EVIDENCE OF LIQUID WATER FLOW THROUGH SNOW FROM THICK-SECTION PHOTOGRAPHY

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In combination with rain or melt intensity, the snowpack's physical characteristics control the travel of rain and meltwater through the snowpack. Factors such as snow temperature, crusts, ice lenses, density, layer discontinuities, and liquid water content are some of the important flow-controlling characteristics. California's central Sierra Nevada snowpack is typically composed of between five and ten distinct bands that correspoind to the major storm events. The bands are generally separated by clear-weather, melt-freeze crusts. The temperature and grain size within each band are determined by storm characteristics.

Insolation can cause melt at the snow's surface during any winter month, and the manner in which the meltwater penetrates the snowpack depends on the the multitude of factors listed above. Although snow scientists acknowledge the existence of vertical channels (flow fingers) through which rain or meltwater preferentially travel, there has been little success in documenting or quantifying the phenomenon in the field, or in defining the conditions that control flow finger formation. To this end, a thick-section cutter and photo box were constructed.

The thick-section cutter box is made of aluminum and cuts a 36-cm square slice of snow that is 2.5 or 3.8 cm thick. Once a snow pit is dug, the frame of the cutter is tapped into either a vertical pit face or a horizontal snow surface. The two stainless steel cutter blades are placed into the guide grooves and sequentially inserted (Figure 1). The cutter box is removed and the lower blade is replaced with a translucent acrylic sheet. In subfreezing snow, a spray-on cooking oil was found to be crucial in preventing the snow from freezing onto the cutter blades. The upper blade is removed, and the cutter box is placed on top of the bottom half of the photo box (38 cm square x 48 cm deep). The top half of the photo box fits onto the cutter box, and a camera with a 50 mm lens is inserted through a hole in the top. An electronic flash in the bottom of the photo box backlights the snow section. With Kodak Tech-Pan film (ASA 100) and a 4X neutral density filter, exposures range from f5.6 to f11, depending on snow density and flash strength. With a minimum of equipment, the film can be developed at your own laboratory.

The clear-ice flow fingers and the portions of the snow that have been

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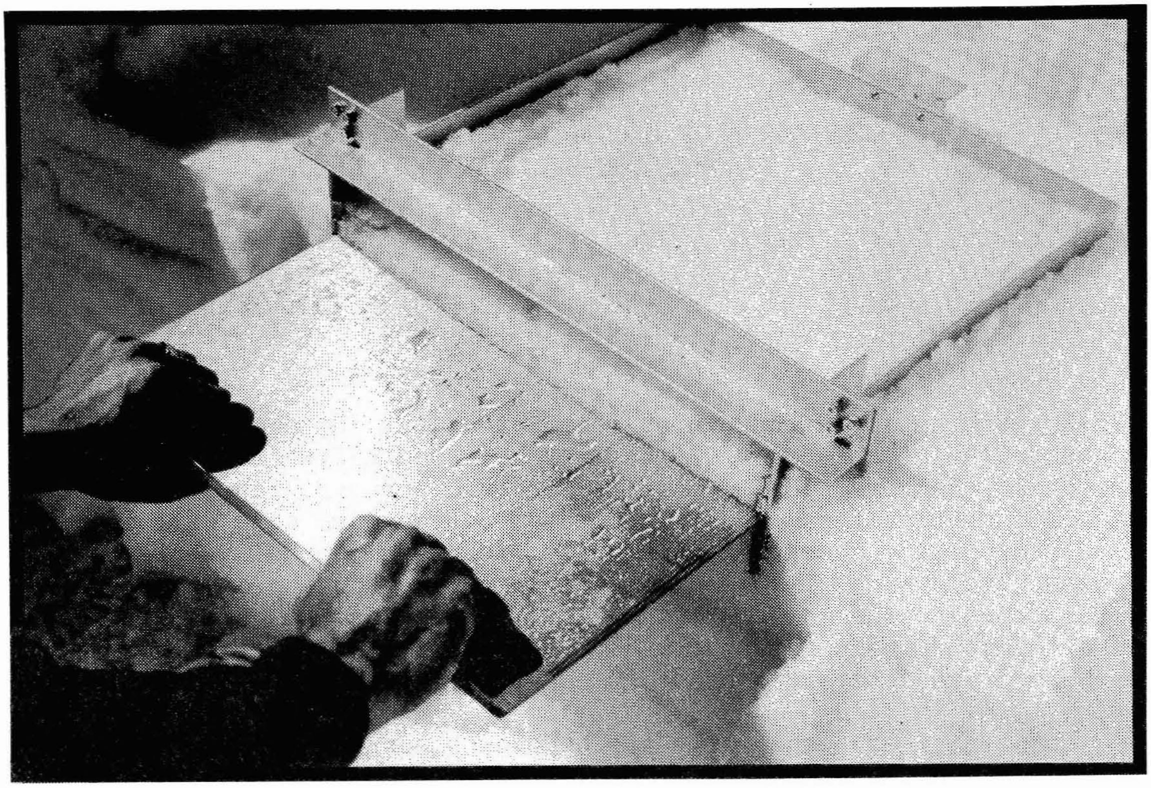

Figure 1 Insertion of the blade into the thick-section cutter box

wetted are more transparent than the surrounding snow. They appear as dark spots or bands on the film negatives, or as bright spots on black-and-white prints. Flow fingers are easily detected in horizontal sections as round or irregular patterns (Figure 2A). Within a storm layer, the fingers are generally the same size and of similar abundance over some distance, but the next lower layer may have very different patterns or no apparent fingers. The vertical section shows that even on flat terrain, considerable lateral movement of the water occurs (Figure 2B). For this reason, successive horizontal sections at 10 cm intervals from the surface to the ground typically show significant variation of the presence and size distribution of flow features. The snowpack section in Figure 2B is actively melting, and the "inverted mushroom" features are wetting fronts that result in the flow fingers shown in Figure 2A.

The existence of flow fingers and channels are often suggested by surface topography. After periods of intense melt, bowl-shaped melt depressions (flat terrain) or long rill and ridge patterns (sloping terrain) often appear. Based on over 125 snow pits and both horizontal and vertical sectioning in 1986 and 1988, the nature of the flow paths associated with the surface features were revealed. Depressions that appear in March and April are generally caused by intense melt and form over large flow pipes. On flat sites, the depression is formed when water collects from a 30- to 50-cm area and creates a 5- to 15-cm flow pipe that channels water down to the next lower crust or ice lens. The water flow removes the small grains in the snowpack and lubricates the remaining ice lattice, leading to the sub-surface collapse that creates the depressions. This process can also be produced by

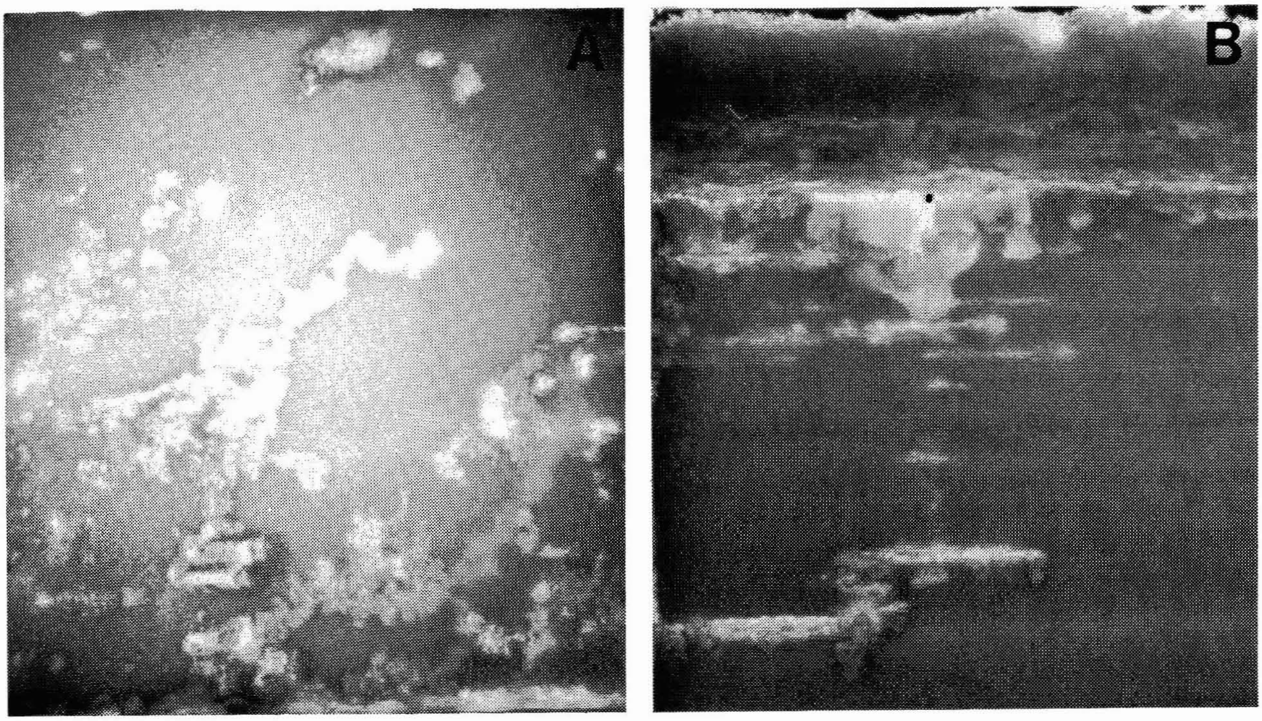

Figure 2 Photographic prints of a horizontal section (A) and a vertical section (B) of a snowpack showing flow fingers and wetted layers

rain in early- or mid-winter months. In some cases, subsequent daytime melting and nighttime freezing reverse the surface topography. The icy skeleton of the filled, frozen finger supports the region around it while the surrounding snow settles. The depression thereby becomes a pedestal after several days, but the pedestal eventually collapses or melts and the snow surface again becomes smooth. On hillslopes, rain or intense melt cause the same grain destruction and lattice lubrication process and produce rills and troughs that interconnect to form a distinctive dendritic pattern.

Early season melt has lower flux rates and seldom produces melt depressions. December and January snowpacks usually have grain sizes of less than 1 mm and densities less than 300 kg m^{-3}, and they sometimes have layers that are temporarily as cold as -8°C. Low-intensity melt penetrates the snowpack via flow fingers that are typically less than 1 cm in diameter and are spaced 3- to 10-cm apart. The fingers penetrate to various depths within a storm layer and subsequently become ice columns. Throughout the winter, some fingers terminate at layers caused by within-storm grain size changes. Water spreads laterally along these lenses to become millimeter-thick ice lenses that resemble pieces of window glass when excavated. This water-transport system moves both heat and mass into the snowpack and is an important part of the metamorphic process commonly known as "ripening".

Because of the complex interaction between physical features of the snowpack and rain and melt fluxes, these observations should be considered to be preliminary and limited to the central Sierra Nevada.

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