Crevasse Patterns in Glaciers*

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Although most mountaineers are familiar with crevasses from the practical standpoint, few know much about the physics of the formation of crevasses or the reasons why crevasses assume certain shapes or patterns on glaciers.

Crevasses are formed as a result of forces great enough to break ice as a glacier moves over its bed. These forces or stresses can be tensile, compressive, or shear in nature, or a combination of these. Ten possible idealized combinations of stresses and the resulting crevasse patterns are illustrated in *Figure 1.* The first and third columns give the type of stress or stresses that are assumed to exist at the top edge of a plan view of a glacier as shown in the second and fourth columns. The glaciers flow from left to right and the surface of the glacier moves faster in the center in general than at its edges. The second and fourth columns show the type of crevasse pattern to be expected with each type of stress or combination of stresses. Each of these types of crevasse patterns will be discussed in more detail.

The type of stress illustrated in the upper left corner of *Figure 1* is pure longitudinal tension. This gives rise to a series of crevasses running across the glacier at right angles to the direction of the stress. This type of crevasse is quite common on glaciers. It occurs when the bed of the glacier changes from one slope to a greater downhill slope. Thus, this is the type of crevasse found in most icefalls. Nye's theoretical work (1)† has shown that this type of crevasse may also be expected in the accumulation area near the head of a glacier even though the slope of the bed does not change. This comes about because of the fact that most glaciers flow faster as they move down glacier in the accumulation area. This increase in speed tends to make the ice in front pull on the ice behind it. (See the work of Nye (1) and Nielsen (2) for a mathematical treatment of this subject of glacier mechanics.)

Pure transverse tension is illustrated in the second sketch of the left side of *Figure 1.* This type of stress produces straight crevasses running parallel to the glacier. These crevasses can be expected where the width of a glacier

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† Bibliography at end of article.

increases. Good examples are often found where a narrow valley glacier leaves the mountains and forms a bulb on the end as it spreads over a level plain.

The middle sketch on the left side of *Figure 1* represents a pure shearing stress. The stress diagram is for the left side of the glacier as one faces down hill; the stress diagram would be the reverse for the right hand side of the glacier. The crevasses are straight lines running up glacier from the edge and forming 45-degree angles with respect to the edge. Crevasses of approximately this shape are often found near the edge of glaciers where the flow rapidly increases in going towards the middle.

The next sketch represents pure tension in both the longitudinal and transverse directions. Two series of crevasses are formed at right angles to each other. This type of crevasse pattern may be found where the ice goes over a dome-like protrusion in the bed. This pattern may also be found where the bed of the glacier suddenly increases its slope at the same time that its width increases.

The bottom sketch on the left side of *Figure 1* represents longitudinal tension with simultaneous lateral compression. The straight transverse crevasses are similar to those discussed with the first sketch and occur under similar circumstances.

At the top right hand side of *Figure 1,* the stresses are simultaneous shear and longitudinal tension. The resulting crevasses form angles between 45 and 90 degrees with respect to the sides, and they curve away from the edges towards the center. Sometimes smaller crevasses may be found at right angles to the main crevasses. This pattern of crevasses may occur in the accumulation regions or near the edges where the slope of the bed increases.

The next sketch illustrates another common type of crevasse. The stresses are simultaneous shear and longitudinal compression. The crevasses form angles less than 45 degrees to the sides, gradually turn up glacier, and disappear as they approach the middle of the glacier. This crevasse pattern may be found near the edges where the slope decreases—for example, near the base of icefalls. It is also found in cases where the center of the glacier is considerably higher than the edges. One might also expect to find such crevasses in the ablation area of the lower parts of glaciers where the glacier is slowing down and putting the ice under compression.

The next sketch illustrates the type of crevasses where the ice is under longitudinal compression and transverse tension. These longitudinal crevasses are essentially the same as the case of transverse tension.

The next crevasse pattern shown in *Figure 1* results when ice is subjected to shear and transverse tension. In addition to crevasses which turn up

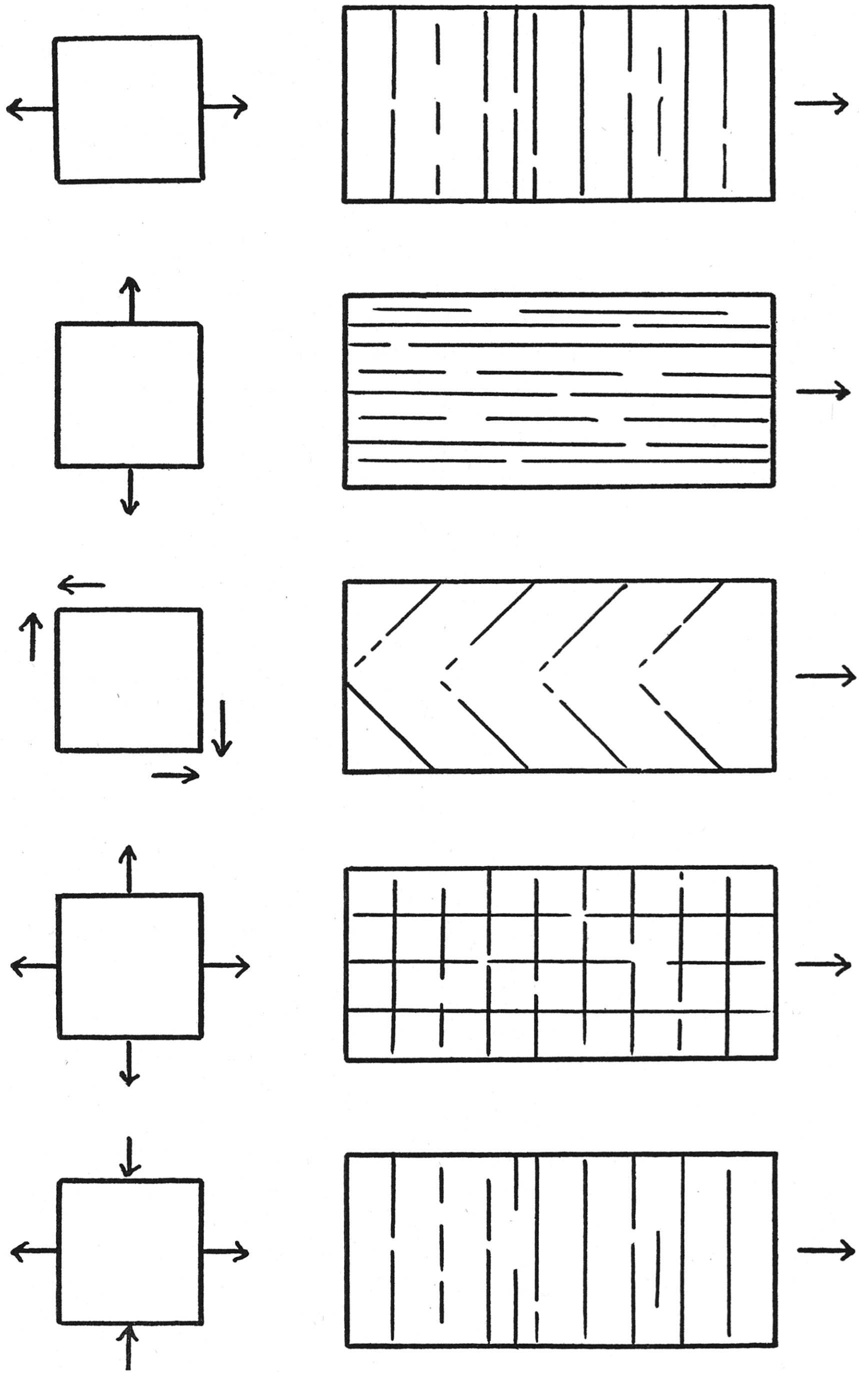
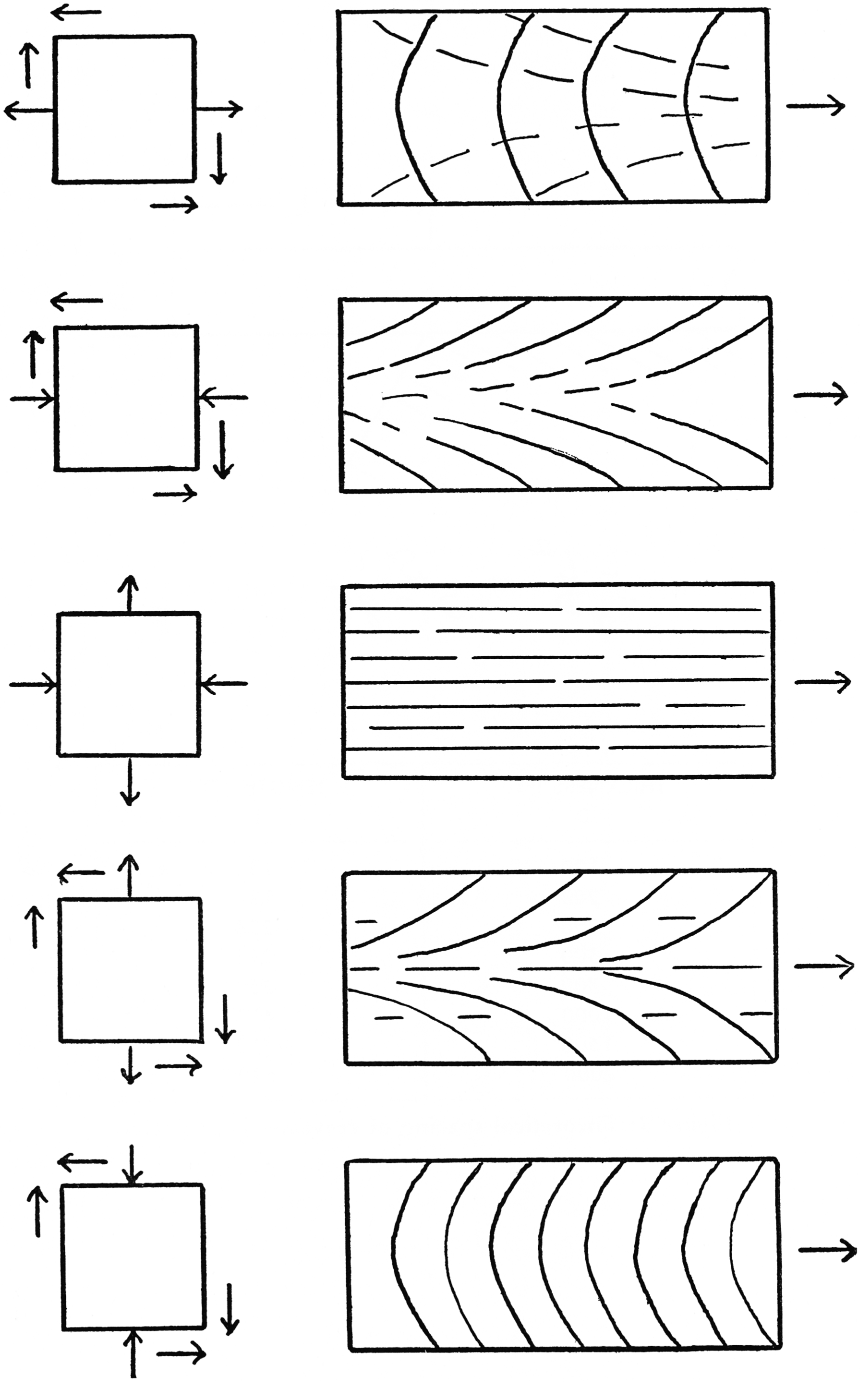
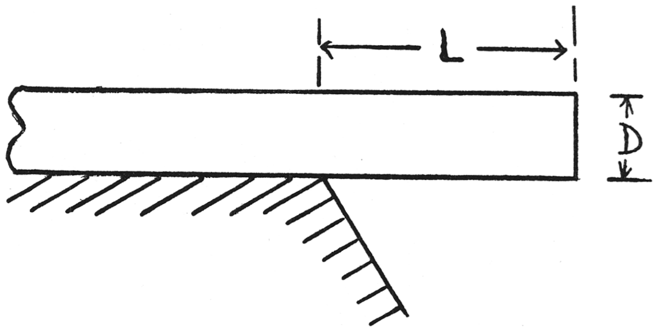


Figure 1: **Idealized stress patterns and the resulting crevasse patterns in glaciers.**





$$\frac{L^2}{D} = \frac{S}{3\rho g}$$

THICKNESS (FT.) D	LENGTH (FT.) L
100	132
200	187
300	228
500	295
700	350
1000	417
1500	512
2000	590

Figure 3: Theoretical spacing of crevasses in a glacier.

glacier, there are longitudinal crevasses. Such crevassses may be found where the glacier increases its width.

The last crevasse pattern shown in *Figure 1* is caused by simultaneous shear and transverse compression. These crevasses point up glacier at the edges, but gradually turn in toward the center of the glacier. They may be found where the glacier narrows down.

In general, crevasses which are curved are largely a result of a shearing action brought about by an increase in the speed of flow of the glacier in going from the edges to the center.

Crevasses have other interesting aspects in addition to the patterns they form. For instance, crevasses are often amazingly uniformly spaced. This is especially true of transverse crevasses in the center of a glacier such as are shown in *Figure 2.** It is easily shown that this phenomenon is exactly what one would expect. When the bed of a glacier is uniform, there is in general little compression or tension on the ice. However, if the slope increases as the glacier moves down hill, tension is applied to the surface. *Figure 3* illustrates an extreme case where the glacier goes over a cliff. As the glacier moves, a block of ice is pushed out over the edge of the cliff. The weight of the overhanging ice puts a tension on the surface above the cliff edge. When the tension reaches the breaking strength of ice, a crevasse forms and a block of ice breaks off. When the block breaks off, the tension is relieved until the glacier pushes another block out over the edge. Thus, every time a crevasse forms, the tension is relieved until the glacier moves enough to build the tension back up to the breaking strength. Therefore, the spacing of crevasses indicates how far the glacier must move to build up sufficient stress to break the surface ice. Since the important factors such as the thickness of the ice and its breaking strength are essentially constant, the crevasses should be uniformly spaced.

Figure 3 illustrates an extreme case, and L, the theoretical spacing of crevasses, should be the largest possible for a solid glacier moving over an abrupt drop-off in its bed. Theory predicts that approximately

$$\frac{L^2}{D} = \frac{S}{3\rho g}$$

where L is the spacing of crevasses, D is the thickness of the ice, S is the breaking strength of ice, ρ is the density of ice, and g is the acceleration of gravity.

If one takes 200 pounds per square inch as the breaking strength of ice, then the table accompanying *Figure 3* gives the spacing L as a function of

*Plate 24, opposite page 74.

the thickness of the glacier. From observations on glaciers it appears that the theoretical spacing is too large by a factor of about four. This is not surprising as the value for S was the value for pure ice while glacier ice at the surface is usually firn or consolidated snow, which is much weaker than pure ice. In addition a glacier contains many imperfections and an irregular surface; these act as stress concentrators and further lower the strength of ice. Although the above equation qualitatively predicts the spacing of crevasses, it has never been checked by data collected on a glacier. Research on crevasses is woefully lacking. Maybe it will be a mountaineer who will furnish the data required to test the theories of crevasse formation.

On the basis of what has been said above about the build up of stresses and their relief, it could be assumed that the birth of a crevasse is a sudden event. This is certainly true in many cases. The glacier suddenly cracks open with a loud report, the surface shakes, and a long narrow crack appears in the ice. A crack about half an inch wide and several hundred feet long appears to be a typical "baby" crevasse.

Many people expect to find the most crevasses where the slope is steepest. This is not necessarily true. Crevasses generally do not form on uniform slopes (except near the edges) even if they are steep. They form where the slope changes from one value to a steeper value. Thus, on many occasions, a steep slope may contain few if any crevasses, but at the top of the slope where it levels out there may be many crevasses.

Most glaciers move from several inches to over five feet a day. This movement carries crevasses downstream from the points of their origin. However, if one looks at a crevassed area from year to year, the pattern of crevasses generally remains fairly constant and appears to remain nearly stationary because most crevasses are formed at about the same place, they grow for a while as they move down glacier, and then they close up again when they reach an area of compression.

One often hears statements something like: "This glacier must be very active as it is highly crevassed." This statement is not necessarily true, although it is often justified. There are several reasons why glaciers are more crevassed when they are active than when they are stagnant: (1) Active glaciers are fast moving, so crevasses are formed at a faster rate than normal; once formed they have less chance to seal up or be filled by snow. (2) If the activity is due to greater than normal accumulation, the longitudinal differential velocity is great. Tension produced by this differential velocity can cause more crevasses than normal to form or crevasses may develop in areas where they normally are absent. (3) Increased velocity of flow also causes an increased transverse differential velocity.

There is a greater than normal change in velocity between the edges and the center of the glacier. This produces increased shearing stresses. (4) Increased activity in glaciers is often accompanied by waves of ice. The bulges created by the waves put a tension on the surface which results in many crevasses. (5) The properties of ice depend upon the speed of deformation. Ice is brittle to a hammer blow, but it can be deformed to the extent of hundreds of percent by mild stresses which act for a period of months. Thus, as a glacier moves down a rough bed, the ice may have time to flow over humps or small cliffs without forming crevasses if the rate of flow is slow enough. However, when the ice moves faster, time may not be available for deformation to occur, so crevasses are formed which relieve the built-up stresses. Ice is not the only material which shows this "viscoelastic" behavior; many plastics, pitch, etc., are ductile to slowly applied forces, but brittle to rapidly applied forces.

Next time you look down on a glacier from a mountain top, notice the various patterns formed by the crevasses. Would you have predicted these from the topography? With a little practice you will be able to correlate the crevasse patterns with changes of slope of the glacier, underground topography, and changes in width or curvature of the glacier. At the same time you will find you appreciate your climbing more.

Bibliography

(1) J. F. Nye, "The Mechanics of Glacier Flow," *Journal of Glaciology,* 1952, vol. 2, pp. 82-93. Also: *Proceedings of the Royal Society* (London), 1951, vol. 207A, pp. 554-572.

(2) L. E. Nielsen, "Regimen and Flow of Ice in Equilibrium Glaciers," *Geological Society of America Bulletin,* 1955, vol. 66, pp. 1-8. Also: "Flow Patterns in Glacier Ice," *Journal of Applied Physics,* 1956, vol. 27, pp. 448-453.