PATTERNS OF SNOW ACCUMULATION IN A FOREST-TUNDRA ENVIRONMENT, CENTRAL LABRADOR-UNGAVA.

BY

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INTRODUCTION

Studies of snow accumulation and patterns of distribution have been an integral part of the winter program conducted at the McGill Laboratory at Schefferville, Quebec, over the last 10 years. Most of the emphasis has been in lowland terrain near the townsite and within the Knob Lake drainage basis (13.5 m^2). Previous laboratory personnel have had the pleasure of presenting aspects of this work to the members of the Eastern Snow Conference (Adams and Findlay, 1966; Adams and Rogerson, 1968). To a lesser extent there have been attempts to characterize snow cover in the upland areas to the west of Schefferville, areas which possess much more variability in relief and exposure and are less influenced by the presence of large wooded tracts and extensive lakes. Barnett (1963) and Annersten (1966) have examined snow distribution at a locality called Ferriman where permafrost investigations have been in operation since 1958. Unfortunately, these studies have not been continuous, although they do reveal many of the contrasts encountered in the central Labrador-Ungava region when compared with lowland data nearer to Schefferville. During the winter of 1967-1968, one of us (B.G.T.) initiated a snow program at another mine site called Timmins 1 where again the emphasis was on snow cover in relation to permafrost distribution (Thom, 1969). As an outgrowth of this particular study a new program was developed close by at Timmins 4, a site which is not going to be disturbed by mining operations in the near future. This program was instituted in the winter of 1968-1969 and is being continued during the present season (1969-1970). In the following discussion, our attention will be focused on the snow year 1968-1969.

PHYSICAL SETTING

Schefferville is situated close to the geographical center of the Labrador-Ungava Peninsula, the eastern-most extension of the Canadian Shield. It is located about 54° 48' N. The townsite elevation is 1645 feet above sea level, while the Timmins 4 area, located 13 miles west-northwest of Schefferville, ranges in elevation from 2200 to 2500 feet. Both townsite and Timmins 4 lie within the Labrador Trough, a geological province dominated by folded and faulted Proterozoic sediments. Geologic structure controls topography to a significant degree. A pronounced northwest-southeast elongation of ridges and valleys is most marked. Generally, the ridges are glacially eroded surfaces sparsely covered by angular rock fragments. Till mantles adjacent slopes and valleys floors to a depth of 10 feet of more.

The southern end of Timmins 4 is characterized by low-relief valleys which descend northward to a relatively flat, wooded area where the drainage is poorly co-ordinated and several shallow ponds exist.

Whereas the Schefferville Vale tends to be dominated by woodland, muskeg and lake, the ridge country above 2000 feet is more an area of rock desert or tundra-type vegetation in which scattered trees occur. The rock desert areas of the ridge crests are characterized by low-growing heath plants and lichens which form a discontinuous cover. On patches of bare ground it is quite common to observe sorted or non-sorted circles and occasionally miniature sorted polygons. Where the lichen cover is continuous as along hill slopes and drier soils of depressions, the presence of taller woody plants or brush becomes more marked. Betula spp. are particularly characteristic of this brush which seldom exceeds 3 feet in height. Stunted spruce (Picea glauca and Picea mariana) also occur. In the lowland at the north end of Timmins 4 these trees attain heights of 30 feet and are more closely spaced. Along water courses, and adjacent to small ephemeral ponds, sedges, sphagnum moss, birch and willow shrub, and other moisture-loving plants are found. All these units are easily mapped and their distribution reflects many of the factors which influence snow patterns.

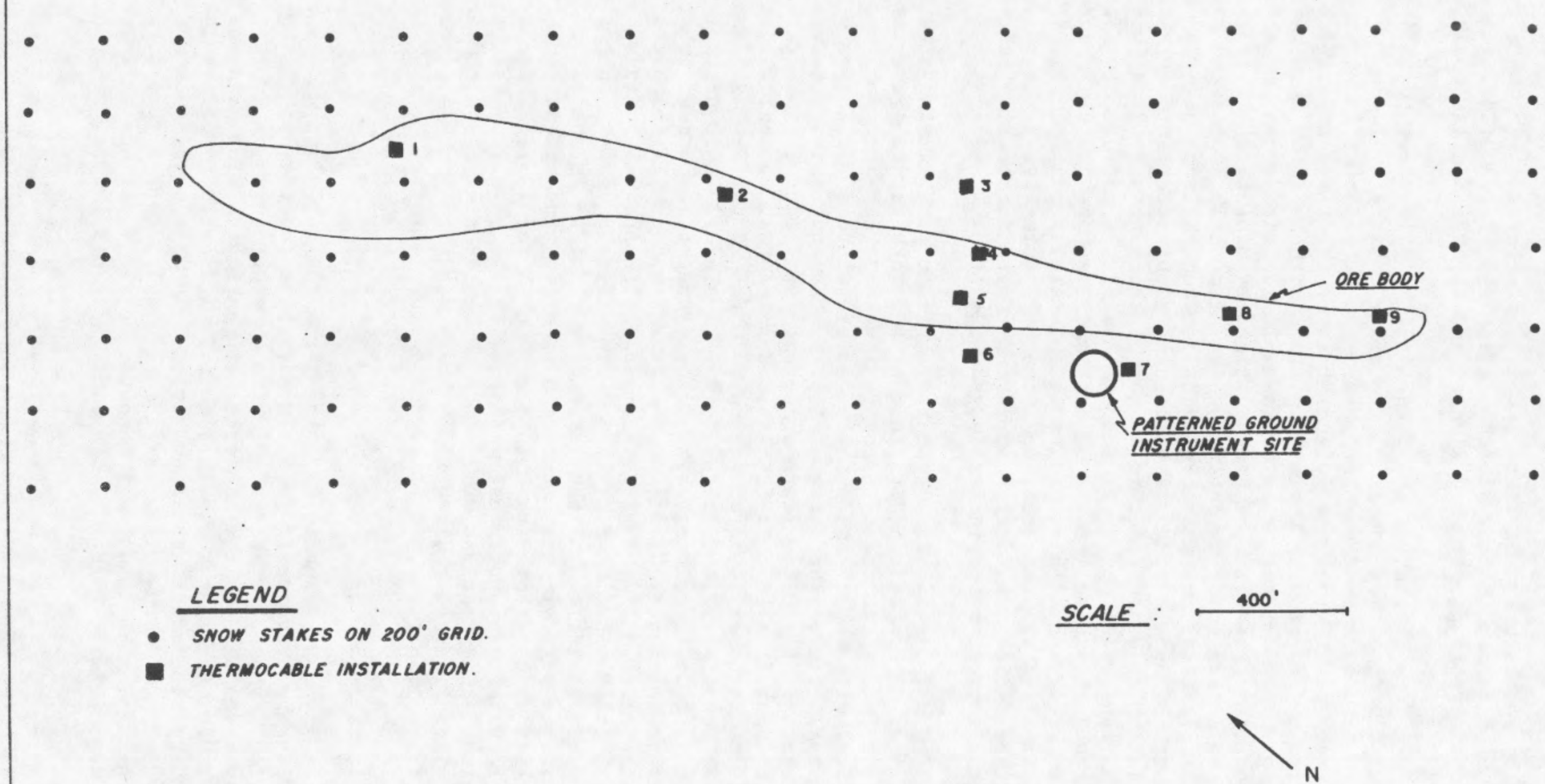
Climatic characteristics of the Timmins area are little known in comparison with that of the Schefferville townsite. In general, the central Labrador-Quebec region has a sub-arctic climate (Köppen's Dfc) with short cool summers, severe winters and adequate precipitation at all times (see Barry, 1960). Two summer months show mean temperatures above 50°F (10°C). There are great variations in temperature during winter ranging from 40°F to -50°F (4.5°C to -44°C). Commonly, mean temperatures from December to March are below 0°F (-17°C). The mean annual temperature at Schefferville is close to 24°F (-4.4°C). It is probably 2-3°F (1-2°C) cooler on the ridges, although extreme minimums seem to occur in the vale on calm nights. Greater exposure and wind chill undoubtedly characterize the climate of the ridges compared with the vale. Winds speeds average about 10 mph (16 km/h) at Schefferville for every month although in the early winter months the average is close to 12 mph (19 km/h). On the ridges periodic measurements have shown wind speeds to be at least 4 mph (6.5 km/h) greater than in the vale (Dyke, 1967). There is a very strong prevalence of northwest winds during the year. However, the passage of frontal depressions will often be accompanied by short periods of strong winds from other directions. These winds are very effective in the distribution of snow in ridge and valley terrain.

FIELD PROGRAMME

Experience gained from the 1967-1968 snow survey at Timmins 1 where traverses were employed, suggested the use of a grid plan for the layout of stakes at Timmins 4. Accordingly, a 200 ft (60m) spacing was selected as the distance between stakes. The grid was installed following the plan shown in Figure 1. This grid comprises 147 stakes which were read after each snow "event". In total, the snow course was read 25 times in the winter of 1968-1969 with depths read directly from the stakes. Densities were measured on two occasions in late winter. This paper will concern itself solely with depth data.

TIMMINS Nº 4 PERMAFROST EXPERIMENTAL SITE

(COMMENCED OCTOBER 1968)



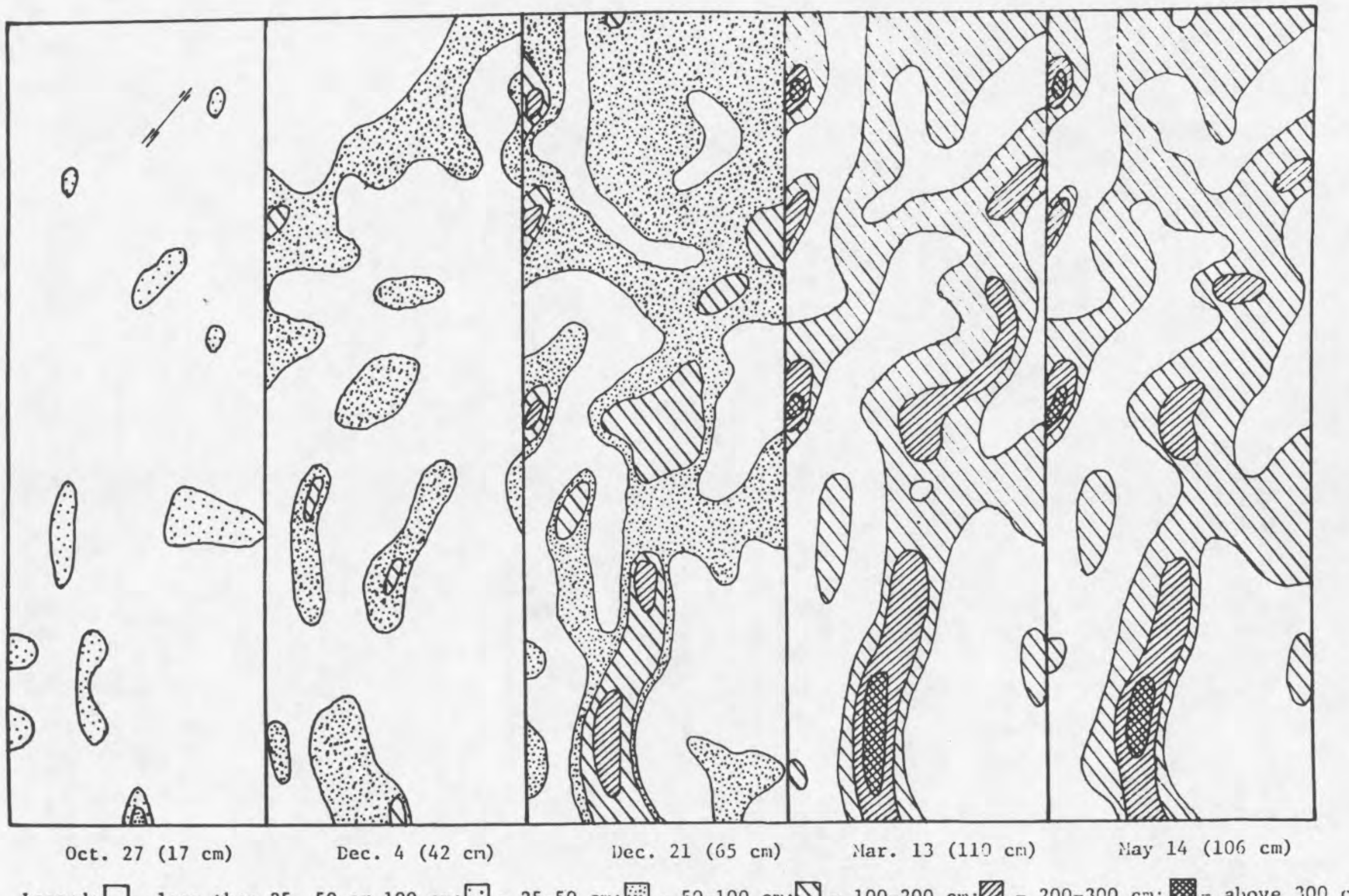


Figure 2. Map sequence of snow depth for five surveys undertaken during the winter, 1968-1969. Mean depth of 147 stakes is indicated in parenthesis for each survey.

PATTERNS OF SNOW DISTRIBUTION

The following discussion will concentrate on changes in snow depth between five separate occasions which have been selected to reflect different aspects of the seasonal snow cover. Figure 2 shows isolines joining points of equal snow depth for five surveys: October 27, December 4, December 21, March 13 and May 14.

a) Early Winter.

This is the period of initial snow accumulation after a short September-October accumulation-thaw period. Winter snow persisted after the second week in October and the map depicting snow distribution on October 27 gives some idea of the early accumulation pattern. Except for the most extremely exposed sites, the area in general has a relatively even cover with low standard deviation from the mean (S.D. 9.3). Some but not all of the areas which later received maximum accumulation are already highlighted at this early date. By December 4 the mean snow depth had built up from 17.2cm to 48.5cm. Redistribution of the cover is now more evident with sheltered valleys at the south end of the snow course being sites for localized accumulation in comparison with the more even cover to the north. The December 21 survey was undertaken at the end of what we designate early winter, and immediately followed a pronounced period of accumulation and redistribution especially by easterly winds. The mean depth is now 64.6cm and the patterns of the 4th are further reinforced. The linear trends in relation to topography are even now apparent in the open wooded terrain at the NW end of the study area. In five places snow depth exceeds 2m, but there are 14 stakes where snow is less than 20cm thick.

b) Mid-Winter.

Only one map is used to depict snow distribution for this season which lasted from late December to late April. It is a period of slow accumulation as the intensity of frontal disturbances declined in the early months of the year. With lower temperatures and periods of wind redistribution of snow, the pattern which is achieved during the mid-winter season is relatively constant. Tendencies perceived in late December are reinforced with maximum accumulation being attained on west-facing slopes and in valley bottoms. The mean depth on March 13 was 109.8cm (S.D. - 75) with maximum depth exceeding 350cm, but minimum depths were as low as 6cm. These figures emphasize the considerable variation in snow cover in an area where local relief rarely exceeds 30 feet (10m). The importance of this phenomenon in the distribution of permafrost and vegetation has been stressed elsewhere (Thom, 1969).

c) Thaw Period.

The onset of snow melt began in late April-early May and lasted until late July when all snow was removed from Timmins 4. May 14 typifies snow distribution during the early melt season. No wind redistribution occurs during this period. The pattern of mid-winter persists. Sites which become free of snow are those on highly exposed ridge crests. These are mostly convex upper slopes; concave and straight profiles are still well-covered. Close to 98% of the study area remains snow covered at this date. As the spring melt advanced, the snow cover retreated off the ridges isolating deep patches facing west and in valley bottoms.

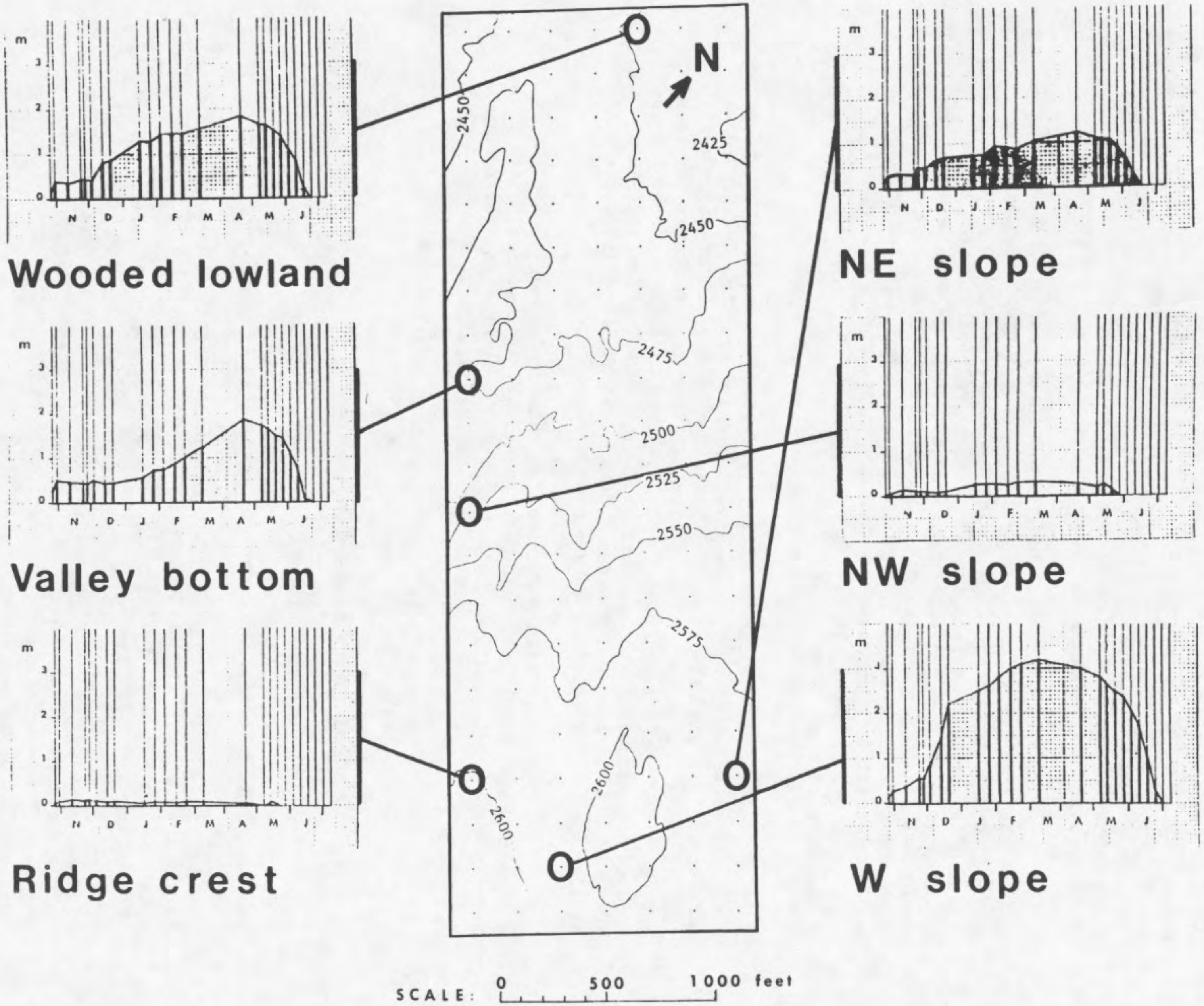


Figure 3. Accumulation curves for selected sites within the snow course area at Timmins 4. Contour interval for the map is 25 ft.

FACTORS INFLUENCING SNOW DISTRIBUTION AT TIMMINS 4.

At Timmins 4, where slope angles rarely exceed 20°, wind is the most important factor in snow transport. In order to understand the accumulation patterns discussed above, it is necessary to consider the impact of various factors which influence the wind regime. It is clear that topography plays an important role in spite of low local relief. The NW-SE grain imparted by the selective erosion of folded-faulted strata results in linear patterns of accumulation of snow cover.

Surface roughness and changes in surface roughness must also be considered. Surface roughness is a function of tree, shrub and exposed rock distribution. Changes in roughness occur throughout the winter with burial of vegetation and gradual reshaping of the micro-topography. Scattered trees at the north end of study area modifies the wind resulting in lee drifts and erosional hollows close to trees. The fact that by late December most of the birch scrub is buried by snow means a reduction in surface roughness in those areas where this type of vegetation predominates. Unfortunately, our program lacked on-the-site measurement of wind speed and direction so that the quantitative impact of wind on snow transport could not be determined.

It is possible to relate snow depth at any one time to such variables as aspect, slope angle, relief, and vegetation density in an attempt to "explain" the degree of variation by any one or any combination of these variables. The step-wise multiple linear regression technique has been used for this purpose by Mr. G. Young of McGill University who applied the technique at Axel Heiberg Island, N.W.T. (Young, 1968). One of us (H.G.) has analysed Timmins 4 data from the 1968-1969 winter in a similar way. The results will be published elsewhere.

What has been practical for this preliminary report has been a comparison of accumulation curves for all 147 stakes. Six stakes have been selected as indicating specific "growth" patterns related to the controlling variables outlined above. The six sites are:

1- Exposed ridge crest--tundra vegetation
2- Valley bottom--hygrophytic vegetation
3- Wooded lowland
4- NE-facing slope--birch scrub
5- W-facing slope--birch scrub
6- NW-facing slope--tundra vegetation

The location of stakes representing these sites is depicted in Figure 3.

In the case of the exposed ridge crest the most obvious point is the inability of snow to accumulate beyond a certain depth for the entire snow season. The depth of snow attained barely exceeds the thickness of the lichen-heath vegetation. Stones often protrude through the snow cover at this site (Fig. 4a). No matter what changes occur in wind direction and source of snow deposition, the growth of snow cover is limited by the extreme exposure. Temporary increases in snow depth were noted when wet snow was falling (e.g. just prior to May 14) or during those rare periods of calm. Winds are observed to be sufficiently effective to erode ice crusts developed under conditions of freezing precipitation as occurred on December 16. Snow first accumulates on slopes adjacent to a valley bottom as a cornice drift. Figure 4b was photographed in mid-December after winds from the east built a drift on the west-facing slope.

Brush vegetation is still apparent in the valley floor. With time, the drift envelopes the valley bottom and the reduced rate of growth to the lee of the drift is superseded by more rapid accumulation. The typical growth curve (shown in Figure 3) is therefore concave between November and the point of maximum accumulation in late April. Vegetation appears to have little influence on the snow accumulation pattern at this site. It can also be seen that as vegetation on the surface adjacent to the hollow gets buried then the efficiency of the valley bottom as an accumulation site improves relative to its surroundings.

At the northern end of the snow course, wooded lowland sites show a relatively steady increase in snow depth throughout the season with some exceptions. The exceptions are local topographic highs barely more than 15 feet (5m) above the general level of the lowland. Irregularities in detail in the steady increase are due to the changing position of lee drifts behind trees (Fig. 4c). Drifts in the open woodland may attain lengths of 60 feet (20m). Aerial photographs clearly show the high frequency of drifts in the woodland after a storm, (Fig. 5).

In contrast to the woodland area, those sites which possess a particular slope aspect are characterized by uneven growth. This reflects the relationship of the aspect to a particular direction of wind responsible for the deposition of snow. If it is a steep slope (exceeding 6-10^{o}), then during the early winter cornices build out and grow steadyly with increasing slipface angle until the valley is bridged. On slopes of less declivity accumulation tends to be concentrated towards the base. The west-facing slope clearly demonstrates rapid accumulation during the early part of the snow season under the influence of easterly snow falls (Fig. 4b). Comparison of wind mileage from 8 directions indicates that NW is the prevalent wind. However, the five periods of maximum snow deposition all had their source from the E or SE (October 25-27; December 5-6; December 16-17; December 23-24; and February 4). The growth curve shows a rapid increase in depth in December, the rate of which declines in later months. After March, little snow came from the east and therefore redistribution by NW winds is evident in the slow decrease in depth between mid-March and early May.

The NW slope is not a site of snow accumulation although some localized growth may occur as drifts behind obstacles (e.g. boulders). Shallow scrub is not a factor in promoting drift at this site. Exposure to prevalent NW winds maintains a low cover (see Fig. 4d), which is hard-packed.

Finally, there is the NE slope represented in Figure 3 by a steady accumulation of snow throughout the winter, but always deviating negatively below the mean for the snow course. The site represented has a low declivity (4^{o}). Deposition does take place on this slope with easterly winds as indicated by sudden increases in the growth curve. It is a slope somewhat sheltered from NW winds and this permits accumulation to continue uninterrupted, but at a reduced rate because of general exposure.

CONCLUSION

At Timmins 4, snow accumulation is strongly influenced by topography, particularly for the period from late December until thaw commences in May. Scrub vegetation is an important factor in early winter

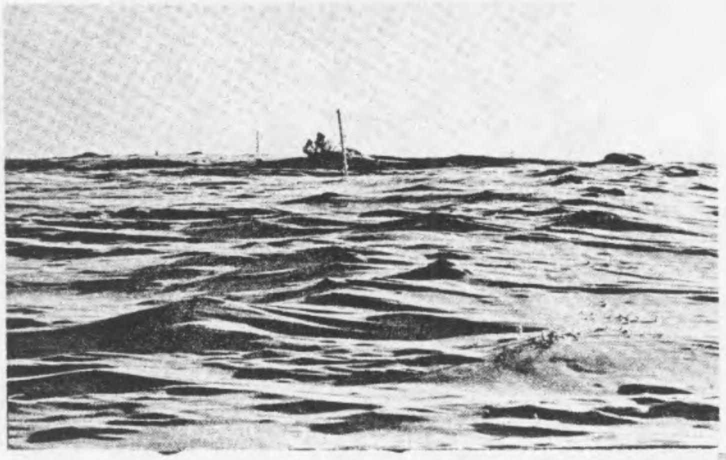


Figure 4a. Exposed ridge site showing boulders protruding through the thin snow cover.

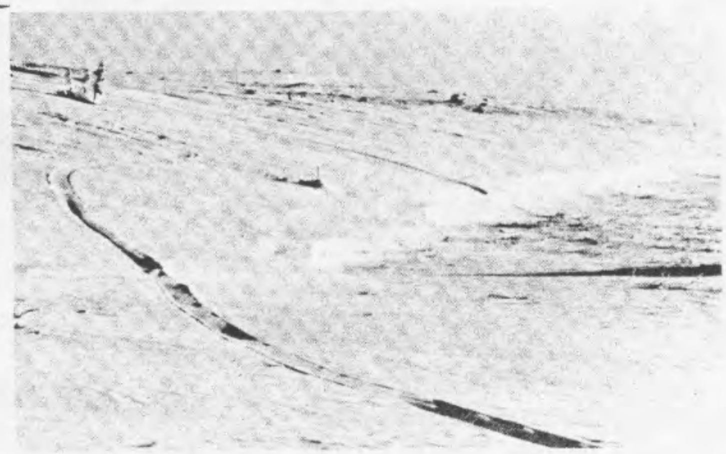


Figure 4b. West-facing slope towards valley bottom where the cornice drift has reached beyond the stake located on the lower part of the slope. Photo was taken in mid-December.

Figure 4c. Wooded lowland site showing soft snow accumulated as lee drifts behind trees.

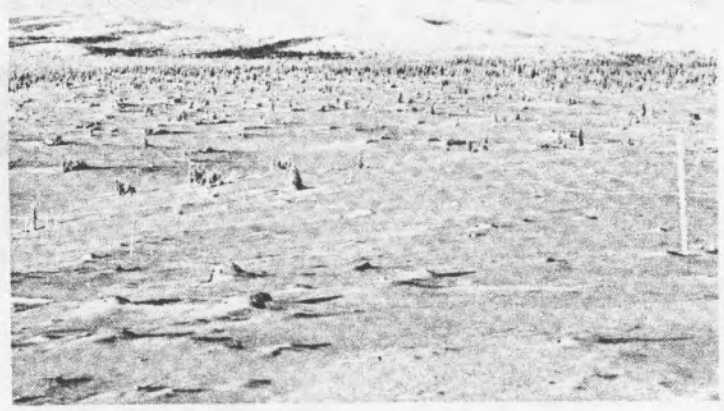


Figure 4d. View from the upper part of the Timmins 4 snow course to the north showing a northwest-facing slope with a generally thin snow cover.

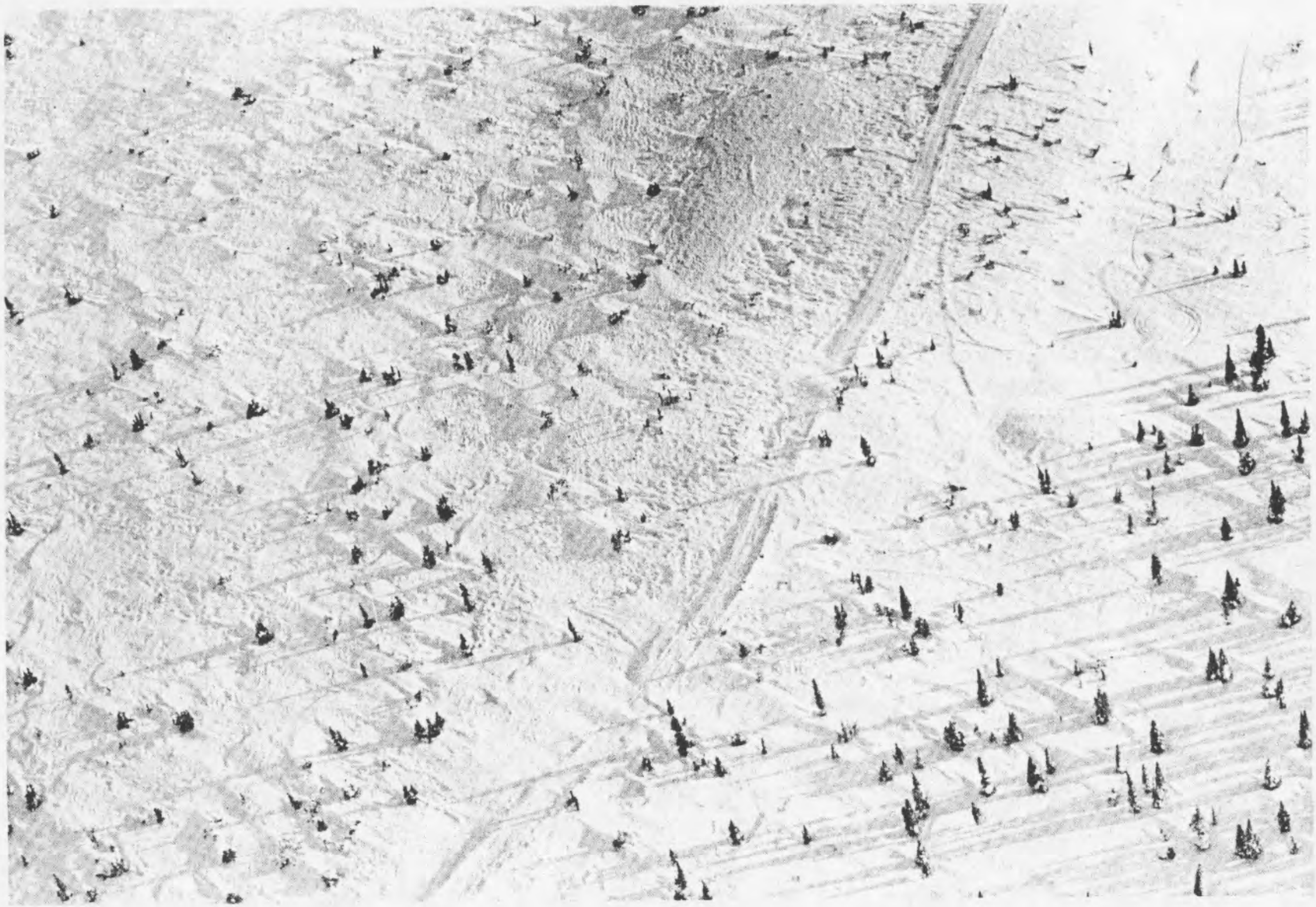


Figure 5. Aerial view of part of the northwest end of the Timmins 4 snow course after a westerly storm in late December. A. Cornice drift upper right from a preceeding easterly storm has been eroded by westerly winds, which have in turn deposited snow as lee drifts behind the scattered trees. The strong erosion is further shown by old raised ski-doo trails on the west-facing slope. More recent trails demonstrate a typical trace of a ski-doo in freshly deposited snow.

as it provides shelter from wind erosion of snow trapped within the brush. However, its importance declines as the snow pack deepens in mid-winter and the scrub becomes buried. Trees, on the other hand, provide a more continuous effect. In the studied area, they occur as an open woodland at the north end, and the shape and density of individual conifers influences the pattern of erosion or deposition in the adjacent area. For instance, a dense, evenly branched tree promotes erosion around its base during periods of strong wind. The hollows tend to be filled under conditions of light drifting snow.

The general sequence of events by which snow accumulates in this forest-tundra environment could be summarized as follows. In early winter, ridge crests soon become covered with snow, providing source areas for drifting and blowing snow. The moving snow is intercepted by adjacent scrub-vegetated areas. On lee slopes cornices build out to merge as the winter progresses with deposits in the valley bottoms. Interception of snow at the edge of cornices or by the scrub reduces the distance of snow transport in early winter and during this period the snow surface is quite soft. Accumulation patterns change their character once the scrub is buried and the cornices disappear. Long distance transport of snow is most marked in the months of January, February and March. Snow accumulates in locations where the air stream is decelerated and eroded where it accelerates. As a result, topography of the entire area is smoothened to approximate a surface providing minimum resistance to the air stream.

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