rain. This section describes most of the surface permutations that mountaineers typically encounter. Table 27-1 summarizes the dangers and travel considerations associated with these various forms of snow.

Rime. Formed right at ground level, rime is the dense, dull white deposit formed by water droplets freezing on trees, rocks, and other objects exposed to the wind. Rime deposits build into the oncoming wind. Rime may form large, feathery flakes or a solid incrustation, but it lacks regular crystalline patterns. Typically it is easy to break, forming a weak, crusty surface when it is on top of snow and a poor, unreliable anchor when it is on rock or ice faces.

Hoarfrost. Another type of snow that forms at ground level, hoarfrost forms on solid objects by the process of sublimation: the direct conversion of atmospheric water vapor to a solid. Unlike rime, hoarfrost displays distinct crystalline shapes: blades, cups, and scrolls. The crystals appear fragile and feathery, sparkling brilliantly in sunlight. When deposited on top of snow, hoarfrost is known as *surface hoar*, generally produced during a cold, clear night. A heavy deposit of surface hoar makes for fast, excellent skiing with fun, crinkly sounds. (For depth hoar, see "Aging of the Snow Cover" later in this chapter.)

Powder snow. A popular term for light, fluffy new-fallen snow, *powder snow* is more specifically defined as new snow that has lost some of its cohesion because large temperature differences between the pits and peaks of its feathery *dendrite* (branching) crystals have caused recrystallization. The changed snow is loose (uncohesive) and powdery (mostly air). It commonly affords good downhill skiing and may form dry loose-snow avalanches. Climbing or walking through powder is difficult, and any weight on it readily sinks.

Corn snow. After the advent of melting in early spring, a period of fair weather may lead to the formation of coarse, rounded crystals on the snow surface. The crystals, often called *corn snow*, are formed when the same surface layer of snow melts and refreezes for several days. When corn snow thaws each morning after the nighttime freeze, it is great for skiing and step-kicking. Later in the day, after thawing has continued, corn snow can become too thick and gooey for easy travel. During the afternoon, the associated meltwater also may lubricate the underlying snow and promote wet loose-snow avalanches, especially if the snow is stressed by people glissading on it or by the sliding and turning actions of skis, snowboards, and snowmobiles.

Rotten snow. Rotten snow is a spring condition characterized by soft, wet lower layers that offer little support to the firmer layers above. Rotten snow forms when lower layers of depth hoar (see "Aging of the Snow Cover" later in this chapter) become wet and lose what little strength they have. It is a condition that often leads to wet loose-snow or slab avalanches running clear to the bare ground. Continental climates, such as that of the North American Rockies, often produce rotten snow. Maritime climates, such as that of the Pacific coastal ranges, which usually have deep, dense snow covers, are less likely to produce rotten snow conditions. In its worst forms, rotten snow will not support the weight of even a skier. Snow that promises good spring skiing in the morning, when there is some strength in the crust, may deteriorate to rotten snow later in the day.

Meltwater crust. A snow crust that forms when water that melted on the snow's surface refreezes and bonds snow crystals into a cohesive layer is called a *meltwater crust*. Sources of heat that cause meltwater crusts include warm air, condensation at the snow surface, direct sunlight, and rain.

Sun crust. Sun crust is a common variety of meltwater crust that derives its name from the main source of heat for melting. In winter and early spring, the thickness of a sun crust over dry snow usually is determined by the depth of solar heating. Often it is thin enough that skiers and hikers break through, which is very uncomfortable. In later spring and summer, when free water is found throughout the snow cover, the sun crust's thickness—usually less than about 2 inches (5 centimeters)—depends on how cold temperatures become at night.

TABLE 27-1. SNOW CONDITIONS AND THEIR RELATED TRAVEL CONSIDERATIONS AND DANGERS

SNOW CONDITION	EFFECTS ON TRAVEL	EFFECTS ON PROTECTION	DANGERS
Rime	Breakable; can trap feet		

	or skis		
Hoarfrost	Fun skiing		If hoarfrost is buried, potential avalanche danger
Powder snow	Difficult walking, good skiing	Ropes cut through it; ice axes do not hold in it; clogs crampons; deadmen need reinforcing with buried packs, etc.	Potential avalanche danger
Corn snow	Walking on it best in morning; skiing on it best in afternoon	Bollards must be large to hold	When frozen, avalanche potential low; when melted, stability depends on water content and underlying layer strengths
Rotten snow	Difficult traveling	Ropes cut through it; ice axes do not hold in it; deadmen need reinforcing with buried packs, etc.	Potential avalanche danger
Meltwater crust	Breakable; can trap feet if crust thin; good walking	May require crampons	Slippery

	if crust thick; skis require edges		
Wind slab	Good walking		Potential avalanche danger, especially on leeward slopes
Firnspiegel	Breakable		
Verglas	Breakable; impedes rock travel		Slippery
Suncups	Uneven but solid walking or skiing		Low danger because usually form in old, stable snow
Nieves penitentes	Difficult to negotiate	Ropes catch on them	Low danger because usually form in old, stable snow
Drain channels	Uneven but solid walking or skiing		Low danger because usually form in old, stable snow
Sastrugi and barchans	Uneven but solid walking or skiing	Ropes catch on them	A sign of wind transport and potential slab formation; ski edges may catch on them

Cornices	Difficult to negotiate; best to avoid	Ropes cut through them	Can break away underneath or above traveler
Crevasses	Difficult to negotiate; may be hidden by snow; best to avoid	Require rope protection	Easy to fall into, especially if hidden
Seracs	Difficult to negotiate; best to avoid	Ropes catch on them	Very unstable; can break catastrophically
Avalanche paths	Hard surface, good walking		Slippery; relatively free from avalanche danger unless portion of slab remains or is recharged by new snow
Avalanche debris	Difficult to negotiate		Relatively free from avalanche danger unless portion of slab remains or is recharged by new snow

Rain crust. Another type of meltwater crust, rain crust forms after rainwater has percolated into the surface layers of snow. The rain water often follows preferred paths as it percolates through the snow, creating fingerlike features that act as pinning points, holding the crust to the underlying snow after it refreezes. The pinning action of many rain crusts helps to stabilize the snow against avalanching and makes for strong walking surfaces, especially in the Pacific's coastal ranges where heavy winter rainfall is common, even at high elevations. Glazed rain crusts can be extremely slippery and dangerous. Rain nearly always freezes on top of glacier ice, even during summer. This makes travel on glaciers following a fresh rain particularly hazardous.

Wind slab. After surface snow layers are disturbed by the wind, age hardening takes place to form a wind slab. When fragments of snow crystals broken by the wind come to rest, they are compacted together. Then the wind provides heat, particularly through water vapor condensation, which causes melting. Even when there is not enough heat to cause melting, the disturbed surface layer warms and then cools when the wind dies, providing additional metamorphic hardening. Traveling usually is fast and easy on hard wind slabs, but the slabs can break in long-running fractures, and if they overlie a weak layer or form a cornice, added stress causes avalanching.

Firnspiegel. The thin layer of clear ice sometimes seen on snow surfaces in spring or summer is called *firnspiegel* (a German word meaning "snow mirror," pronounced FEARN-spee-gull). Under the right conditions of sunlight and slope angle, the reflecting of sunlight on firnspiegel produces the brilliant sheen called *glacier fire*. Firnspiegel forms when solar radiation penetrates the snow and causes melting just below the surface at the same time that freezing conditions prevail at the surface. Once firnspiegel is formed, it acts like a greenhouse, allowing snow beneath to melt while the transparent ice layer at the surface remains frozen. Firnspiegel usually is paper thin and quite breakable. Breaking through firnspiegel while traveling causes little discomfort, unlike breaking through sun crusts.

Verglas. A layer of thin, clear ice formed by water (from either rainfall or snowmelt) freezing on rock is called *verglas*. It is most commonly encountered at higher elevations in the spring or summer when a freeze follows a thaw. *Verglas* (a French word meaning "glazed frost" or "glass ice," pronounced vair-GLAH) also may be formed by super-cooled raindrops freezing directly as they fall onto exposed objects—a phenomenon known as *freezing rain*, also sometimes inaccurately called *silver thaw. Verglas* forms a very slippery surface, and like black ice on a roadway, it can be difficult to anticipate.

Suncups. Also called *ablation hollows*, suncups can vary in depth from 1 inch to 3 feet (2.5 centimeters to 1 meter) or more (fig. 27-2a). Where sunshine is intense and the air is relatively dry, suncup depths usually increase with increasing elevation and decreasing latitude. On the ridges of each cup, sun-heated water molecules evaporate from the snow surface. In the hollows, water molecules released by solar heating are trapped near the snow surface, forming a liquid layer that promotes further melt. Because melting can occur with only one-seventh of the heat that is required for evaporation, the hollows melt and deepen faster than the ridges evaporate. The hollows are further deepened by differential melting when dirt in the hollows absorbs solar radiation. The suncups melt faster on the south (sunny) side in the northern hemisphere, so the whole suncup pattern gradually migrates northward across a snowfield.

Warm, moist winds tend to destroy suncups by causing faster melt at the high points and edges. A prolonged summer storm accompanied by fog, wind, and rain often will erase a suncup pattern completely, but the cups start to form again as soon as dry, fair weather returns. While skiing over suncups, it is easy to catch an edge, especially if the cups are hard and frozen from nighttime cooling. The unevenness of suncupped surfaces makes walking uphill tedious, but traveling downhill is made a little easier by "skating" into each hollow.

Nieves penitentes. When suncups grow up, they become *nieves penitentes* (pronounced nee-EH-vays pen-ih-TEN-tays, from the Spanish for "snow penitents," derived from the forms' similarity to the shape of a penitent's cowl). Nieves penitentes are the pillars produced when suncup hollows become very deep, accentuating the ridges into columns of snow that look like praying statues (fig. 27-2b). They are peculiar to snowfields at high altitudes and low latitudes, where solar radiation and atmospheric conditions conducive to suncups are intense. The columns often slant toward the midday sun. Nieves penitentes reach their most striking development among the higher peaks of South America's Andes and the Himalaya, where they may become several feet high and make mountain travel very difficult.

Drain channels. After melting has begun in spring, water runoff forms drainage patterns on snowfields. The actual flow takes place within the snowpack, not on the surface. As snow melts at the surface, the water that is formed percolates downward until it encounters either impervious layers that deflect its course or highly permeable layers that it can easily follow. Much of the water also reaches the ground beneath. Water that flows within the snow often causes a branching pattern of drain channels that appear on the surface. This happens because the flowing water accelerates the snow settlement around its channels, which are soon outlined by depressions at the surface.

The dirt that collects in these depressions absorbs solar radiation, causing differential melting that further deepens them.

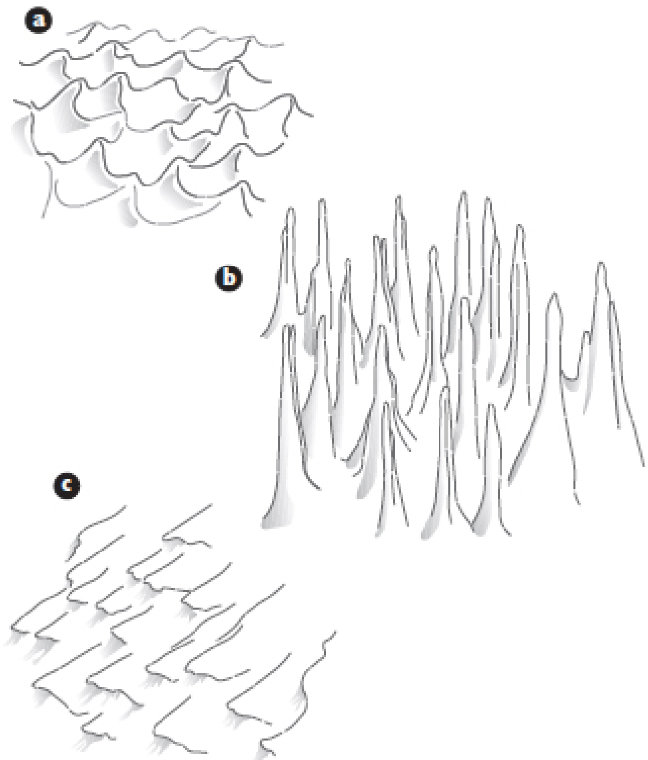

Fig. 27-2. Surface features on snow: a, suncups; b, nieves penitentes*; c,* sastrugi.

On a sloping surface, drain channels flow downhill and form a parallel ridge pattern that can make it a little difficult to turn while glissading or skiing. On flat surfaces, drain fields create a dimpled-looking surface, similar to suncups but more rounded. The appearance of dimples or drain channels suggests that a significant amount of water has percolated into the snow cover. If these dimples or channels are frozen, it can be a good sign of stability against avalanches. However, if they are newly formed and still soft with liquid water, snow stability may be compromised by meltwater that has percolated into a susceptible buried layer and weakened it.

***Sastrugi* and barchans.** When it is scoured by wind, the surface of dry snow develops a variety of erosional forms, such as small ripples and irregularities. On flat, treeless territory and high ridges, both of which are under the full sweep of the wind, these features attain considerable size. Most characteristic are *sastrugi* (pronounced sass-TRUE-gee, a Russian word meaning “grooves”), the wavelike forms with sharp prows directed into the prevailing wind (fig. 27-2c). A field of *sastrugi*—hard, unyielding, and as much as several feet high—can make for tough going.

High winds over featureless snow plains also produce dunes similar to those found in desert sand, with the crescent-shaped dune, or *barchan*, being most common. These stiff, uneven features cause difficult traveling, especially when ice or rocky ground is exposed between each one.

Cornices. Deposits of snow on the lee edge of a ridgetop, pinnacle, or cliff are called *cornices*. Snow that falls during storms furnishes material for cornice formation. Cornices also are formed or enlarged by snow blown from snowfields that lie to the windward side of the ridge or feature (see Figure 17-5a). As a general rule, cornices formed during snowstorms (see Figure 17-5b) are softer than those produced by wind drift alone. Cornices present a particular hazard because they overhang, forming an unsupported, unstable mass (which may not be solid all the way through) that can break off (see Figure 17-5c) due to natural causes or human disturbance. It is dangerous to walk on a cornice. In addition, falling cornices are dangerous to those below and also can set off avalanches.

AGING OF THE SNOW COVER

Snow that remains on the ground changes with time. The crystals undergo a process of change—*metamorphism*—that usually results in smaller, simpler forms and a snowpack that shrinks and settles. Metamorphism begins the moment that snow falls and lasts until it completely melts away. Because the snowpack continually changes over time, mountaineers find it useful to know the recent history of weather and snow conditions in an area, in order to calculate what the snow cover will be like.

Equilibrium growth process. One type of metamorphism, the equilibrium growth process, gradually converts the varied original forms of the snow crystals into old snow: homogeneous, rounded grains of ice (fig. 27-3). Both temperature and pressure affect the rate of change. When temperature within the snow is near the freezing point—32 degrees Fahrenheit (0 degrees Celsius)—change is rapid. The colder it gets, the slower the change; it virtually stops below minus 40 degrees Fahrenheit (minus 40 degrees Celsius). Pressure from the weight of new snowfall speeds changes within older layers. Snow that has reached old age—surviving at least one year and with all original snow crystals now converted into grains of ice—is called *firn* or *névé*. Any further changes to firn snow lead to formation of glacier ice (see the next section).

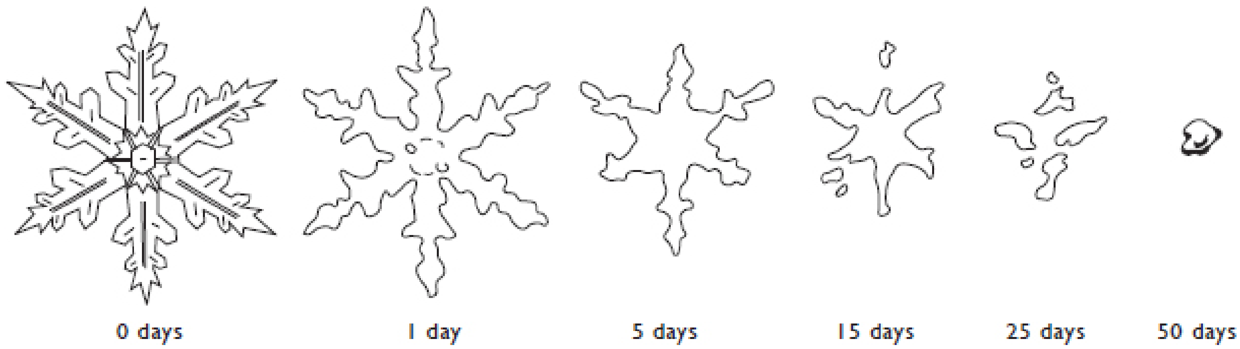

Fig. 27-3. Metamorphism of a snow crystal in the equilibrium growth process; days indicate time required for shapes to change under average temperature and pressure conditions in a typical seasonal snow cover.

Kinetic growth process. Another type of metamorphism, the kinetic growth process, takes place when water vapor moves from one part of the snowpack to another by vapor diffusion, which deposits ice crystals that are different from those of the original snow. This kinetic growth produces faceted crystals (fig. 27-4). When the process is completed, the crystals often have a scroll or cup shape, appear to be layered, and may grow to considerable size—up to 1 inch (2.5 centimeters) or so. They form a fragile structure known as *depth hoar* that loses all strength when crushed and becomes very soft and weak when wet. This weak, unstable snow form is popularly referred to as *sugar snow* when dry and rotten snow when wet. The conditions necessary for its formation are a large difference in temperature at different depths in the snow and sufficient air space so that water vapor can diffuse freely. The conditions are most common early in winter when the snowpack is shallow and unconsolidated.

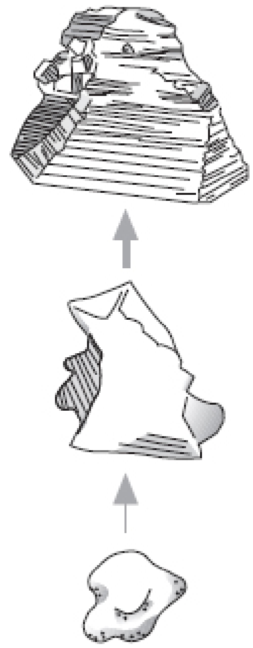

Fig. 27-4. Metamorphism of a snow crystal in the kinetic growth process results in a scroll or cup shape that appears layered and may become relatively large.

Age hardening. In addition to undergoing metamorphic changes caused by variations in temperature and pressure, snow can age by mechanical means, such as wind. Snow particles broken by wind or other mechanical disturbances undergo a process known as age hardening for several hours after they are disturbed. This age hardening is the reason why it is easier to travel in snow if you follow tracks previously set by feet, skis, snowshoes, or snowmobiles.

Snow's variations in strength are among the widest strength variations found in nature: New snow is about 90 percent air, and the individual, unconnected grains make it a fluffy, weak material that is easy to break apart. In contrast, wind-packed old snow may contain less than 30 percent air, with the small, broken particles forming strong interconnected bonds that can create layers 50,000 times harder than fluffy new snow. The variations between these two extremes and the continual changes in strength caused by changes in temperature, pressure, and wind make for highly variable conditions from place to place and hour to hour.

THE FORMATION OF GLACIERS

Glaciers form for a rather simple reason: Snow that does not melt or evaporate during the course of a year is carried over to the next winter. If snow continues to accumulate year after year, eventually consolidating and beginning a slow downhill movement, it has become a glacier.

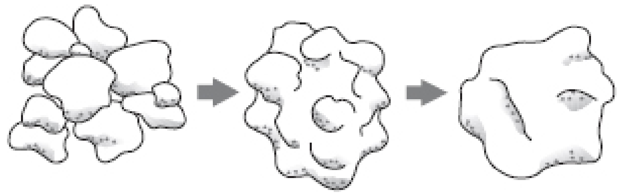

Fig. 27-5. Rounded snow grains that are pressed and squeezed together form a large glacier ice crystal.

Within the old snow—the firn or névé—the metamorphic conversion of snow crystals into grains of ice has been completed. Now the grains of ice are changed into glacier ice in a process called *firnification*. Firn turns into glacier ice when the air spaces between the grains become sealed off from each other so the mass becomes airtight (fig. 27-5).

Each spring when the lower snow layers are still at temperatures below freezing, percolating meltwater refreezes when it reaches these lower layers. This refrozen meltwater forms ice layers within the firn. Therefore, by the time compaction and metamorphism have prepared an entire area of firn for conversion to glacier ice, the firn may already contain irregular bodies of ice.

Once glacier ice has formed, metamorphism does not cease. Some of the ice grains continue to grow at the expense of their neighbors, and the average size of the ice crystals increases with age (fig. 27-6). Large glaciers, in which the ice takes centuries to reach the glacier's foot, may produce crystals more than 12 inches (30 centimeters) in diameter, gigantic specimens grown from minute snow particles.

To understand how a simple, valley-type alpine glacier is born, picture a mountain in the northern hemisphere that has no glaciers. Now suppose climatic changes occur that cause snow to persist from year to year in a sheltered spot with northern exposure. From the beginning, snow starts to flow toward the valley in the very slow motion called *creep*. New layers are added each year, the patch of firn snow grows deeper and bigger, and the amount of snow in motion increases. The creeping snow, while melting and refreezing, dislodges soil and rock, and the flow of water around and under the snow patch additionally influences the surroundings. This small-scale process of erosion eventually leads to formation of a hollow where the winter snows are deposited in deeper drifts. After the snow deepens beyond 100 feet

(30 meters) or so, the increasing pressure of the many upper layers of firn causes the lower layers to begin turning to glacier ice. A glacier is born.

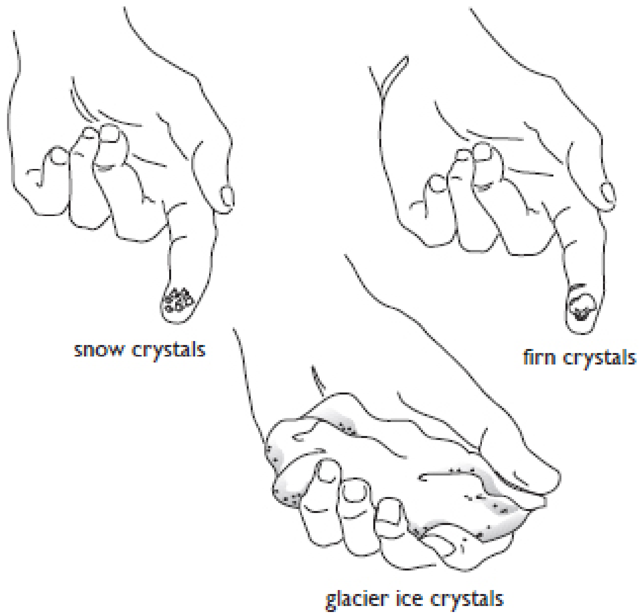

Fig. 27-6. Ice crystals increase greatly in size as they transform from snowflakes and firn into glacier ice.

With continued nourishment from heavy winter snows, the glacier flows toward the valley as a stream of ice. At some point in its descent, the glacier reaches an elevation low enough and warm enough that no new snow accumulates. The glacier ice begins to melt. Eventually the glacier reaches a point, even lower and warmer, at which all ice carried down from above melts each year. This is the lower limit of the glacier.

Glaciers vary from stagnant masses with little motion to vigorously flowing rivers of ice that transport large masses each year from higher to lower elevations. Glaciers in relatively temperate climates flow both by internal deformation and by sliding on their beds. Differences in speed within the glacier are somewhat like those in a river: fastest at the center and surface and slower at the sides and bottom where bedrock creates drag. Small polar glaciers present a striking difference in appearance from their temperate cousins, for they are frozen to their beds and can flow only by internal deformation. The polar glaciers look much like flowing molasses, whereas temperate glaciers are rivers of broken ice.

CREVASSES

Crevasses are important features of glaciers. Crevasses are fractures that occur when ice encounters a force greater than it can bear. Near the surface of a glacier, where ice is just beginning to form, the ice is full of tiny flaws and weakly bonded crystals. When it stretches or bends too fast, it can break apart in a brittle manner, like glass. The result is a crevasse.

Crevasses typically are 80 to 100 feet (25 to 30 meters) deep. At depths greater than that, ice layers become stronger, with increasingly large and well-bonded crystals. When stresses try to pull this deeply buried ice apart, overlying pressure further squeezes it together, causing it to flow and deform like thick, gooey honey. In colder glaciers—at high elevations or in polar climates—crevasses can penetrate somewhat deeper because colder ice is more brittle and tends to break more easily.

Temperate glaciers normally have more, and shallower, crevasses than polar glaciers because temperate glaciers usually move faster. When glaciers move very fast, such as over a very precipitous drop, extensive fracturing occurs, which forms an *icefall.* The numerous crevasses link together, isolating columns of ice called *seracs*.

ICE AVALANCHES

Ice avalanches can pour from hanging glaciers, icefalls, and any serac-covered portion of a glacier. Ice avalanches are caused by a combination of glacier movement, temperature, and serac configuration. On warm, lowelevation glaciers, ice avalanches are most common during late summer and early fall when meltwater has accumulated enough to flow underneath the glacier and increase its movement. The avalanche activity of high-elevation glaciers and cold glaciers that are frozen to the bedrock has no such seasonal cycle.

Reports differ on the time of day when ice avalanches are most active. Field observers suggest that they are most common during the afternoon. This may be possible in a snow-covered serac field if daytime heating loosens snow enough to avalanche into seracs and cause them to fall, creating an ice avalanche. However, scientists have discovered an increase in activity during the early morning hours when the ice is cold and most brittle. Ice avalanches can occur any time of year and any time of day or night.

THE FORMATION OF SNOW AVALANCHES

Numerous combinations of snow patterns cause avalanches. Every snowstorm deposits a new layer of snow. Even during the same storm, a different type of layer may be deposited each time the wind shifts or the temperature changes. After snow layers are deposited, their character is continually altered by the forces of wind, temperature, sun, and gravity. Each layer is composed of a set of snow crystals that are similar in shape to each other and that are bonded together in similar ways. Because each layer—each set of crystals—is different, each reacts differently to the various forces. Knowing something about these differences can help climbers understand and avoid avalanches.

Snow avalanches usually are categorized by their release mechanism: *loose-snow avalanches* start at a point; *slab avalanches* begin in blocks. Slab avalanches usually are much larger and involve deeper layers of snow. Loose-snow avalanches can be equally dangerous, however—especially if they are wet and heavy, if they catch victims who are above cliffs or crevasses, or if they trigger slab avalanches or serac falls.

LOOSE-SNOW AVALANCHES

Loose-snow avalanches can occur when new snow builds up on steep slopes and loses its ability to remain on the slope. The snow rolls off the slope, drawing more snow along as it descends. Sun and rain also can weaken the bonds between snow crystals, especially if they are newly deposited, causing individual grains to roll and slide into loose-snow avalanches. Skiing, glissading, and other human activities also can set off loose-snow avalanches by disturbing the snow. Loose-snow avalanches can easily sweep climbers into crevasses and over cliffs, destroy tents, and bury or carry away vital equipment.

SLAB AVALANCHES

Slab avalanches are more difficult to anticipate than loose-snow avalanches because they involve buried layers of snow that often cannot be detected from the surface. Usually a buried weak layer or weak interface is sandwiched between a slab layer and a bed layer or the ground (fig. 27-7). The buried weakness is disturbed in a way that causes it to reduce its frictional hold on the overlying slab.

Slab avalanches create an amount of havoc to climbers that is equal to or greater than that of loose-snow avalanches. Not only can slab avalanches fling people and equipment off slopes or bury them, but the tremendous speed of a slab avalanche and the force of impact have been known to move entire buildings and transport objects and people hundreds of yards downslope. It is difficult to survive an avalanche that is hurtling downslope, and once a person is buried, the snow hardens, rapidly making it difficult to breathe and hampering rescue.

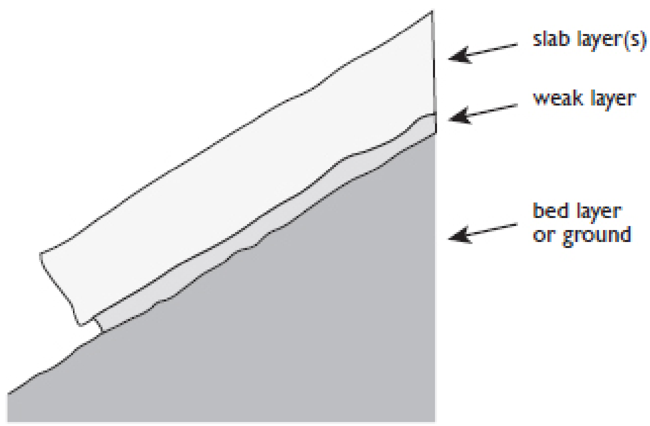

Fig. 27-7. Typical snow layering in a slab avalanche, with a weak layer between the slab and bed layers.

The Buried Weak Layer

Depth hoar and buried surface hoar (hoarfrost) are the most notorious weak layers. They can withstand a significant amount of vertical load but have little or no *shear strength*—that is, they slide easily along their horizontal interface. They may collapse like a house of cards, or their structure may give way like a row of dominoes. In addition, depth hoar and buried surface hoar can survive weeks to months with little change in their fragile structure.

Surface hoar (also known as “frost”) can form all across the snow cover, persisting most in shaded places that are protected from wind. Buried by subsequent snowfall, it becomes a weak layer that can promote avalanching. It becomes most dangerous if the first storm following hoarfrost formation begins with cool, calm conditions. This is because it can quickly form a thin layer, even in a matter of hours. This layer is hard to detect, but can still function as a layer for subsequent snow loading.

Depth hoar matures fastest in the shallow snow of early winter, when the ground is still warm and the air is cold (common in continental regions), but it can develop anytime or anyplace where there are large differences in temperature at different depths of snow. Weakness begins as soon as temperature and associated vapor-pressure differences cause molecules of water vapor to move onto facets of individual ice crystals instead of into bonds between crystals. This causes a loose, sugar-like collection of ice grains. Therefore, immature depth hoar (solid, faceted shapes) may be just as weak as mature depth hoar (open, cup, and scroll shapes).

Buried graupel (soft hail; see Figure 27-1g) is another classic weakness within the snowpack because it can act like ball bearings if disrupted. Other weaknesses that can make it easier for slabs to avalanche include plate-shaped crystals (see Figure 27-1a).

Buried weak layers may persist longer over glacier ice than over bare ground. The glacier reduces the amount of geothermal heating available to the snow from the ground, keeping temperatures somewhat cooler and slowing metamorphism. This means that buried weaknesses in seasonal snow underlain by glaciers can persist following storms and well into the summer long after adjacent snowy slopes have stabilized.

The Slab Layer

Once the underpinning of a snowpack is sufficiently weakened, the overlying snow (either a single layer or group of layers) begins to slide. If the overlying snow is cohesive enough to develop some tension as sliding begins—that is, if it sticks together enough to form a slab—it may break in long fractures that propagate across the slope. Lengthy fractures can result in large, heavy blocks that easily pull away from the rest of the slope, such as along the side and bottom of a slope where more-stable snow may exist.

Slabs commonly are formed by brittle, wind-deposited snow layers. Wind often deposits snow in pillow-like patterns on the leeward side of ridges, thickest in the middle of the slope (where most of the weight of the slab, and thus the greatest avalanche danger, exists) and thinner on the edges. Wind slabs can maintain their blocky integrity throughout a slide, thrusting powerful masses downslope.

Slabs also are commonly formed by layers of needle-shaped crystals (see Figure 27-1d) deposited like a pile of pickup sticks and by layers of branching crystals with many interlocking arms (see Figure 27-1b and e), which often pulverize immediately after release to form fast-moving powder avalanches.

Thick rain crusts often bridge over weakened surfaces and are rarely involved in avalanches until they begin to melt in spring. Sun crusts, on the other hand, usually are thinner and weaker than rain crusts and can be incorporated in a group of slab layers.

If the overlying snow is too warm or too wet compared with the underlying weakness, it may not break, instead just deforming slightly in response to the change in basal friction and staying on the slope. However, if the underlying weak layer fails quickly and initial movement is significant, even this wet and pliable slab can avalanche. This scenario occurs commonly during spring when thick layers of old depth hoar are weakened by percolating meltwater. The resulting collapse of the depth hoar can cause a bending motion, like a whip, that overstresses the slab and causes it to fracture and slide. This whiplike effect also can occur in dry snow.

If the overlying snow is fragile and noncohesive—technically not a slab—the failure of a weak layer may simply result in snow grains in the overlying snow collapsing over each other but remaining in place. However, if the weak layer is buried surface hoar or slightly rounded branching or plate crystals, the failure can be so rapid that even the most fragile snow layers can turn into slab avalanches.

The Bed Layer

A bed layer provides the initial sliding surface of avalanches. Common bed layers are the smooth surfaces of old snow, meltwater crust, glaciers, bedrock, or grass. The interface of these smooth surfaces and the snow above can be further weakened if temperature changes promote the formation of depth hoar or if the interface is lubricated by meltwater or percolating rainwater. The bed layer also can be the collapsed fragments of old depth hoar.

AVALANCHE TRIGGERS

Humans are efficient trigger mechanisms for avalanches. Descending glissaders, stomping snowshoers, and ascending skiers, especially when executing kick turns, disturb layers of depth hoar or buried surface hoar. The sweeping turns and traversing motions of downhill skiers and snow-boarders are effective at releasing loose-snow avalanches and fragile but fast-moving soft-slab avalanches. Snow-plow turns, hockey-stops, sideslipping downhill, or falling may release wet loose-snow and wet slab avalanches. It is even possible to initiate an avalanche by traveling below a slope, especially if the buried weakness is surface or depth hoar, because a domino effect can occur as the delicate crystal structure collapses, propagating the failure uphill. The weight and vibration of snowmobiles can set off avalanches in places where nonmotorized travel would not.

Storms also trigger avalanches. Many types of buried layers (such as thin layers of slightly rounded branches and platelike crystals) fail when a force is applied evenly over a broad surface, as occurs when storms deposit layers of new snow. Earthquakes, cornice and serac falls, and other internal and external effects on the snow can cause avalanches at unpredictable times and places. Loud sounds alone cannot trigger avalanches; for example, it is the concussive impact (not the percussive noise) of bombs set off by ski professionals that triggers a controlled slide. To learn more about avalanches, see Chapter 17, Avalanche Safety.

UNDERSTANDING THE CYCLE OF SNOW

Learning about the terrain and weather preceding a trip can help climbers anticipate snow conditions before leaving home. During a trip, understanding how wind, sun, and precipitation affect snow at different elevations and on different slope aspects will help determine choice of route and use of equipment.

Dense snow can provide good walking surfaces and sound bollards for rope belays, but if the snow is dense enough to have transformed to ice, then the walking can be slippery and carving bollards can be difficult. Fluffy new snow is fun for skiing downhill but makes uphill travel arduous and provides little or no support for belaying. The variety, combination, and timing of snow layering can promote avalanching.

The cycle of snow, from the first falling flake to glacier ice to meltwater, creates a dramatic and ever-evolving environment to challenge and delight climbers.