# LAYER AND CRUST DEVELOPMENT IN A CENTRAL SIERRA NEVADA SNOWPACK: 712-82

## SOME PRELIMINARY OBSERVATIONS

By

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## INTRODUCTION

Snowpacks usually consist of layers varying in structure and density. Those on the West Coast are known to develop high density snow or ice layers between zones of lower density snow (U.S. Army Corps of Engineers, 1956).

Several mechanisms have been postulated for the formation of ice layers. They may form by the percolation of melt or rain water into the snowpack, where the water freezes into a dense layer. They also may develop by snow compression when a weak snow layer densifies after its collapse beneath the weight of a sufficiently massive snow overburden.

Surface crusts may be the main source of high-density snow or ice layers in the Sierra Nevada (Halverson, 1980). These crusts are produced by several processes including windpacking or the sublimation of water vapor onto the snow surface under humid, windy conditions. And cycles of freezing and thawing occurring at the surface during inter-storm periods in cloudless weather result in surface densification. Subsequent burial of crusts by new snowfall produces layers whose density is greater than the surrounding snow.

The development of these high-density snow or ice layers affects the flow of water through the snowpack and the subsequent runoff from snow-covered basins. These layers may impede or accelerate vertical flow and provide a surface over which liquid flows nearly horizontally. A snowpack containing impeding layers reduces the vertical percolation lag and effectively expands the area over which overland flow occurs (Colbeck, 1978: 1979; Wankiewicz, 1979). These layers can also provide a shear surface base on which avalanches originate. They can support portions of the overlying snowpack and thus affect snow sensor (pillow) measurements.

This paper reports preliminary observations of the basic properties of surface crusts and subsurface high density snow and ice layers in the central Sierra Nevada of California.

## METHODS

A study was conducted near Donner Summit at the Forest Service's Central Sierra Snow Laboratory. The maritime-influenced climatology at the elevation there (2100 m) can produce snowmelt and water runoff from the snowpack during any winter month. Daily snowpack density information was collected from this site in a forest clearing about 60 m in diameter.

For varying periods since 1969, daily snow density-depth changes have been monitored in a non-destructive manner at 1-cm intervals by means of an isotopic density-profiling snow gage. When properly calibrated this instrument has a stated accuracy to within $\pm$1.5 percent of true density (Smith and Halverson, 1969). Limitations of the gage preclude the study of "ice lenses" less than 1 cm thick. Surface "crusts" or subsurface "layers" are identified as having a density increase of at least 0.05 g/cm$^3$ over a 1- to 25-cm depth change. The 1- to 25- cm thickness range incorporates phenomena normally labelled "ice layers" and "radiation crusts" (Halverson, 1980; Langham, 1974).

The snow gage produces graphical outputs which can be compared to determine rates of change in basic snow properties (Figure 1). For 5 years, 17 surface crusts were

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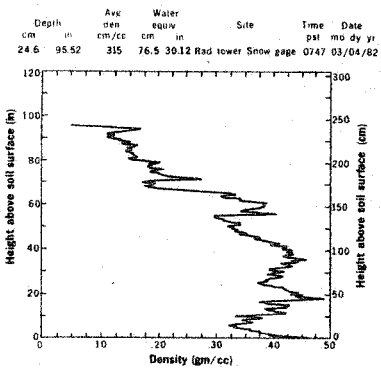


Figure 1

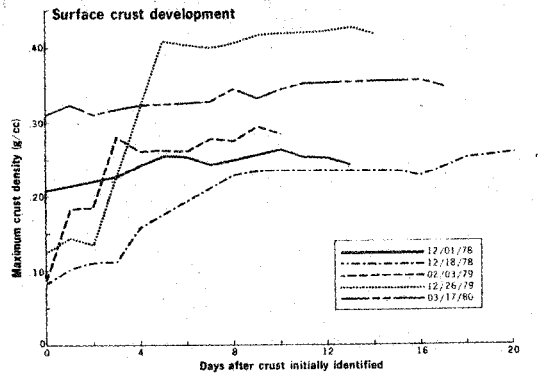


Figure 2

tracked throughout their "lifespans." Nine of these 17 became buried and became internal layers. Additionally, four layers that formed from short-lived crusts were studied.

Observations of the horizontal extent of layer development were based upon comparisons of pit profiles at two sites near the snow gage. One site, on level ground, is about 10 m from the snow gage; a second site, on sloping terrain, is 20 m from the gage.

## RESULTS AND DISCUSSION

### Crusts

Crusts formed or persisted on most non-snowfall winter days studied (Table 1). Annual crust occurrence and lifespan depended directly upon the duration of inter-storm periods--the longer the period the more likely they were to develop or persist. Crusts seldom developed during the spring melt period; they were present during only 18 percent of all May snow-cover days. Crusts generally endured for 4 to 10 days, although they were observed to persist up to 20 days (Figure 2).

Table 1

Formation of Crusts in Snowpacks in the Central Sierra Nevada, California

| Water Year | Snow Cover Period (Days) | Days with no Snowfall (Percent) | Observed Days with Surface Crusts (Percent) | Days with no Snowfall having Surface Crusts (Percent) |
|---|---|---|---|---|
| 1971 | 177 | 64 | 41 | 64 |
| 1972 | 166 | 69 | 45 | 65 |
| 1979 | 180 | 61 | 54 | 89 |
| 1980 | 162 | 66 | 54 | 82 |
| 1981 | 146 | 72 | 36 | 54 |

Crust density increased rapidly during the first few days of development (Figures 2 and 3). Thereafter, it increased only moderately until, as crusts melted or otherwise lost

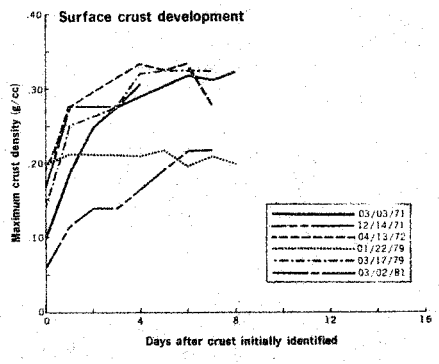


Figure 3

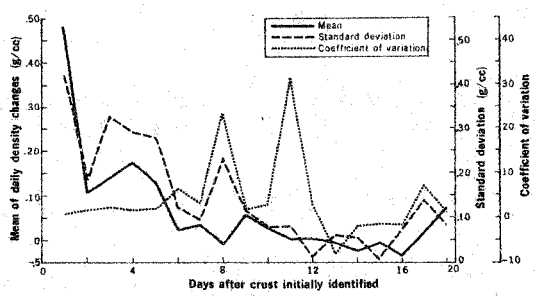


Figure 4

definition, maximum crustal density decreased. Changes in maximum crustal density were exponential (Figure 4). Coefficient of variation values were large--in part due to the near-zero mean values and the small sample size. For longer periods of crustal development, fewer than six observations were available.

Figures 2 and 3 also illustrate the seasonal variability of maximum crustal densities. Except for the 12/26/79 crust (Figure 2), all of the 11 crusts depicted show a general trend toward higher density during the later months of the season.

The intensity of crustal development can best be shown by comparing maximum crust density to that of the immediately underlying snow. Soon after the crust appeared the density difference increased, reaching a maximum 2 to 5 days later. Thereafter the differences generally decreased until the crust disappeared or became buried. In a few cases, however, the density difference remained relatively constant, with little apparent weakening in crustal intensity (Figure 5).

Crust thickness change followed a different pattern from that of crustal densification. On a daily time scale, thickness typically shows less variability than the density measurements for the same crusts. However, crusts may merge with older, recently buried crusts, producing a single "duplex" crust often twice the thickness of the original crust. Crusts developing on 2/3/79 and 12/26/79 (Figure 6) exemplify this occurrence. After merging, the new features basically retained a constant thickness. Crusts that disappear due to melt or through densification of snow immediately below the surface thin as definition is lost.

Layers

All layers studied originated as crusts. Although subsurface formation has been documented by Wankiewicz (1979), no layers--as defined in this study--spontaneously developed within the snowpack.

Developed layers can persist for up to 50 days (Figure 7), often lasting until exposed by spring melt of the overlying snow. Under some situations the layers lose prominence as the overlying and underlying snow metamorphoses and the density differential between the layer and the surrounding snow is minimized.

Although I did not have enough observations for a rigorous statistical analysis, several trends were apparent. The exponential increase in maximum density demonstrated by the surface crust data is also evident in layer development. After about 7 days of relatively rapid densification, the rate generally decreases to that for the entire snowpack. An exponential increase was observed in 12 of the 13 layers examined, the exception being the 1/11/71 layer (Figure 7), which increases at a near-linear rate. The persistence of the same densification rate patterns for layers having both complete and incomplete prior surface crustal development suggests that any link between crustal and subsurface densification mechanisms is not a strong one.

Layer thicknesses were greater and daily thickness changes more variable than in crusts (Figure 8). Mean crustal thickness 2 days after crust identification equalled 7.4 cm. Two days after burial the layers averaged 14.9 cm thick. Although the layers evidenced less inter-sample variation than the crusts (day 2 coefficient of variations equalling 0.28 and 0.38, respectively), daily thickness change often equalled 5 cm for the layers but only 1 to 2 cm for the crusts.

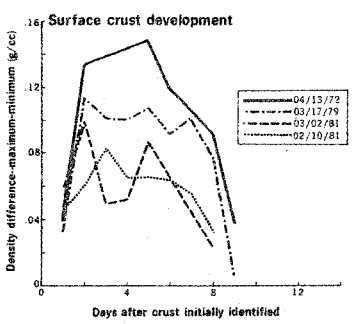


Figure 5

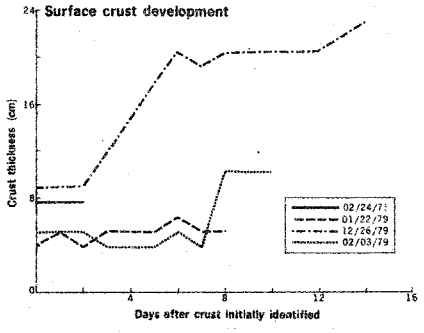


Figure 6

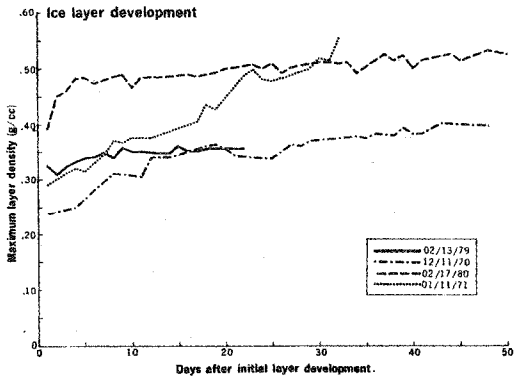


Figure 7

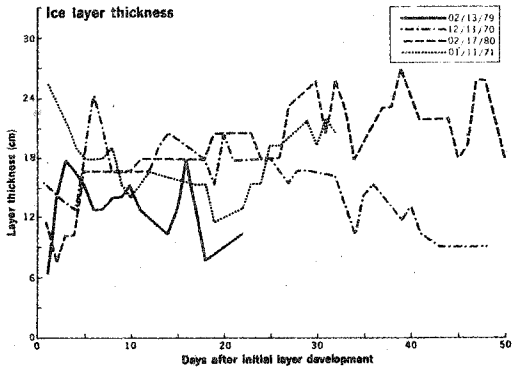


Figure 8

To ascertain the horizontal extent of layers, snow pits were dug near the snow gage site--one at a level location 10 m from the gage and the second 20 m from the gage on sloping terrain--and snow stratigraphy comparisons were made. A surface crust and layers at 180-188 cm and 139-167 cm above the soil (Figure 1) persisted in the pit 10 m away from the gage. The high density zone at 139 cm above the soil appeared to be a 1 cm thick ice layer in the pit.

Snow in the pit 20 m from the gage showed two layers corresponding to those at the gage--one, stratigraphically equivalent to the 180-188 cm at the gage, was as thick as that at the gage; a second, deeper layer, was only one-quarter as thick as the equivalent layer at the gage. These observations suggest that it is inappropriate to extrapolate from point estimates of internal snowpack properties to wider areas.

## CONCLUSIONS

The daily time scale upon which this study is based may be too broad. In many situations, crusts begin developing within 48 hours after snowfall ends. Future work will investigate changes in crust densification and thickness over shorter time spans. Also, the link between crusts and the meteorological processes that produce them needs to be more closely identified.

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