ON THE EFFECT OF STRONG DENSITY LAYERING ON METAMORPHISM OF SEASONAL SNOWCOVER

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EXTENDED SUMMARY

Recent studies by the authors in the Bridger Mountains near Bozeman, MT and at the South Pole have indicated the presence of peculiar metamorphism processes which can be significant under certain conditions. Normally temperature gradient metamorphism is the predominant process which produces the kinetic growth forms widely recognized in alpine snow. However, the authors have observed that in low density snow adjacent to a dense layer such as a thick melt-freeze curst or wind crust, the less dense snow appeared to lose mass and strength over the period of the winter prior to snow becoming isothermal in the spring. This was observed to happen even when the temperature gradient in this region was insignificant. Further observations have been made by the authors at the South Pole.

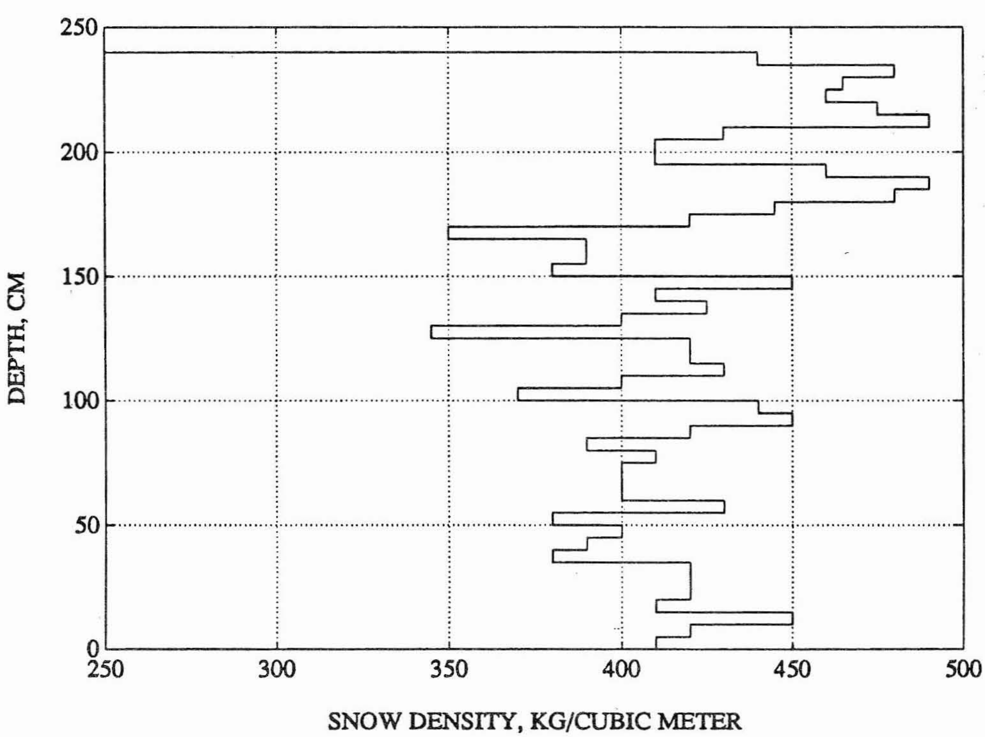

Figure 1. Density layering at the South Pole.

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In Figure 1, the density layering is shown in the top 2.5 m of the firn. Note here the considerable fluctuation in the density and that the relative magnitudes of these fluctuations do not decrease with depth. At 2 meters, the overburden is 0.008 MPa, certainly large enough to cause a substantial pressure sintering to occur with subsequent densification, especially in the weaker lower density layers. Obviously a process which opposes the accelerated pressure sintering of the low density layers must be present.

In order to evaluate this process quantitatively, a theory recently developed by the authors (Adams and Brown, 1988) was utilized. The approach makes use of modern mixture theory (Passman, Nunziato and Walsh, 1984). The material is modeled as a mixture of two phases, the granular ice phase, and the vapor phase. The balance equations for each phase (mass, momentum, energy, and equilibrated force) are then solved.

Two cases are considered. In both cases a 1 meter deep idealized snow cover with a density of 276 kg/m^3 with a 10 cm thick dense layer (366 kg/m^3) is considered. The density profile is shown in Figure 2.

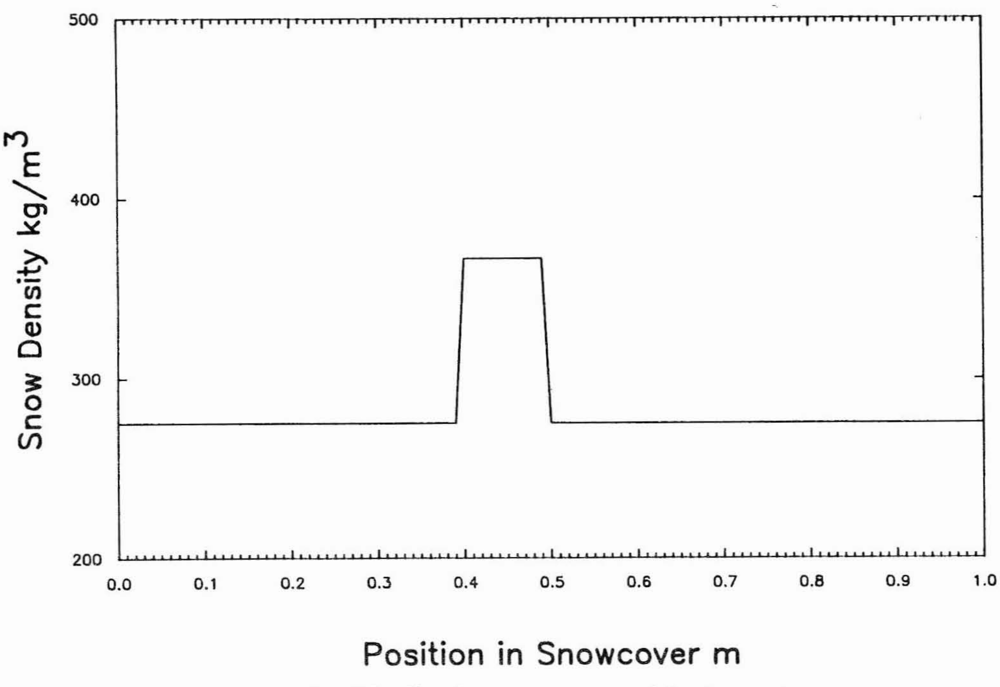

Figure 2. Idealized snow cover with dense layer.

In the first case the 1 meter deep snow cover is subjected to a cooling temperature of -20^0 C on the top surface so that a temperature gradient is established in the snow. In the second case the snow is isothermal. Figures 3 and 4 illustrate the resulting vapor flow in the snowcover, respectively, for the first and second case. We see that the process, while well established under isothermal conditions is much slower than in the first case. This points out the coupling effects which makes snow metamorphism such an overall complicated phenomenon.

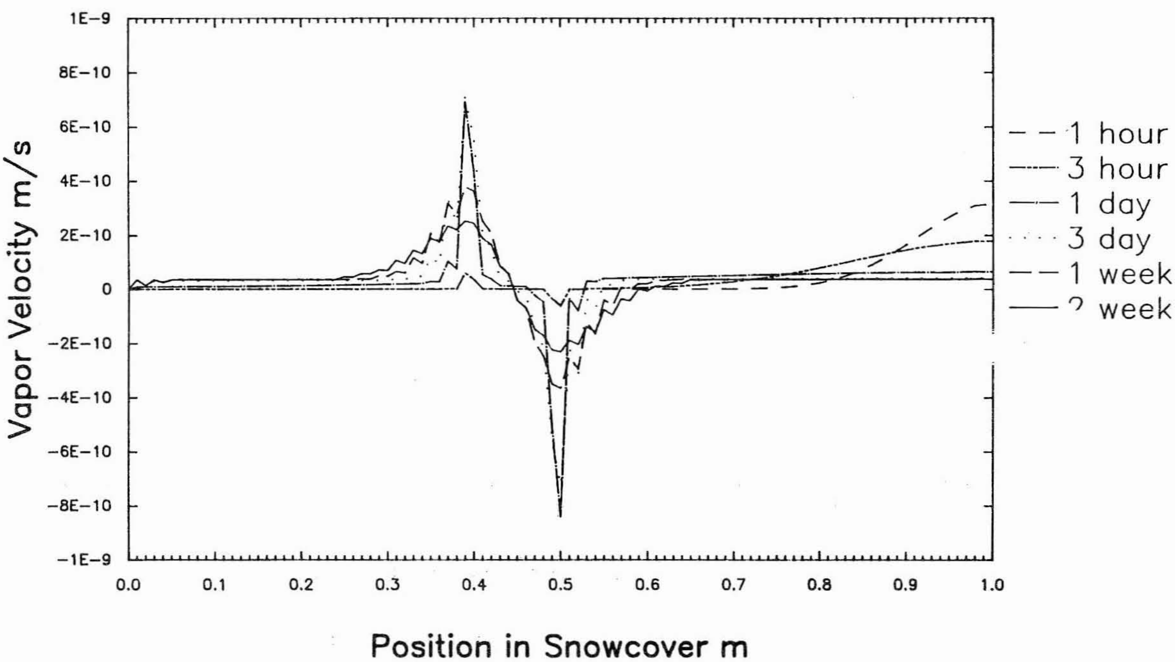

Figure 3. Vapor flow with temperature gradient.

The six curves in Figure 3 show how the vapor transport proceeds as a function of time. Of most interest is the fact that vapor is transported from the low density snow into the dense layer, both from above and below. Even after steady state was reached, small temperature differences between the vapor and ice were found accompanied by a net sublimation of ice in the low density layers near the dense layer. In the dense layer, there was a net condensation taking place.

In the second case, the snow was assumed to be isothermal throughout the snowcover, so that no temperature gradient effects were present. As can be seen in Figure 4, there is again a net flow of vapor from the less dense snow into the dense layer with subsequent condensation (mass gain) in the dense layer and sublimation (mass loss) in the less dense layers.

The results of these studies have not been verified experimentally, since a very precise experimental program would be needed to provide valid measurements of density change, differences in phase temperatures, etc. However, the studies have shown that this process, which we refer to as "density gradient metamorphism" can be potentially a significant process which may contribute to slope instability due to increased weakness at interfaces between crusts and less dense snow layers.

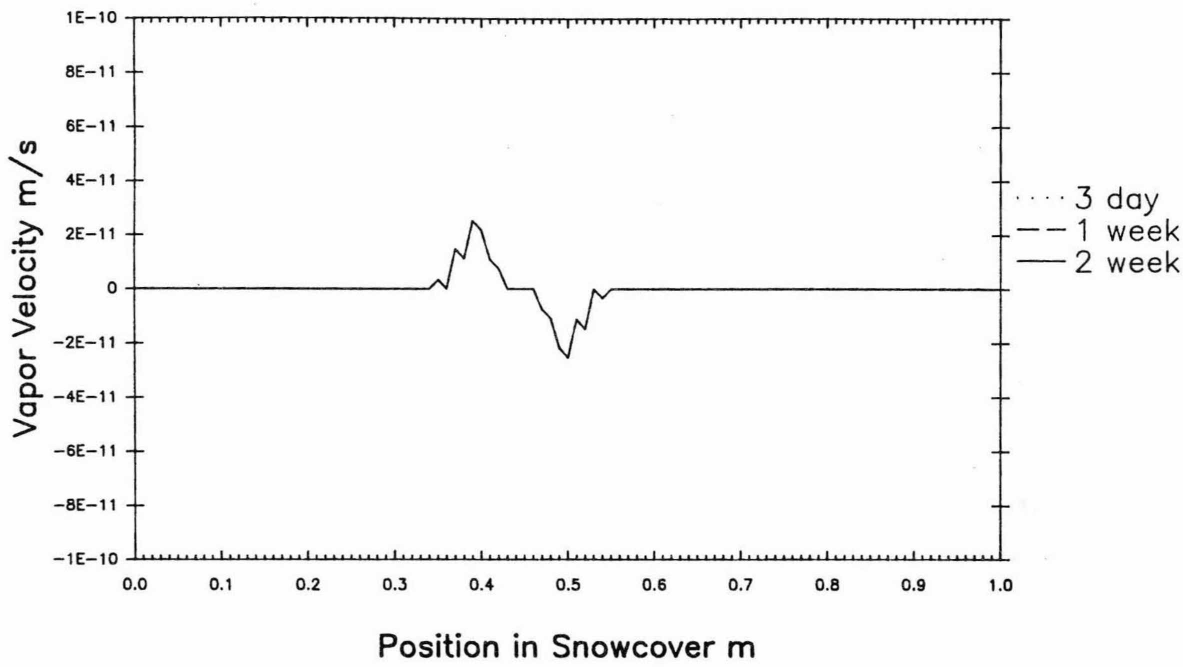

Figure 4. Vapor flow in isothermal snowcover.

REFERENCES

Adams, E.E. and R. L. Brown, "A Constitutive Theory for Snow as a Continuous Multiphase Mixture", Journal of Multiphase Flow (submitted)

Passman, S.L., J. Nunziato, and E.K. Walsh, "A Theory of Multiphase Mixtures", in Rational Thermodynamics, by C. Truesdell, Springer-Verlag, 1984.

ACKNOWLEDGEMENT

The research reported here was funded by the U. S. Army Research Office (Grant No. DAAG29-85-K-0259).