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SHORT NOTES

A RECONSTRUCTION OF SNOW-AVALANCHE CHARACTERISTICS IN MONTANA, U.S.A., USING VEGETATIVE INDICATORS

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ABSTRACT. Widespread wet-snow avalanches were observed on the southern boundary of Glacier National Park, Montana, in February 1979. Severe tilting, scarring, and breakage of trees were observed along a transverse trim-line of one path, 70 m from a wet-snow deposit. Tree-ring data were used to establish the date of occurrence, and the nature of damage was used to characterize the avalanche event. The event probably included a previously unrecognized dry-snow avalanche and associated wind blast. Such events present different problems for natural-hazard planning. The nature of vegetative damage along the margins of avalanche paths is shown to be a useful indicator of the characteristics of past unobserved avalanche events.

RÉSUMÉ. *Une reconstitution des caractéristiques d'une avalanche de neige dans le Montana, U.S.A., à partir d'indicateurs végétaux.* Un grand nombre d'avalanches de neige mouillées ont été observées à la limite Sud du Glacier National Park, dans le Montana en février 1979. On a constaté que des arbres avaient été fortement couchés, blessés, rompus le long d'un transversal à l'un des couloirs, à 70 m du culot de neige mouillée. On a utilisé les cernes annuels des arbres pour établir la date d'occurence et la nature des dommages pour caractériser l'avalanche. L'événement a probablement comporté une avalanche de neige poudreuse jusqu'ici inconnue et associée à un souffle important. De tels phénomènes posent divers problèmes pour le zonage des risques d'avalanche. On montre que la nature des dommages aux végétaux sur les bords des couloirs d'avalanches est un utile indice des caractéristiques d'avalanches anciennes non observées.

ZUSAMMENFASSUNG. *Eine Rekonstruktion von Schneelawinen-Charakteristiken in Montana, U.S.A., aus Vegetationsmerkmalen.* Im Februar 1979 wurde eine umfangreiche Schneelawinentätigkeit an der südlichen Grenze des Glacier National Park in Montana beobachtet. Starke Verkippungen, Beschädigungen und Brüche von Bäumen waren längs einer Trimmlinie, die quer zur Bahn einer Lawine verläuft, in 70 m Abstand von einer Nassschneeablagerung festzustellen. Zur Ermittlung des Zeitpunkts dieses Ereignisses wurden Baumringdaten herangezogen; die Art der Schäden liess Rückschlüsse auf den Charakter des Lawinenabganges zu. Der Abgang schloss vermutlich eine vorher nicht erkannte Trockenschneelawine und den mit ihr verbundenen Winddruck ein. Solche Vorgänge werfen verschiedene Probleme beim Schutz gegen Naturkatastrophen auf. Die Art der Vegetationsschäden längs der Ränder von Lawinenbahnen erweist sich als nützlicher Hinweis auf die Charakteristiken von früher nicht beobachteten Lawinenabgängen.

INTRODUCTION

During the night and early morning hours of 12 and 13 February 1979, large-scale destructive snow avalanches occurred along the southern boundary of Glacier National Park, Montana (Fig. 1). Major transportation links were immediately disrupted. Several sections of track of the Burlington Northern railroad were buried by snow which exceeded the protective capabilities of snowsheds. A bridge on U.S. Highway 2 was destroyed and transported almost one hundred meters down-slope to the banks of the Middle Fork of the Flathead River (Anonymous, 1979; Panebaker, 1982).

Meteorological conditions prior to and during the avalanche period were very unstable. Between 5 February and 12-13 February, a total of 7 cm of precipitation was recorded at a ranger station 3 km north-west of the bridge avalanche site. A total of 20.6 cm of snow fell in this time period. Snow depth at the ranger station, at an elevation of 1171 m, varied from 122 to 135 cm (Anonymous, 1979). During the night of the heavy avalanching, constant rain was falling on to a heavy snow-cover (Panebaker, 1982), with 3.3 cm of precipitation recorded for the 24 h period in which the avalanches occurred. Also contributing to snow-pack instability were warm winds and temperatures of 4.4 °C (Anonymous, 1979).

Most avalanches apparently started as point avalanches, followed by slab avalanches on adjacent slopes. The avalanche deposit seen on the Goat Lick path (the path providing the avalanche which destroyed the Highway 2 bridge) comprised very wet snow in large loose balls and chunks (Panebaker, 1982). Some of these balls and chunks, when broken open, revealed dry snow in the center (personal communication from D. Panebaker, July 1983).

The distribution of avalanche snow on the Goat Lick path was photographed immediately after the destructive event (Anonymous, 1979; unpublished photographs on file at Glacier National Park headquarters, West Glacier, Montana). Field observations of vegetative damage to trees bordering the transverse trim-lines of the Goat Lick path, carried out during June and July of 1983, are compatible with the pattern of snow distribution as photographed in 1979. Other avalanche paths photographed after the night of 12-13 February also experienced vegetative damage directly attributable to snow impact. In one case, however, the pattern of vegetative damage exhibited along a transverse trim-line did not coincide with the pattern of avalanche snow distribution as revealed in photographs. We noticed an area of heavily damaged trees along the transverse trim-line of this path while conducting fieldwork in 1983. This area of damage did not match the pattern of snow distribution photographed in February 1979. We examine possible causes for this anomaly, and comment on the use of vegetative indicators in reconstructing past avalanche events.

THE STUDY SITE

The specific avalanche path in question, referred to informally as the "Shed Seven path", is approximately 10 km east of the small village of Essex, Montana. The source areas for the path, as well as the majority of the track, are located in Glacier National Park. The lower portion of the track and run-out zone extend across Burlington Northern railroad property.

The major portion of the avalanche track and the run-out zone are oriented north to south (Fig. 1). Two source areas of unequal size channel snow into the track. Source area number 1 faces roughly east-south-east (115°), whereas source area number 2 is more generally south-south-east in orientation (155°). A deep gully, with an intermittent stream, extends down the center of the track. Near the lower section of the track, the path crosses over a snowshed. The run-out zone below the snowshed is fan-shaped. Vegetative damage and trimming

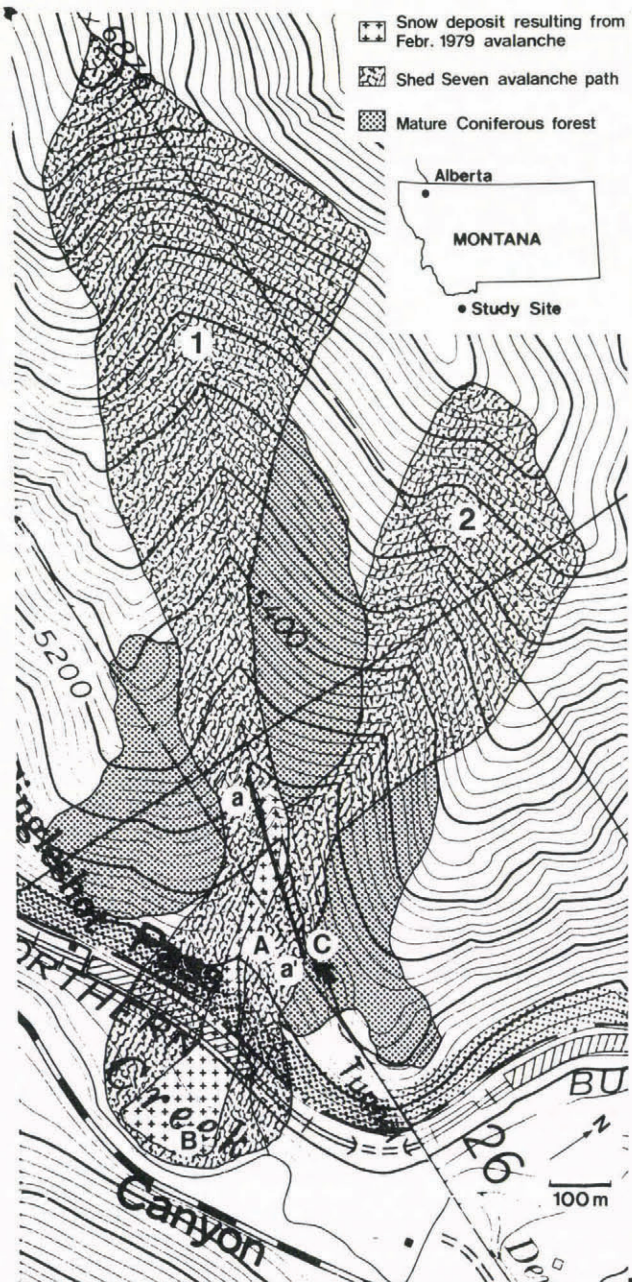

Fig. 1. Location map of the Shed Seven avalanche path. A, B, and C illustrate locations of tree-ring sampling. The arrow points to the specific site where twenty-two trees along the eastern transverse trim-line were sampled. The line a-a' illustrates the position of the profile shown in Figure 2. 1, source area number 1; 2, source area number 2. Note the position of the snow deposit relative to the position of the eastern transverse trim-line and zone C trees.

are apparent at the toe of the run-out zone, as well as along the transverse trim-lines on the eastern and western margins of the path.

INVESTIGATION OF VEGETATIVE DAMAGE

Photographs of the February 1979 avalanche deposit on file at Park headquarters, and taken 1-3 d after the event, show a very fluid wet-snow avalanche. The slide was largely confined to the central gully above the snowshed, with some spillage over the snowshed and into the run-out zone. The extent of the snow deposit definitely within the confines of the avalanche path, is shown on Figure 1. Vegetative patterns of disruption within the central gully area and the run-out zone (A and B, Fig. 1) are directly attributable to the snow distribution from the 1979 avalanche event. Trees are generally tilted directly down-slope, an observation also made by Burrows and others (1979). Tilt directions of trees in these zones average 136° and 150° (Table I).

TABLE I. TILT DIRECTIONS AND AVERAGE MAXIMUM TRIMMING HEIGHTS, ZONES A, B, AND C

	Average tilt direction	*Average maximum trimming height*
		m
Zone A, Central track	136°	2.1
Zone B, Run-out zone	150°	2.5
Zone C, Transverse trim-line	110°	4.2

Tree-ring analysis of fifteen sample trees in the central gully zone, and eleven in the run-out zone illustrated avalanche-induced trauma attributable to the winter of 1978-89 (for discussions of the field and laboratory techniques of tree-ring analysis employed, see Burrows and Burrows, 1976). Maximum heights of trimmed branches in these two groups of trees averaged 2.1 m and 2.5 m, respectively (Table I).

Anomalous patterns of vegetative disturbance occur, however, on the eastern trim-line of the avalanche path. Heavily trimmed, tilted, and scarred trees are located in a zone along the eastern trim-line of the track, more than 70 m from the eastern margin of the actual avalanche deposit (Fig. 1). Trees in this zone exhibit scarring and and trimming of branches on up-slope portions of the trunks, up to a height of 6 m above the ground surface. Trees 11.5 cm in diameter at breast height were broken sharply at heights of approximately 4 m above the ground. Tree-ring analysis of twenty-two damaged trees (location shown in Figure 1) revealed that 100% of the sampled trees were traumatized after the 1978 growth season but before the 1979 growth season, i.e. during the winter of 1978-79 (Butler and Malanson, in press). All twenty-two sampled trees were severely tilted from the vertical. The average direction of tilt for the trees was 110° (Table I).

DISCUSSION

We discount the possibilities that local winds, soil creep, or snow creep produced the patterns of vegetative destruction described above. The extensive damage to trim-line trees relatively far removed from the avalanche deposit of February 1979 raises two alternative realistic explanations: (1) an unrecorded large-scale avalanche occurred earlier in the winter of 1978-79 with enough force from snow contact or wind blast to account for the vegetative damage, or (2) a previously unrecognized dry-snow avalanche and wind blast occurred immediately prior to, or concurrently with, the wet-snow avalanche seen in photographs at Glacier National Park headquarters. We believe that the latter is more likely than the former; three arguments apply.

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First, there is little likelihood that a large avalanche on the Shed Seven path would go unnoticed. An event of the magnitude necessary to damage the transverse vegetation would surely also block the railroad tracks. No such blockage has been reported in the local press at any time during the winter of 1978-79 except for the avalanches of 12-13 February. Avalanches in the Highway 2 area tend to occur simultaneously, not as isolated incidences, also increasing the likelihood that any previous avalanche episode would have been reported.

Second, the nature of the damage to the trees indicates a very clean avalanche event. Wet-snow avalanches in the Glacier Park area are characterized by heavy debris loads of rock and soil (Butler, unpublished). No rocks or soil debris were wedged into, or plastered onto, trunks of trees which were tilted and scarred by the avalanche of 1979. Only woody debris from trees immediately adjacent or up-slope was found resting in corrosion scars produced during the 1978-79 winter. The absence of non-woody debris implies the possibility of a dry-snow avalanche and wind blast.

Third, the heights of scarring and trimming exhibited on sampled trees in the transverse trim-line indicates a dry snow slide. The heights exceed the depth of snow in this zone (illustrated in the 1979 photographs of the avalanche deposit). These indicators are also higher than the average heights of trimming in the central portion of the track on trees of similar size (Table I), where direct impact by wet snow is photographically documented. Local topographic shielding conditions (Fig. 2) apparently precluded the production of higher transverse trimming of trees such as has been recorded elsewhere (Carrara, 1979; Mears, 1980).

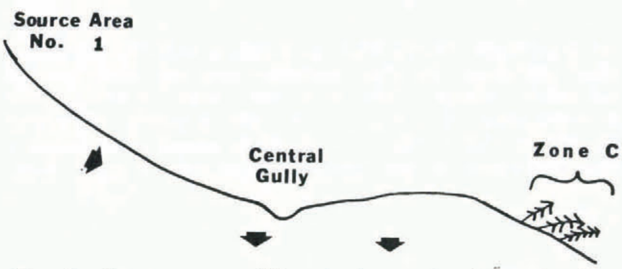

Fig. 2. Transverse profile of the avalanche path, from source area number 1 (position a) and across the central gully, to zone C (position a'). Notice the topographic rise immediately up-profile from zone C, which offered some protection from the full force of a wind blast. Arrows indicate fall line.

If direct snow impact did not produce the damage to the trim-line trees, the only other possibility is damage from wind blast associated with a dry-snow avalanche (Voelmmy, 1955; Mellor, 1968; Leaf and Martinelli, 1977). Although dry-snow avalanches in Glacier National Park are uncommon, they have been reported (Butler, 1979). The presence of dry snow in the center of wet-snow chunks on the Goat Lick path also suggests that dry-snow avalanches may occur in conjunction with periods of wet-snow avalanching.

CONCLUSIONS

The nature of the damage to trees in the transverse trim-line indicates that it was produced by a clean, debris-free, dry-snow avalanche and associated wind blast. The height of the trimming of the branches in this zone also suggests wind blast as a causative agent. The direction of tilt of the damaged trees along the transverse trim-line, combined with extensive scarring of stems and trimming of branches opposite the direction of tilt, indicate that the source of the dry-snow avalanche and wind blast was source area number 1 (Fig. 1) (average tree-tilt direction, 110°; source area number 1 orientation, 115°). This dry-snow avalanche and wind blast evidently occurred immediately prior to, or simultaneously with the avalanche event depositing wet snow in the central track and run-out zone.

General implications of the study of the vegetative damage in the transverse trim-line include: (1) height and nature of damage to trees on the margins of avalanche paths are extremely useful indicators of the nature of past unobserved avalanches; and (2) the direction of tilt of trees along transverse trim-lines can be used to determine the source location of past avalanches, particularly on paths which have multiple potential source areas. These sources of information, when combined with tree-ring analysis of the frequency of past avalanche events, can provide excellent summaries of the nature of the avalanche hazard in a remote area.

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