BACKGROUND

In a 15 year period, 172 people died in the Scottish hills in winter. Of these, 36 were killed in avalanches. In 1988 the government, under considerable pressure from the mountaineering fraternity to reduce this toll decided to fund an avalanche forecasting service that would provide daily reports for two of Scotland's more popular climbing areas, Glencoe and the Northern Cairngorms. Mountaineers were employed to collect snow and weather data and distribute a daily avalanche report through media outlets and local bulletin boards. Encouraged by the public's response to the reports it was decided to establish a third forecasting unit the following season for the area on and around Britain's highest mountain, Ben Nevis. At the end of a 2 year trial period the forecasting unit became collectively known as the Scottish Avalanche Information Service.

SNOWPACK AND CLIMATE

Despite the fact that the Scottish hills are relatively low in altitude, (the highest being around 4000 feet), their location so close to the Arctic Circle can make conditions in the winter extremely hostile with winds regularly in excess of 100 mph. The prevailing weather is from the south west and this often leads to sudden and dramatic changes in temperature and stability of the snowpack.

Snow cover can vary from zero to 30 or 40 feet in areas sheltered from the wind.

Windslab avalanches are predominant.
FORECASTING

Avalanche forecasts are issued from the middle of December through to the end of the Easter holidays (mid April). Using the lift facilities available at each of the areas, field observers will go to slopes they consider to be highest risk to make their hazard evaluations. Study pit information is supplemented by hasty pits and a variety of shear tests. As no explosive control work is allowed, forecasters often use ropes to access slopes. Ski and cornice cutting is also widely used. Reports are issued at 3pm and detail the days observations as well as what is likely to occur in the next 24 hours.

EDUCATION

Despite the fact that mountaineers are still being killed (5 in the last 2 seasons), it is felt that the issuing of daily reports have significantly heightened public awareness of the avalanche hazard in Britain. Education is of course of paramount importance and in 1992 forecasters from the Cairngorm area established a series of weekend courses held at the Scottish Sports Council's National Centre at Glenmore Lodge. Courses cater for novice mountaineers as well as experienced instructors or guides and deal with all aspects of hazard evaluation, safe travel techniques and rescue procedure.

RESEARCH

Ski Rutschblocks are widely used by SAIS forecasters whilst making their avalanche hazard evaluation. However the majority of British winter hill users travel on foot rather than ski and as such cannot utilize this valuable test.

In 1991 we started conducting walking shear tests. Test blocks are cut 1m by 1m down to a stable layer. Loads are then exerted in a similar way to the ski Rutschblock but this time by someone on foot rather than skis. Walking tests were conducted adjacent to ski tests on slopes of varying angles so that results could be directly compared.

NB The problem of transferring weight evenly onto the block was overcome by the person sitting down in the snow and lifting their feet, toe to heel, onto the test block. From that position they gradually rise up into a standing position.
Steps for loading the walking shear test are;

Cutting out and isolating the block. 
Approaching the block (by foot) from above. 
From a sitting position, placing weight on the block (toe to heel). 
Rising to a standing position. 
Downsinking on the block. 
Soft jump. 
Second soft jump. 
Hard jump. 
Does not fail.

FINDINGS
(are purely based on comparison studies and observations made in the field and not scientific tests)

Our initial results indicate that the early loading steps for the walking test are reasonably comparable with those of the ski test.i.e; 
Cutting out and isolating the block. 
Approaching the block from above. 
Gradually weighting the block.

Further loading steps for the walking test proved less comparable as forces exerted by jumping on the block are extreme and the test is rapidly concluded.

DISADVANTAGES of the walking test are;

Small test area (1m by 1m) 
Difficulty of evenly weighting the block 
Less loading steps than the ski test (only 4 or 5) 
Poor at identifying near surface instabilities

However as an alternative test to the hand/shovel shear test it has proved popular to British mountaineers as it;

Readily identifies moderate to high instabilities in the snowpack 
Easier to learn 
Easier to teach 
Larger test area 
Quantifiable 
Quick to dig out with an ice axe

It is recognized that further research is needed in this area.
KINETIC GROWTH AND ASSOCIATED WEAKENING OF THE SNOWPACK
IN THE BRITISH ISLES
Revised January 1993

by Stephen Blagbrough

(with thanks to Paul Thompson, Wes Sterritt and Tom Rupar)

Paper written in consultation with E. Adams of the Dept. of Civil Engineering and Engineering Mechanics, Montana State University, Bozeman, Montana. U.S.A.

Abstract.

Considerable research has been undertaken in the United States, Switzerland and Japan on the formation of depth hoar and the weakening in the snowpack associated with its growth. This paper is based on information gathered in those countries as well as observations made in Great Britain.

The science of snow mechanics is very complex and I have endeavoured to keep explanations as simple as possible. With this in mind some knowledge of snow structure and avalanche mechanics will make comprehension of this paper easier.

The growth of depth hoar crystals in the British snowpack has always been considered unlikely as their formation was thought to require periods of cold weather lasting several weeks. However, two Japanese scientists, Fukuzawa and Akitaya have shown that under the right conditions faceted crystal formation (early depth hoar) can occur in less than a day.

The winter of 1991 produced several periods of sustained cold weather in which depth hoar growth was observed, documented and photographed for the very first time in Great Britain.

Note. Faceted crystals which develop as a result of temperature gradient metamorphism (T.G. met.) are now known as kinetic growth form (K.G.). (Colbeck 1984)
THE IMPLICATIONS OF KINETIC GROWTH WEAKENING IN THE BRITISH SNOWPACK.

Snowpacks in the European Alps and North America, which are influenced by a continental climate, commonly have avalanche problems associated with kinetic growth early in their winter seasons. If snowfalls are light and temperatures are low then large temperature gradients are established across the shallow snowpacks. If these conditions are sustained for long enough then the process of kinetic growth leads to the formation of mature depth hoar crystals (cup crystals) at the base of the snowpack. These crystals are very resistant to change and often survive in their unstable and uncohesive form well into the winter season. Further accumulations of snow onto this unstable basal layer can lead to the overloading and subsequent failure of this layer, which in turn may result in an avalanche event.

The British maritime climate rarely replicates the conditions necessary to create depth hoar to the extent outlined above. The rapid and large fluctuations in temperature often cause the snowpack to undergo a thaw and refreeze right down to the ground. Ensuing melt/freeze crystals, due to their strong and compact structure, drastically inhibit vapour movement and subsequent depth hoar formation. The rapid and large fluctuations in temperature, although reducing the likelihood of mature depth hoar crystal growth, in turn causes its own particular and perhaps more serious problems.

Example: The snowpack undergoes a heavy thaw. The temperature of the snow is raised close to freezing and the snow is saturated.

Snowpack undergoing heavy thaw

RAIN

THAWING SNOWPACK
TEMPERATURE AROUND 0°C
The weather become wintry, temperatures drop and snow begins to fall. The old dense, wet snowpack maintains its relatively mild temperature due to conductive warming from below.

New snow fall on thawed snowpack.

SNOW

* * * *

TEMPERATURE MAINTAINED AT AROUND 0°C.

If the surface temperature is cold enough then a temperature gradient is established across the new snowfall.

A temperature gradient is established across the new snow.

SURFACE TEMPERATURE -4°C

20cm

0°C

TEMPERATURE GRADIENT OF 4°C/20cm or 2°C/10cm

If we assume that the process of kinetic growth is as rapid as the Japanese work suggests then vapour movement and ensuing structural changes within the new snow are likely to occur immediately and will be sustained so long as conditions are suitable i.e.

- large temperature gradient
- low density new snow
- temperatures are close to freezing (in particular, this will apply in the region of new snow adjacent to the melt/freeze layer).

NB. As stated before, structural weakening that occurs in the area of high vapour pressure (i.e. the warmer region) may result in mechanical failure and avalanching.
CASE HISTORY 1

21/12/90

Mild conditions lead to a thaw at all levels with the weather station on the summit of Cairngorm reading +0.3 degrees C. by midday.

22/12/90

Freezing level rises and summit temperatures reach + 5.0 degrees C. Heavy rainfall occurs throughout the period. The top metre of the snowpack rises to approx. -0.5 degrees C.

23/12/90

Wintry conditions return with the freezing level falling to just below 4000' (1200 metres). Some snow showers occur over the high ground. Snowpack remains relatively mild due to conductive warming from below (ie. around -0.5 degrees C. to -1.0 degrees C.)

24/12/90

Freezing level falls further (summit temperatures -6.0 degrees C.). Heavy snow showers are accompanied by strong south-westerly winds. Large temperature gradients recorded within new snowfall.

Easy shears occur in the slab whilst being tested. Small avalanches are observed in the coire.

25/12/90

Cold conditions continue with further snowfall and strong winds increasing the build-up of windslab. One person injured in a slab avalanche in Coire Bhrochain on Braeriach in the Cairngorms.
CASE HISTORY 2

14/2/92

Cold conditions with summit temperatures around -3.0 degrees C. and strong SW winds. Small accumulations of windslab exist on sheltered east-facing slopes.

15/2/92

For a short time during the night the temperature unexpectedly rises above freezing and rain falls at all levels. By morning the freezing level has dropped again with summit temperatures reaching -4.0 degrees C. Snow and strong winds continue to lead to accumulations of windslab on south through to east-facing slopes. During the morning a small slab avalanche is triggered in Ciste Mheread, Cairngorms. Closer inspection reveals the slab to have sheared just above a melt-freeze crust within the snowpack. This melt-freeze crust can only have formed during the overnight thaw. By morning the temperature throughout the windslab was more or less the same - approximately -3.0 degrees C.

For a short period during the night - whilst it was raining - temperatures at the snow surface were close to zero degrees C. Subsequent cold conditions and accumulations of new snow upon the thawed layer would have established a temperature gradient great enough to encourage the movement of vapour away from the warm region, thereby weakening the snow cover immediately above the crust.

A few hours after the release in Ciste Mheread, two climbers narrowly avoided serious injuries in a slab avalanche on the east-facing Hell's Lum crag, Cairngorms, that carried the leader over 200'. Fortunately only cuts and bruises were sustained by the pair.
SUMMARY AND CONCLUSION

New snow accumulating on a recently thawed snowpack is commonplace in this country and can occur many times in the course of any winter season.

If the combination of temperature and depth of snow allow, a temperature gradient can be quickly established. Ensuing vapour migration will be enhanced by the presence of low density snow close to freezing point. Structural weakening that occurs within a layer of windslab can produce a potential avalanche hazard if the snowpack is subsequently overloaded by the weight of fresh snowfall, or the passage of an unwary walker, climber or skier. At exactly what point this structural weakening reaches a critical threshold has yet to be ascertained, although this may be earlier in the process than previously thought.

Further research is needed in order to correlate and then substantiate the processes just outlined. Initial findings, however, support the proposition that kinetic growth and its associated structural weakening has a considerable influence on stability within the British snowpack.

REFERENCES


E.AKITAYA & T.FUKUZAWA. Quick growth of depth hoar in a surface layer.


M.B.MOORE (1982). T.G. weakening of snowpacks near rain crusts or melt-freeze layers.

S.A.I.S. records.


508