THE ROLE OF SNOW COVER IN THE NUTRIENT REGIME OF OLIGOTROPHIC, SUBARCTIC SOILS

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ABSTRACT

The effect of the snow cover on the nutrient regime of northern soils was investigated at four different sites, representing a lichen woodland, a lichen-heath tundra, a feathermoss forest and a sedge-moss fen, in the subarctic environment near Schefferville, Quebec. Snow cover accumulation was controlled by the topography and vegetation of the sites and snowpack chemistry, which showed high spatial and vertical variability, was largely affected by the presence of a forest canopy and the nature of the ground cover. Particulate matter, particularly litter, was a major source of the nutrients which accumulated in the snowpack. This accumulation was not, however, a major factor leading to the increases in the exchangeable cation concentrations of the soil surface horizons, which occurred between the fall and the spring. These increases were due to over-winter decomposition and nutrient release occurring beneath a deep, insulating snowpack.

RÉSUMÉ

Les effets qu'a une couche de neige sur le régime nutritif des sols du nord furent étudiés à quatre sites différents; comprenant un boisé à lichen, une toundra é lichen, une forêt à mousse et un marécage. Cette étude fut faite dans la zone subarctique près de Schefferville, Quebéc. L'accumulation de neige dépendait de la topographie et la vègétation des sites ainsi que de la composition chimique de la couche de neige. Cette composition, d'une variabilité prononcée tant spatiale que verticale, se trouvait en grande partie affectèe par le couvert forestier et le type de surface. Les particules, surtout celles provenant de la litière de feuilles mortes, étaient la source principale des éléments nutritifs s'accumulant dans la couche de neige. Ceux-ci, par contre, n'étaient pas un facteur important quand à l'accroissement des concentrations de cations échangeables des horizons supérieurs du sol entre l'automme et le printemps. Cet accroissement était peutôt dû à la litière de feuilles mortes résistant l'hiver, à la libération d'éléments nutritifs sous une nappe de neige profounde et isolante.

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PREFACE

I wish to thank Professor T.R. Moore for his supervision of this project, particularly during its final stages, and also my committee member, Dr. H.B. Granberg, for his constructive suggestions. In spite of the infamous Schefferville weather, the numerous field sessions were a success, due largely to the encouraging support and help of Doug Barr and the staff of the McGill Subarctic Research Station. The field sessions were financed by a summer field fellowship from the Centre for Northern Studies and Research. I would also like to thank Norbert Sebastian for his very valuable field assistance and Jamshed Merchant for his helpful suggestions concerning the laboratory analyses. I wish to extend special thanks to Dirk Werle for his support, interest and thoughtful criticisms throughout much of the thesis' preparation and to the people of 'Theater B', Glebe Avenue, Ottawa, for their stoicism during the many hours of manuscript typing.

CHAPTER 1
Introduction and Review

1.1 Introduction

Northern terrestrial and freshwater ecosystems have relatively low levels of primary production in comparison to southern ecosystems (ie. Bliss et al., 1981 and UNESCO, 1970). The productivity of northern ecosystems depends on many variables, any one of which can be limiting. These include nutrient availability, moisture, temperature, length of growing season, animal utilization and fire.

The few studies of the nutrient status of northern soils that have been made indicate particularly low base cation, phosphorus and nitrogen availability (Moore, 1980; Tedrow, 1977). Studies of plant productivity in subarctic environments have shown that when the subarctic soils in the lichen woodlands around Schefferville, Quebec were fertilized with nitrogen and phosphorus fertilizers, black spruce and Labrador tea showed increased rates of growth, thus suggesting that nutrient availability is a limiting factor in this region ([illegible], 1982; Prudhomme, per. comm.). Haag (1974) also found that production in both a sedge-meadow and a birch-willow-heath community in the northwestern arctic was limited by a low supply of available nitrogen and showed large increases in production following nitrogen fertilization.

The soil system receives nutrients through inputs from the weathering of parent material, precipitation and the decomposition of litter and soil organic matter. The low temperatures and frequent lack of moisture in the high arctic retard chemical weathering processes and, consequently, the release of base cations such as calcium, magnesium, potassium and sodium to the soil is very slow. The Precambrian granites and granitoid gneisses of the Canadian Shield in the eastern arctic and subarctic are highly resistant to weathering so that the nature of the parent material further inhibits the weathering process. In addition, northern soils are very young as a result of only recent deglaciation (as recent as 6,000 years B.P. in some arctic and even subarctic areas, such as the region around Schefferville, Quebec) which further contributes to the low nutrient status of these soils. Internal nutrient recycling is impeded by the slow rate of litter and soil organic matter decomposition. Studies of some northern soils have indicated that this slow rate of decay is a major limiting factor since the majority of nutrients are contained in the soil organic matter and do not readily become available in a form useable by plants (Rencz, 1976). Since the internal release of nutrients through weathering or organic matter decomposition is slow, it would be reasonable to place some importance on precipitation as a source of nutrients in northern ecosystems.

Inputs from precipitation are low. Moore (1980) calculated inputs of less than 10 kg/ha/yr for the major macronutrients contributed through rain and snow to the Schefferville, Quebec region. However, inputs from rain and snow were found to be very similar. Not only is the chemical composition of the precipitation important, but the nature of the precipitation itself, especially in regions where up to one half of the yearly precipitation falls as snow and where a continuous, seasonal snow cover remains for as long as seven months in the subarctic and up to 10 months in the high arctic. The role of snow cover in the nutrient regime of northern ecosystems is not understood and is a topic which, owing to the extent of snow cover in these areas, deserves investigation. The purpose of this study is to investigate the role which snow cover has in influencing the nutrient regime of oligotrophic soils in a subarctic environment.

1.2 Snow Chemistry

Studies concerning snow chemistry are largely inventory in nature, quantifying the amounts of various compounds contained in fresh snow or in the snowpack and are frequently reported in conjunction with projects of much larger scope. Winter limnological studies are the most common type in this regard (Armstrong and Schindler, 1971; Barica and Armstrong, 1971; Schindler et al., 1974). This has come about as a direct result of the need to study winter acid precipitation and to identify the processes by which the melting of the snowpack in a drainage basin affects the pH of lakes and streams during the spring melt (Gjessing et al., 1976; Haapla et al., 1975; Henriksen and Wright, 1977; Jeffries et al., 1979; Jeffries and Snyder, 1981).

The chemistry of the snowpack is influenced by:
i) atmospheric inputs through either the wet deposition of chemical constituents during precipitation or dry deposition of chemical constituents between p precipitationn events and
ii) inputs from vegetation through either litter incorporated in the snowcover or through the vegetation/litter layer at the base of the snowpack.

1.2.1 Atmospheric Inputs

The initial chemical composition of a developing snowpack depends on the wet deposition of chemical components contributed by falling snow. This chemistry is determined in part by the elemental composition of the air mass in which the snow crystals form and the composition of the air masses through which they fall. The process by which snow and ice crystals accumulate contaminants is called "precipitation scavenging". Four mechanisms involved in controlling the chemical make-up of falling snow are summarized by Takahashi (1963):

1) chemical elements are included in the ice nuclei on which the snow crystals form;
2) chemical elements in aerosols (such as sea spray) are captured during crystal growth;
3) chemical elements are included in the condensation nuclei of water droplets which adhere to the snow crystals, especially in the case of rimed crystals;

4) chemical elements in aerosols are captured by snow crystals after leaving the cloud base by either a) Brownian motion of the aerosol particles to the snow crystal or b) the gravitational accretion process.

The first three processes correspond to "rainout" or within-cloud scavenging and the last to "washout" or below-cloud scavenging. Fletcher (1970) suggests that the washout process is more important when he indicates that although small amounts of some materials may be incorporated into the lattice of the ice crystals, the majority of the chemical components are believed to be adsorbed to the surface of the crystals themselves. The primary capture mechanism, as studied by Knuston (1975), is thought to be simple interception.

Elements contained on or in snow crystals originate from a variety of sources including sea spray, land erosion, biogenic emissions, forest fires, vulcanism and agricultural and industrial activities. Sea spray and erosion are major suppliers of inorganic ions in snow. Phosphate contents are also largely due to natural processes. Sulphate, nitrate and particulate carbon are likewise supplied by natural sources, but industrial activity is becoming increasingly important in many areas as a primary source of these ions.

As the snow accumulates and between periods of precipitation, when washout/rainout processes are active, particulate organic and inorganic material and certain chemical compounds settle on the snow surface via dry deposition processes. This material becomes incorporated into the snowpack so that the bulk chemical composition is not simply due to the contribution from the individual crystals which comprise it. The process is cumulative, each snowfall and dry deposition event adding to the net snowpack chemical composition.

Precipitation sampling conducted in a variety of regions throughout Canada reflects the effects which the proximity to coastal areas or inland locations, isolated from the immediate influences of agricultural and industrial activity, can have on precipitation chemistry (Barica and Armstrong, 1971; Schindler and Nighswander, 1970; Schindler et al., 1974). Basic cation concentrations have been found to be higher in both rain and snow in northern coastal areas where these cations would be contributed from sea spray (Schindler et al., 1974). Inland regions, such as northwestern Ontario, tend to show low base cation concentrations in precipitation as they are removed from the pronounced influences of sea spray. However, the lower chemical concentrations in rain and snow in the Canadian Shield area, where soils are thin and often absent, may also be due to the lack of inputs from airborne dust that is contributed through natural erosion processes. Higher concentrations of organic nutrients, such as nitrogen and phosphorus compounds, are found in the precipitation of more southerly regions, such as south-central Ontario (Schindler and Nighswander, 1970). These compounds are supplied from organic material which has a faster rate of accumulation and decomposition in southern, compared to northern, environments. These compounds become airborne through natural erosion processes, agricultural disturbance or fire. In addition, nitrogen and sulphur compounds are released by industrial activity and the combustion of oil and gasoline which would also account for higher concentrations of these compounds in the precipitation from southern areas located near major industrial and/or residential centres.

Although the effects of long-range transport of industrial pollutants on the precipitation chemistry of northern Canada may not be as pronounced as in Norway and Sweden, point sources have been found to be an influencing factor on a local scale. In addition to contributions from sea spray, Schindler et al. (1974) suggested that higher concentrations of chemical constituents in snow and rain samples, collected from the Resolute area, Cornwallis Island, may also have been in part due to the proximity of the sampling area to the town site, although this was not tested directly. Drake and Moore (1980) found that

SO_2 emissions from Schefferville, Quebec in winter lowered the pH of the snowpack in areas down-wind from the town site.

Over-winter sampling of the snowpack on the ice surface of two small lakes in northwestern Ontario, conducted by Barica and Armstrong (1971), indicated that nutrients do accumulate in the snow cover over the winter season. The snowpacks were sampled in an open area, away from the effects of overlying vegetation, suggesting that the contributions were from atmospheric sources. The investigators reported cumulative tendencies for all the constituents measured (NH_4^+, NO_2^- and NO_3^- -nitrogen, total soluble nitrogen, PO_4 -phosphorus, total dissolved phosphorus, carbonate and particulate C, N and P), which was most pronounced for particulate matter. They found that changes in inorganic nitrogen compounds and nitrate were not as uniform as for the other compounds and explained this as possibly being due to the effects of denitrification.

1.2.2 Vegetation Inputs

A second source of chemical constituents in snow is vegetation. In many regions, the snowpack is deep enough that it not only covers and incorporates ground vegetation such as grasses, mosses, vascular plants etc., but also low-lying bushes and young or stunted trees. In addition, litter becomes directly incorporated into the snow cover. In northern areas, a snow cover may be established before litter fall is complete so that litter accumulates on the snow surface rather than on the ground. Snow also accumulates on tree branches and stems and carries pieces of bark and leaves with it as it cascades to the snow surface below. It may also become enriched with nutrients or particles as it falls through the tree canopy.

Several investigators have found that snow sampled from the snowpack beneath coniferous, mixed or deciduous forest canopies had higher concentrations of major nutrients than snow collected from adjacent open areas (Fahey, 1979; Pierson and

Taylor, 1980; Verry and Timmons, 1977). They attributed the higher concentrations to enrichment from the overlying forest canopies. Concentrations were also found to be higher under the denser stands and also higher under coniferous, compared to deciduous, canopies. The absence of a leaf canopy in deciduous forests during the winter could be a reason for the lower concentrations found in these snowpacks. Fahey (1979) and Pierson and Taylor (1980) also found nutrient enrichment in fresh snow samples collected from beneath forest canopies. Fahey (1979) suggested that since fresh snow showed nutrient enrichment, this indicated leaching and/or washing of particles from branch and needle surfaces rather than augmentation of nutrients in the snow after it had reached the ground.

In the studies conducted by Fahey (1979) and Verry and Timmons (1977), nutrient values were expressed as concentrations and did not account for the snowpack water equivalents. Shallower depths beneath trees can lead to lower snowpack water equivalents in forested areas compared to open, but sheltered, regions where the snow may be deeper. In addition, snow depths and water equivalents will also be greater between trees in forested areas than around the tree base. Given the possibility of equal inputs of nutrients to both a forested and an adjacent, open area, nutrient concentrations could be dependant on the snowpack water equivalent. Since nutrient concentrations are a function of the volume of water and the amount of nutrients, it would thus be expected that a higher snowpack water equivalent would lead to lower concentrations than a snowpack with the same nutrient content but lower water equivalent. This possibility was not reported as having been accounted for in these two studies so that the increases in nutrient concentration, beneath the tree canopy, should be regarded as indicative of absolute increases only with some caution.

1.2.3 Changes in Snowpack Chemistry During the Winter

The snowpack chemistry is also dependent on changes occurring within the snowpack. Until quite recently, the effects of snowpack chemistry dynamics were ignored when assessing the representative bulk chemical composition of the snowpack. The work of Elgmork et al. (1973) on laminated snow profiles in Norway indicated that the snowpack structure is preserved throughout the winter as long as temperatures remain well below 0°C. It was assumed that late-winter sampling, using snow-core techniques, could provide information on the chemical composition of the entire winter's precipitation. On this basis, a large-scale, regional snow-core survey program was performed in Norway from 1973 to 1976 (Wright and Dovland, 1978). The assumption was found to be incorrect. A comparison of snow-core concentrations with corresponding cumulative values from precipitation collectors showed that the snowpack had generally lower concentrations for many parameters (Wright and Dovland, 1978). This suggests that the snowpack underwent nutrient depletion during the winter, despite inputs from wet and dry deposition and/or vegetation. Other investigators have since reported similar findings. Skartveit and Gjessing (1979) found that the acid components (H^+, NH_4^+, NO_3^-) and metallic compounds contained in the snowpack were only 60 to 70 percent of the mean concentration of the snow collected in adjacent precipitation collectors. The same pattern was reported by Jeffries and Snyder (1981).

It is clear that periods of melting during the winter and the spring can drastically affect the distribution of ions and their concentrations in the snowpack. The disproportionate loss of ionic species (relative to water loss) is called fractionation and it is this process which is believed to be responsible for the sharp drop in pH observed in some surface waters during spring melt (Haapla et al., 1975; Henriksen and Wright, 1977; Gjessing et al., 1976).

Field and laboratory melt studies conducted by Johannessen and Henriksen (1978) showed that concentrations of all ionic species tested were three to five times higher in the first meltwater fraction than in the bulk snow samples. They found that in all tests, the first 30 percent of the meltwater contained 41 to 80 percent of the total amount of the components being analysed. In addition, they could find no systematic differences between the behaviour of mono- and divalent ions, leading the researchers to suggest that size and charge of the ions are not important in the fractionation process. The effect was found to be most pronounced in the tests conducted in the field. At one field location, concentrations in the first melt were 6.5 times greater than in the snowpack.

The processes involved in fractionation are not yet fully understood, but are probably related to such factors as diurnal temperature fluctuations in the snowpack during melting, direction of heat transfer, pollutant load and pollutant gradients. One possible explanation may be a mechanism similar to that operating with cryo-concentration in freezing lake water (the concentration of chemical constituents in the water layer directly beneath the ice or freezing front). The first melt begins near the snow surface and refreezing occurs due to diurnal temperature changes. With refreezing, relatively pure ice crystals form, excluding the chemicals contained in the original snow crystals. This results in a concentrated meltwater solution in the snowpack.

Fractionation is most pronounced during the spring melt period. However, Jeffries and Snyder (1981) also found major losses of chemical constituents from snowpacks near Sudbury and Muskoka-Haliburton in central Ontario during cold periods in the winter, prior to melting and after minor, mid-winter melt episodes. Comparisons were made between the concentrations found in the snowpack and corresponding bulk samples collected in precipitation collectors. Of the parameters tested (H^+, $SO_4^=$, NO_3^-, NH_4^+, Ca^{++} and Cl^-), only Cl^- showed practically no difference in concentrations between the snowpack and the bulk deposition samples. With few exceptions, the remaining parameters showed greater concentrations in samples collected in the precipitation collectors than in the snowpack. Their study shows that, even with dry deposition, there appears to have been a loss of chemical components from the snowpack, even during periods of cold weather when no melting had occurred. The investigators suggest that these observations indicate a loss of ions to the underlying soils during the winter. If this is in fact occurring, then the snow/vegetation/soil interface is not an inert boundary and it is therefore not sufficient to consider the snowpack alone. There is direct contact between the snow cover and the ground surface so that the entire system should be viewed as a continuum, where an active snow/vegetation/ soil interface exists and where biological and/or physical weathering processes can occur.

1.3 The Snow Cover and Weathering

Although limnologists treat snow cover and lake ice as a continuum, this approach has not yet become popular with investigators who are concerned with terrestrial systems. This may in part be due to the belief that much of the meltwater runs over the land surface during the spring, carrying with it the majority of nutrients it may contain and deposits them directly into streams and lakes. The opinion has been that little, if any, interaction is occurring between the soil and vegetation surfaces and the base of the snowpack or meltwater runoff.

This is in fact not true. Studies of nivation processes have indicated that chemical weathering was increased by a factor of two to four at a snowpatch and that chemical and mechanical degradation were approximately equal in a nivation hollow (Thorn, 1976). The presence of a snow cover may create an environment at its base which is conducive to carbonation processes. An early study by Williams (1949) showed that air samples taken from the base of snow drifts were 0.077 to 0.098 percent CO_2 by weight compared to the average of 0.035 percent for atmospheric CO_2. Smith (1972) suggested that biological activity at the base of the snowpack could be an important factor in increasing the CO_2

concentration in this environment. Such an environment would be poorly ventilated, allowing a buildup of CO_2 from respiring organisms to occur. Moore (in press, a) measured a CO_2 flux of 0.3 g/m^2/day in woodland soils beneath a mid-April snowpack in a subarctic environment. This compared with mid-summer values of 0.8-1.2 g/m^2/day (Moore, unpublished data) for the same area, suggesting that floral and faunal activity is occurring in the subnivean environment.

Smith (1972) found that limestone solution in arctic environments was concentrated at snow/rock interfaces and that enhanced solution in the arctic may result from the colder water temperatures. His data showed that the hardness values (Ca and Mg) of water draining from snow banks, overlying limestone, were higher in comparison to the average value for the study area and that the mean hardness values for the meltwater were slightly higher than the mean values for the rivers draining the limestone catchment.

Rueslatten and Jorgensen (1978) cite evidence of ion exchange processes occurring between bedrock and the snow meltwater flowing over it and further interaction occurring between the meltwater and vegetation patches overlying the ground surface. Lewis and Grant (1980) found that the snowpack in some way influenced the mobilization of leachable materials in the soils of a mountain watershed in Colorado. They did not identify the mechanisms involved but suggested that the effect of the snowpack on soil temperatures and soil frost is of importance.

1.4 The Snow Cover and Organic Matter Decomposition

Although microbiological activity has been widely investigated for many cold regions (Holding et al., 1974), investigators have tended to ignore winter biological activity, since winter conditions, especially in northern regions, have been regarded as inhibitive to biological activity. However, studies which have been conducted on over-winter decomposition have shown that mechanical and chemical decomposition are occurring beneath the snow cover (Bleak, 1970; McBrayer and Cromack, 1980; Moore, in press a and b; Stark, 1973).

The snow cover acts as an insulator, buffering the ground beneath from the extreme cold and variations in temperatures that occur at the surface. Although the air temperatures may be well below 0°C, the environment at the base of the snowpack, the subnivean environment, can maintain a temperature close to 0°C and occasionally rise above the freezing point so that the soil thaws and water becomes available. In addition, not all water is frozen at 0°C in a porous medium, so that significant amounts of water may be available from the unfrozen water in the soil pores. In the presence of the available water, chemical and biological processes can occur. This is important in terms of macro- and micro-biological activity and over-winter decomposition.

Litter bag studies by Bleak (1970) showed that, between pre-snowfall and post-spring melt, the mass loss of grass and herb litter averaged 30 to 50 percent. Stark (1973) observed a 9 percent winter weight loss in Jeffery pine litter, which accounted for 85 percent of the annual weight loss. McBrayer and Cromack (1980) cite evidence of biological activity beneath the snow. Their study of oak litter decomposition indicated a 6.6 times greater rate of CO_2 production in the litter under the snow than prior to snowfall. In addition, they found that various elements behaved in different ways as the litter appeared to decompose during the winter; elements which were lost rapidly in proportion to litter loss (P, K and B), those which disappeared in proportion to litter loss (Ca, Mg and Mn) and those which concentrated as litter loss occurred (Al, N and Zn).

McBrayer and Cromack (1980) suggest two mechanisms for over-winter decomposition. It is thought that once the snow cover is thick enough to buffer the ground from extreme cold, geothermal heat is trapped at the soil surface, raising the temperature so that decomposition processes can begin. In addition, periodic melting of the pack during the winter provides free water. In early winter and spring, freeze-thaw cycles can contribute to the mechanical breakdown of the litter. The investigators also found that, except for K and P, snow melt did not appear to flush nutrients from the litter horizon.

Moore (in press, a) investigated the over-winter mass and nutrient losses from different tissue species in a subarctic, lichen woodland forest. He found that, over a two and one-half year period, birch and Labrador tea tissues, spruce needles and lichen (Cladina) litter samples lost 55 percent (birch) to 20 percent (lichen) of their original mass. Sixty to 90 percent of the total mass losses occurred from September to June during the first year. Potassium was most readily lost from the tissues; only 50 percent of the original content was retained after the winter. Phosphorus was lost most rapidly from birch and Labrador tea tissues and almost all the loss occurred in the first winter. Nitrogen increases, as large as 200 percent, were measured in the spruce and lichen tissues at the end of the two years. Moore (in press, a) attributed this to the immobilization of N from atmospheric inputs and from the soil horizons and fixation of atmospheric N.

In a subsequent study, it was established that, in the lichen woodland environment, 46 to 80 percent of the over-winter losses occurred in the period from early September to early November when the soils remain wet, precipitation is high, evaporation is low and freeze-thaw cycles are most frequent (Moore, in press, b). A thick, continuous snow cover developed after this time period. It was found that birch showed the greatest mass loss during this period (80 percent of the total winter mass loss) whereas the spruce and lichen tissues showed equal mass losses between this early first period and the remainder of the winter under the snow cover. As in the previous study, K was most readily removed from the litter (80 percent of the total) and 59 to 90 percent of this loss occurred between September and November. Spruce and lichen litter showed significant losses after the snowpack had been established.

1.5 The Need to Investigate the Role of Snow Cover in the Nutrient Regime of Northern Soils

The above review illustrates the ways in which the snow cover may be considered as important to, or possibly influencing, the nutrient regime of arctic and subarctic ecosystems: its variable and changing chemistry; its effect on the underlying soil body and its possible role in supplying nutrients to northern ecosystems. Regardless of this potential importance, very little information is available on the chemical regime of the snow cover or on the way in which the snow cover may affect the nutrient status of arctic or subarctic soils.

The potential importance of snow cover can be readily appreciated when one considers that, in an area such as central Labrador-Quebec, the soil environment remains snow covered for seven months of the year (from mid-October to late May). During this time, the interface, defined by the litter-layer, overlying vegetation and the base of the snowpack, develops, which is very different from the interface of litter-layer/vegetation/air normally involved when conducting studies on the nutrient status or availability of nutrients in a soil system.

During the winter, as the snow cover develops, it is frequently believed that the input of nutrients to the soil system ceases and the nutrients become stored in the snowpack, only to be released in the spring and carried overland with the meltwater runoff. Their contribution to the soil system is seen as unimportant since the ground surface is, at this time, considered to be frozen and incapable of interactions with the meltwater. Interactions between the snowpack, vegetation and soil during the winter are thought to be negligible because of the low temperatures, frozen soil conditions and lack of readily available water. The possibility of nutrient contributions from the overlying snowpack are thus considered to be unlikely. The entire snow/vegetation/soil system is therefore viewed as an inert system in which exchange processes do not occur.

The intention of this investigation is to determine the role of the snow cover in influencing the nutrient regime of oligotrophic, subarctic soils. Two possibilities were considered; the snow cover as a nutrient accumulator and potential nutrient source and, as a result of the presence of the snow cover, the importance of the snow/vegetation/soil interface as an environment in which nutrient release processes can occur. This necessitated several interrelated investigations:

i) to determine the general nutrient status of the soil body as a whole;
ii) to measure the changes in the nutrient status of the upper organic soil horizons between the fall and spring;
iii) to measure the changes in the nutrient content and distribution of the nutrients in the snowpack;
iv) to measure loss in mass of different plant tissues under the snowpack between the fall and spring.

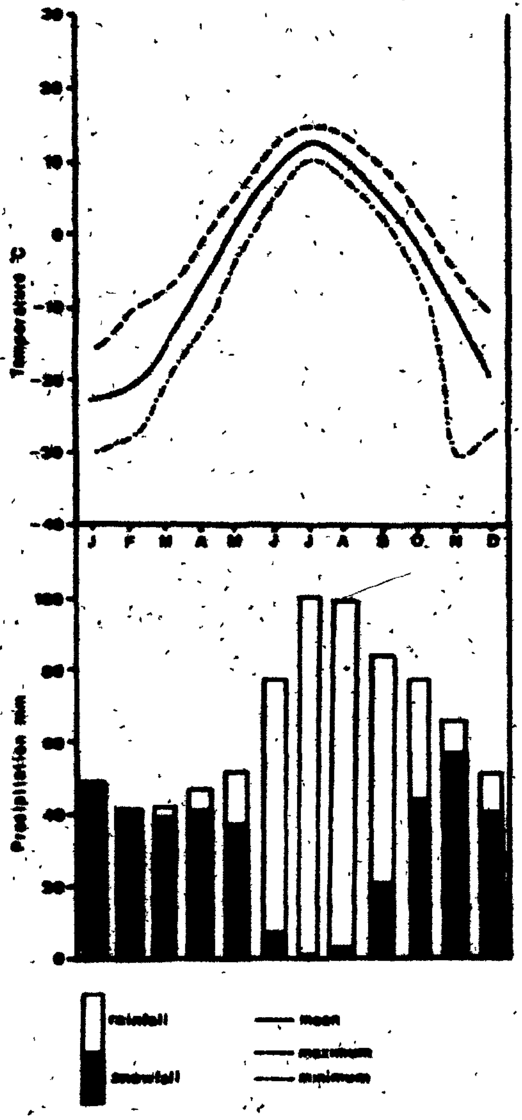


Figure 1

Mean monthly temperatures and precipitation at Schefferville, Quebec, averaged over a 26-year period from 1955 to 1980 (after Barr and Wright, 1981)

CHAPTER 2

The Environmental Setting

2.1 Schefferville as the Study Region

The accumulation and long duration of ~~a~~ thick snow cover and the oligotrophic nature of the soils in the subarctic environment around the town of Schefferville ($54^{\circ}43$'N, $66^{\circ}42$'W) in northern Quebec, provide an opportunity to study the effects of the snow cover on the nutrient regime of oligotrophic soils. Should increases in the amount of nutrients contained in the soil occur between the fall, just prior to the development of a snow cover, and in the spring, immediately following the melt, they would be noticeable against the background of the initially low, fall nutrient contents in the oligotrophic soils of this region. The growing season here is short, so it is important that an available supply of nutrients exists early in the growing season, allowing the plant communities to make optimum use of the short time available for growth. It is therefore of interest to know whether or not a nutrient supply is available at the onset of the growing season.

2.2 Climate

Schefferville lies within the subarctic climatic zone as described by Hare (1950). The mean annual temperature at Schefferville is -4.9°C with mean monthly ranges from 12.5°C in July to -22.2°C in January (Barr and Wright, 1981) (Figure 1). The winters are long, cold and snowy. Periods of bitterly cold weather occur frequently, when the maximum mean temperature does not rise above -20°C and there are frequent minima of -40°C. The summers are short, cool and wet and there are only two months when the mean temperatures rise above 12°C.

Averaged over a 25 year period, Schefferville receives 784 mm of precipitation per year of which 377 mm (water equivalent) falls as snow, representing 48 percent of the total annual precipitation. The distribution of snow and rainfall throughout the year is shown in Figure 1. Precipitation is adequate throughout the summer for normal vegetation and soil chemical activities, but the low temperatures and short frost-free period and growing season definitely reduce the effectiveness of this moisture availability. Evapotranspiration rates are low; one-quarter of the summer rainfall leaves the soil by evapotranspiration from a lichen mat and one-half to two-thirds from a moss-covered surface. Annual potential evapotranspiration rates are estimated to be 250 mm at Schefferville (Canada Department of Energy, Mines and Resources, 1974). Hare and Hay (1971) calculated apparent evapotranspiration to be approximately 100 mm. The predominant lichen mat keeps the soil close to field capacity throughout the summer and reduces evapotranspiration.

Seasonal frost is an important expression of the temperature regime at Schefferville which affects all soil processes. Frost first penetrates the soil when the mean daily temperature falls below 0°C for several consecutive days. This usually occurs towards the end of September. The soil remains frozen until early or mid-June, with frost developing to depths of 1 m or more.

Schefferville is situated at the southern edge of the discontinuous permafrost zone (Brown, 1970). The spatial distribution of a deep, insulating snow cover is one of the major factors in controlling the occurrence of permafrost in this area. Permafrost is found beneath the ridges where a continuous snow cover develops later in the season and remains shallow throughout the winter. Thus, there is very little hindrance to heat loss from the underlying soil and rock. Permafrost can develop to depths of greater than 124 m on the exposed ridges (Nicholson and Granberg, 1973). A much deeper snow cover, of up to 1.5 m in some areas, particularly at the base of slopes, inhibits the excessive over-winter heat transfer away from the ground so that permafrost does not develop in the low-lying areas and valley bottoms.

2.3 Geology and Soils

The Schefferville area lies within the Quebec-Labrador Trough, a 640 km geosyncline in the middle of the Quebec-Labrador peninsula, where approximately 600 m of shale and sandstone were deposited when an arm of the sea invaded the area during the Proterozoic age. Today, the region is dominated by a NW-SE trending ridge and valley topography, which resulted from the recent glacial and subaerial erosion of the weaker members of the sedimentary rock formations which where exposed through folding and faulting events during the Hudsonian orogeny.

The retreat of the Wisconsin ice sheet, approximately 6,000 years B.P., left the area largely covered by glacial and fluvioglacial deposits. Only the sharper ridge crests, steep slopes and lake shore areas are free of glacial till. The disorganized drainage pattern (which developed when river valleys became choked with glacial debris and shallow lakes formed behind these dams) is characterized by the widespread occurrence of bogs and fens. The glacial till is, in general, very gravelly, contains many stones and cobbles and varies in thickness from 20 to 30 cm on ridge crests to 6 m at the foot of slopes. Some areas of fluvioglacial sands and gravels do occur but they are limited in their extent.

The presence of the sedimentary rock formations and glacial till have been important to the soil development in this area. Clay rich material has been derived from the slate and shale formations, calcium and magnesium from the dolomite formations and siliceous and acidic material from quartzite, qreywacke and arkose containing formations. In addition, these soils have high iron contents, contributed from the Sokoman iron formation in the region. Were it not for the presence of the glacial till, soil types in this area would surely have been restricted to the thin, regolithic soils, such as those found in the surrounding Canadian Shield, which have developed from the highly weathering resistant granitic bedrock.

Nicholson (1973) and Nicholson and Moore (1977) have examined the major types of soils and their development in the Schefferville area. The factors which appear to be most important to soil formations in Schefferville have been identified by Nicholson (1973) as: iron-rich glacial deposits derived from the underlying Precambrian sedimentary rocks; short, cool summers with abundant precipitation; variable drainage characteristics; the wide variety of cover types dominated by the lichen ground flora and the limited time since deglaciation. The distribution of soil types has been found to be related to particular environmental factors. Of these, topography and associated vegetation appear to have the greatest effect on soil forming processes in this area. Leaching, podzolization and gleying as well as surficial accumulation of organic matter and frost action are the dominant pedogenic processes active in the Schefferville area (Moore, 1978; Nicholson and Moore, 1977).

The soils fall largely into the Podzolic, Brunisolic, Regosolic, Gleysolic and Organic orders and are further subdivided into Orthic, Degraded or Gleyed Dystric Brunisols, Orthic and Gleyed Humo-Ferric Podzols, Orthic and Lithic Regosols, Orthic, Fera and Fera-Eluviated Gleysols and Fenno- and Sphagno-Fibrisols and Humic Mesisols (Nicholson, 1973). Regosols and shallow Brunisols are found on ridges and on the upper slopes under open lichen woodlands. Thicker Brunisols and Podzols have developed on the well-drained glacial till in the lichen woodlands and on side slopes in feathermoss forests. Gleysols and gleyed soils of other orders frequently occur on the foot slopes in the feathermoss forests and in valley bottoms and adjacent to stream channels and are imperfectly to poorly drained. The organic soils form the bog and fen regions in the area and occupy very poorly drained depressions. The peaty material is derived from sedges, woody shrubs and sphagnum moss and deposits rarely exceed 4 m. Depths of up to 1.5 m are most common. Soils developed from the glacial till have a low soil fertility. Where soils have developed from the fluvial deposits found along-side stream channels, the soil fertility is comparatively high.

Although studies of soil classification and pedological processes have revealed a number of different soil types in the Schefferville region, investigations concerning soil fertility have only been conducted on the soils in the spruce lichen woodlands (Moore, 1980). The lichen woodland soils are generally classified as Orthic or Eluviated Dystric Brunisols, are shallow (rarely exceeding 60 cm in depth), have a thin LFH horizon overlying a Bm horizon and occasionally a poorly expressed Ae horizon above the Bm. The soils are acidic, have a low base saturation, low nitrogen and phosphorus availability and contain relatively small amounts of organic matter in the mineral soil horizons. The organic matter content of the upper horizons can be between 20 and 90 percent. Concentrations in the lower horizons also increase somewhat, probably as a result of translocation or direct contribution from sedimentary parent material (Nicholson and Moore, 1977). Although the CEC can be reasonably high, the exchange sites are occupied by H ions, thus accounting for the low soil fertility.

The low nutrient status of these soils may be attributed to low nutrient concentrations in precipitation and the slow release of nutrients from organic matter and parent material. The concentrations of nutrients in rain and snow, as measured by Moore (1980), range from 0.09 ppm for Mg to 0.45 ppm for Ca and are therefore not considered to play an important role as direct nutrient contributors. Increases for all cations were measured in canopy drip and stem flow. These ranged from 0.45 and 0.68 ppm for Mg to 1.47 and 3.58 ppm for Ca for canopy drip and stemflow respectively. When expressed on an annual areal basis, it was determined that the combined canopy drip and stemflow return significant amounts of nutrients to the soil (Moore, 1980). However, only the small area surrounding each spruce tree benefits from this return. This ranges from 20 to 40 percent for open and closed lichen woodlands, respectively. Losses through leaching tend to be small, with Ca and Mg showing the greatest losses.

The majority of macro-nutrients in the woodland soils are contained in the soil organic matter and, because of slow rates of decomposition, do not become readily available in a form useable by plants (Rencz, 1976). Although fire is a widespread occurrence during the summer in the woodlands, it appears to have little effect on the nutrient status of the soils (Dubreuil and Moore, 1982 and Moore, 1980), unlike the nutrient flushes which have been reported following fires in other ecosystems.

Moore (1981) cites the following factors as leading to the slow rate of organic matter decomposition in the lichen woodland soils around Schefferville: low soil temperatures and long periods of freezing; the low nutrient contents of the plant litter and soil organic matter, especially nitrogen; the lack of a readily available energy source; acidity of the organic horizons; low populations of mesofauna, especially arthropods. He found that increasing soil temperatures, raising the pH, adding an available energy source (sucrose) and adding nitrogen fertilizers, particularly nitrate and urea, stimulated increased decomposer activity in laboratory conducted experiments.

2.4 Vegetation

Schefferville is located near the southern limit of the forest-tundra sub-zone of the boreal forest (Hare, 1950). The ridge and valley landscape provides a number of topographical units where different cover types develop, leading to a mosaic of topographic/vegetation units in this region. The vegetation communities which form are dependent on drainage conditions and micro-climatic and micro-topographic influences of which exposure to wind and zones of snow removal and accumulation are important. Certain cover types, such as sedge meadows, fens and feathermoss forests, are often associated with dolomitic outcrops or dolomitic till, thus suggesting that nutrient availability may also be an influencing factor in detemining where certain vegetation communities become established.

The major tree species in the Schefferville region are black spruce (*Picea mariana*), white spruce (*P. glauca*), tamarack (*Larix laricina*) and balsam fir (*Abies balsamifera*). The most common shrubs are dwarf birch (*Betula glandulosa*), Labrador tea (*Ledum groenlandicum*) and alder (*Alnus crispa*). Woody perennials such as the blueberries (*Vaccinium uliginosum*, *V. caespitosum* and *V. vitis-idaea*) and those comprising the heath associations (ie. *Kalmia polyfolia*) are widespread throughout the region. The only herbs of any importance are fireweed (*Epilobium angustifolium*), golden rod (*Solidago macrophylla*) and cornell (*Cornus canadensis*). The main ground flora are fruticose lichens (most importantly *Cladina stellaris*, *Cl. mitis*, and *Stereocaulon spp.*) and various mosses (*Pleurozium schreberi*, *Ptilium crista-castrensis*, *Dicranum fuscesens*, *Polytrichnum juniperinum* and *Hylocomium splendens*). Sphagnum moss is important only in depressions and sedges and grasses occur on fens and fluvial deposits.

The cover types commonly found in the area and the associated topographic features are: treeless, lichen-heath tundra on exposed ridge crests and upper slopes; open and closed lichen woodlands on sheltered uplands and in the drier lowlands; closed feathermoss forests, sedge meadows, fens and bogs in valley bottoms and wetter lowlands and depressions. Regenerating post-fire communities are also very common in this area. In the early stages, moss-shrub-heath communities often occupy these areas. Post-fire communities are not specifically associated with particular topographic features but, depending on the openness of the area, regeneration may not proceed further than this treeless community in exposed areas of higher elevation.

Lichen woodlands develop on well-drained sites and are characterized by scattered spruce trees (both black and white spruce) at densities of 500 (open woodland) to 5,000 (closed woodland) stems per ha with an understory of dwarf birch and

Labrador tea. The ground story is dominated by lichens, the mat being interspersed with low-lying blueberry and cranberry shrubs. Mosses can be found around the base of the spruce trees.

The feathermoss forests are found in poorly drained valleys. The black and white spruce grow closely together forming a closed canopy. The understory is once again dominated by dwarf birch and Labrador tea and willow and alder also occur in the wetter areas and alongside streams. The ground cover is composed of various mosses, the mat being interspersed with herbs.

The ridges lack important tree species although a few scattered, stunted black spruce can usually be found. Some lichen or moss ground cover is present, but the mat is frequently discontinuous. Where large patches of bare ground occur, frost scars are numerous. The woody perennials, such as blueberry and cranberry, are the dominant vegetation types. Labrador tea is also common.

Bogs and fens are common in the Schefferville region and have been classified by Allington (1961) according to their physiographic characteristics as string bogs, closed strings, sedge meadows, spruce muskeg and tamarack swamp forest. Tamarack and spruce are the dominant tree species in these depressions. The ground vegetation is commonly sphagnum moss and sedges which are also the main peat forming materials. Willow, as well as Labrador tea and dwarf birch, grow toward the drier edges of the depressions or colonize the raised ridges in the string bogs. The wetlands can be separated into two main groups, depending on their nutrient status. Bogs develop where an area becomes increasingly wet and sphagnum moss encroaches, leading to a raised bog surface. They tend to be nutrient poor, receiving nutrients only from precipitation. Where the infilling of lakes and ponds has occurred, nutrient-rich fens, dominated by sedges, develop and nutrients are washed into the depressions by runoff from the surrounding higher regions.

The major litter producers, which are also the major nutrient accumulators and recyclers in the system, are the woody perennials, the shrubs (dwarf birch, Labrador tea, willow and alder) and the tree species (black and white spruce and tamarack). Nutrient contents are highest in birch and Labrador tea leaves and lowest in black spruce needles and lichen litter (Moore, in press, a).

Litter is produced from annual leaf fall, occasional woody material and roots. Roots are found predominantly in the upper 10 cm of the soil profile although penetration to 30 cm is common for the perennials and shrubs. Of the three litter forms, annual leaf fall is probably the most important. The contribution from the shrubs and perennials is the greatest. Tamarack also produces an annual leaf fall and, although the other coniferous tees are thought to shed their needles only periodically, it appears that annual litter loss from spruce trees in the Schefferville region is most pronounced in winter (Werren, 1979). Most of the spruce needles collected in litter samples from a woodland and a feathermoss forest site were found to be brown needles, lost from the trees by normal needle shedding processes. However, fresh needles were more common in litter samples collected from a ridge area, where tree density was small and wind speeds high, suggesting that abrasion by wind is an important litter attrition process in open or exposed areas.

The lichens and mosses form an effective barrier which prohibits the litter from being directly incorporated into the soil organic layers. The lichens, having no normal rooting system, are not incorporated into the mineral soil and probably receive all their moisture and nutrient requirements from the atmosphere. The lower mat decomposes slowly, forming a slimy layer above the ground surface which has a very high water holding capacity. The mosses produce a thick layer of decomposing organic matter which is an important source of nutrients for the underlying mineral soil.

2.5 Snow Cover Characteristics in the Schefferville Region

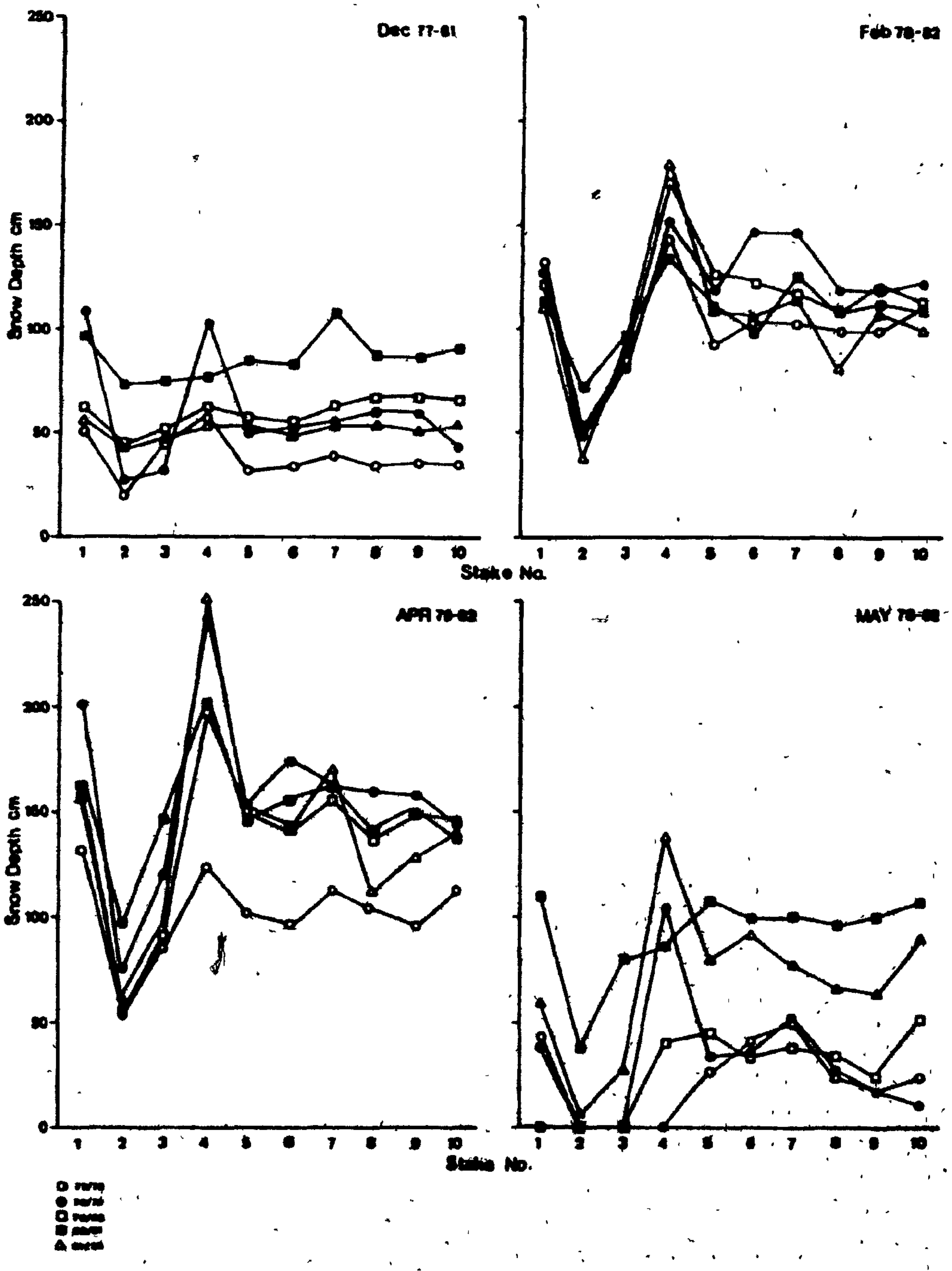
A number of studies have been made on snow depth distribution patterns in the Schefferville area (Adams and Roulet, 1982: Adams *et al*., 1966; Granberg, 1972, 1973, 1975, 1979, 1980; Nicholson and Granberg, 1973; Nicholson, 1975; Thom and Granberg, 1970). The combination of ridge and valley topography, numerous open, flat surfaces, such as frozen lakes and bogs, and the variations in density and height of the vegetation cover, ranging from essentially treeless ridges, bogs and recent burns to open and closed lichen woodlands and feathermoss forest, greatly influences the accumulation of snow in this area. In general, it has been established that the least amount of snow accumulates on the ridge crests. In some cases these areas remain snow free throughout the winter due to extreme exposure to wind. The snow is swept off the ridges and deposited in the valleys below where, at the base of slopes, snow depths of 1.5 m or more are commonly reported (Granberg, 1972, 1975; Nicholson and Granberg, 1973).

Distinctive landscape units, where different patterns of snow accumulation occur, are called roughness zones, referring to topographic roughness and vegetation roughness. In the former, topography influences wind speed (the distributing agent of snow cover) by causing wind speed to increase near convex surfaces. Hence, ridges tend to be areas of wind acceleration and snow removal, whereas valleys are areas of deceleration and snow deposition. On flat terrain, such features do not exist which cause variations in snow accumulation and snow distribution tends to be more regular. Vegetation roughness acts vertically by reaching into the airstream and dissipating wind energy near the ground surface. This is most pronounced in areas where tall, widely spaced trees are found. In the lichen woodlands around Schefferville, the trees increase wind speed locally and create wind scoops around the trunks. Small trees decrease the wind speed, creating small drifts in the downwind direction. With increasing forest density, such as in the closed woodlands and feathermoss forests, wind scoops and drifts become less pronounced. It is estimated that little or no erosion (removal and transport of snow at the snow surface) can take place in forests with a tree density of greater than 30 percent (Granberg, 1975). Since much of the low-lying vegetation becomes buried, its influence decreases through the winter. Snow accumulation in open areas leads to a progressive reduction in surface roughness caused by microtopography and brush vegetation which leads to an increase in the amount of snow drifting. Since individual particles are being affected, this leads to changes in snow density. This effect is seen on ridges and lake surfaces where snow depths are shallow and densities are high.

Major roughness zones in the Schefferville area, which incorporate both topography and vegetation cover types, include lakes, bogs (also fens, muskeg and sedge meadows), ridge crests, ridge slopes, open lichen woodland, closed lichen woodland, feathermoss forests and boundary zones. Boundary zones have their own distinctive character of snow accumulation. An example of a boundary zone effect occurs when wind, carrying snow, blows from a lake or other open area into a wooded area. As soon as the forest edge is reached, the wind speed decreases rapidly and snow deposition occurs. Boundary zones in Schefferville are approximately 100 m wide along a forest edge and have deeper snow depths than the wooded areas beyond (Granberg, 1975).

The Schefferville 10-point snow course, located just northeast of the Schefferville airstrip and oriented approximately perpendicular to it, transects several different vegetation cover types and the snow accumulation patterns along this transect reflect the differences, very consistently, throughout the winter and from year to year. The first two points on the snow course are located just beyond the clearing for the runway in open forest. Points 3 and 4 are located on a string bog, point 5 is located near the forest edge just beyond the bog and point 6 is farther into the forest. Points 7, 8 and 9 are located in an open woodland and point 10 is a short distance from the shore

Figure 2: Snow depths on four dates along the Schefferville 10-point snow course



of a small lake. The snow course has been used since 1961 to provide information on snow depths and water equivalents in the Schefferville region. Granberg (1975) describes some of the problems associated with the snow course as seen in relation to its use for estimating snow water equivalents of the snowpack in the Schefferville area and how this relates to hydrological investigations. The snow course appears to over-estimate the snowpack water equivalent by 30 percent as a result of snow depths along the transect being affected by drifting snow (Granberg, 1975). According to Granberg (1975), only points 7, 8 and 9 are relatively undisturbed by the effects of either snow removal or wind-blown snow deposition and are therefore the only points along the course which are representative of the actual snowfall accumulation.

Although perhaps misleading when estimating average snowpack water storage in the region, the data for the snow course are useful for illustrating the snow accumulation patterns which occur throughout the winter and also the consistent year to year variations seen along the transect. Figure 2 illustrates the snow depth patterns over five years from winter 1977/78 to 1981/82 on four sampling dates. The four sampling dates chosen are early winter (first week of December), mid-winter (late February), late winter (mid to late April), which also represents the peak snow year or the winter's snow accumulation, and mid-melt (late May).

In addition to the yearly variations in snow depths, several strong, recurrent patterns occur which remain prevalent throughout the winter but are most pronounced in the mid and late winter periods after the snow cover has become established. Of the five years displayed in Figure 2, winter 1977/78 clearly shows the least snow accumulation over the entire winter. In addition, unlike the following years, very little accumulation occurred between February and late April and a net loss in snow depth was measured at sampling points 4, 5, 6 and 7. It is dif-

Table 1: Selected mean snow depths at the Schefferville 10-point snow course during the winters 1977/78 to 1981/82

Snow Year	77/78	78/79	79/80	80/80	81/82
Date	08.12	08.12	12.12	08.12	08.12
Depth cm	43.4	59.2	59.0	85.3	50.2
Date	23.02	23.02	23.02	22.02	23.02
Depth cm	102.6	118.6	113.7	108.0	103.9
Date	23.04	10.04	14.04	16.04	26.04
Depth cm	101.7	158.8	138.1	150.0	143.4
Date	23.05	22.05	23.05	22.05	21.05
Depth cm	22.4	32.0	26.7	92.0	69.3

ficult, from the data presented, to determine in which of the five years the greatest overall snow depths occurred. Mean values, averaged for the snow course and presented in Table 1, suggest that, by mid and late winter, 1978/79 had the greatest snow accumulation of the five years. A difference of 57.1 cm between the mean, peak snow-year values of 1978 and 1979 was measured. Yearly differences in snow depths became most pronounced during the melt when the difference between the means increased to 69.7 cm and the greatest single difference in snow depths occurred at point 4 between 1978 and 1982, a difference of 92 cm.

Although year to year differences in snow accumulation exist, several patterns of accumulation are strikingly consistent from year to year. Sampling point 2 shows consistently shallower snow depths during all five years, on all four sampling dates. Snow depths increase at point 3 and reach a peak at point 4. This sampling point, which is near the bog edge and close to the forest, appears to be an area of snow accumulation, perhaps reflecting snow accumulation in a boundary zone. Point 2 is an area of snow removal. The differences in peak snow year accumulation between these two locations ranged from 69.9 cm in 1978 to 190.3 cm in 1982. In comparison to the preceding four points, two of which are in the open, the forest locations 5, 6, 7, 8 and 9 show reasonably consistent snow depths, particularly in early winter. Point 7 does appear to be a site of some snow accumulation which is quite noticeable in December of 1980 but which becomes apparent for most years by February and April. Site 7 may also be affected by snow accumulation in the boundary zone between the closed forest and woodland.

Although rates of melt affect the between year differences in depths measured in May, the basic patterns of snow accumulation do not change. Since snow depths are least at points 2 and 3, it is not surprising that the snowpack should disappear most rapidly at these two locations. However, closer examination of depth changes between April and May indicates that greatest losses during this period occurred at stake 4. Further examination of data not presented here (McGill Subarctic Research Station Snow Course Records) indicates that melt proceeded most rapidly in the less sheltered and open areas where points 1 to 4 are located and was most gradual in the sheltered forest and woodlands (points 5 to 9). Given the reproducibility of the patterns over the five year period presented, the snow course data certainly appear to suggest that:

i) the vegetation structure along the snow course affects the pattern of snow accumulation;

ii) a much greater variation in snow depth is seen in the open areas;

iii) the change from the open bog to closed forest results in a boundary zone accumulation of snow at point 4 and

iv) the sheltered wooded areas beyond are much less affected by large depth variations.

Individual yearly accumulation patterns do change over the winter. Granberg (1979) found that winter snow accumulation patterns adjust to the changing surface roughness characteristics within a given roughness zone and in the surrounding areas. In one study at the Timmins 4 permafrost experimental site, 20 km northwest from Schefferville, six different patterns of snow accumulation, corresponding to different topographic /vegetation units, were recognized (Granberg, 1979). The first pattern was associated with ridge crests and summits where snow depths reached a maximum early in the winter and remained constant or decreased through the rest of the season. The second pattern was found adjacent to ridge crests in narrow valleys and shallow concavities on otherwise exposed convex or flat surfaces where snow depths increased only slowly once low-lying vegetation became covered, providing a smooth surface vulnerable to wind action. The third distribution pattern occurred near valley bottoms and on slopes away from ridge crests. Here, initial snow depth increase was slow, followed by a rapid increase and then once again by slower increases. The fourth type occurred in wider valleys and hollows where, after a short, initial increase, the snow depth remained relatively constant for some time and then suddenly increased. The fifth pattern could not be specifically associated with a given terrain but rather appeared to be dependent on changes in snow conditions and roughness conditions in surrounding areas. The pattern was characterized by a constant or slowly increasing snow depth followed by a more rapidly increasing depth which was proportional to snowfall. The last pattern was one of regularly increasing depth which was proportional to snowfall throughout the accumulation period. This appeared to occur in areas lacking any major roughness characteristics.

One particularly important aspect of snow accumulation is the snow water equivalent or the amount of water held in storage in the snowpack. In one study, snow accumulation and water equivalents in six roughness zones in the Knob Lake basin were compared (Granberg, 1975). It was found that although snowpack density decreased and snowpack depth increased with increasing vegetation roughness, the average water equivalents appeared to be independent of roughness zones, when boundary zones where not included in the comparisons. Inclusion of boundary zones resulted in variability in water equivalent between zones. Snow depth decreased and density and water equivalent increased with decreasing vegetation roughness and increasing topographic roughness.

Granberg (1975) found that the average water equivalent in a closed woodland was more representative of the average for the basin than the other roughness zones sampled. Within the woodland, water equivalent was found to increase rapidly with distance away from trees. Snow depth around trees is generally less, due to buried branches which lead to cavities in the snowpack around tree bases. In the open woodland, where some drifting occurs, greater variability in depth, density and water equivalent was measured. Although the average depth was slightly less, water equivalent and density were found to be slightly greater than in the closed woodland. This is due to drifting and snow compaction. In a recent burn, where small trees lead to the formation of tail drifts which harden between storms and affect the accumulation pattern, the greater drifting leads to an increase in average density and water equivalent. In recent burns, topography is the main control of snow accumulation since the absence of trees allows high wind velocities near the surface to develop and the snow is redistributed. Redistribution produces a general smoothing such that deep accumulation occurs in valleys and little or no snow on the ridge crests. This leads to a large variation in densities and water equivalents in the area. The average density in these areas was found to be higher than in the other zones but water equivalent was less due to large areas of shallow snow depths. Bogs were not sampled in the above mentioned study but were described as having a flat terrain and therefore little or no variation in snow accumulation due to topography. If a bog is small, drift transport from the bog into the surrounding forests can cause a depletion in water equivalent. For larger bogs, this effect is insignificant. One important factor in bogs is that the wet surface causes partial melting of the snowpack at its base, if accumulation occurs before the bog surface freezes. The same effect occurs on lakes when water penetrates the ice cover through cracks. The lakes have the lowest roughness of all surfaces and thus allow the greatest amount of drift to occur. This in turn leads to the highest average densities. Snow depth tends to be less than half the snow depth in woodlands. Roughness boundaries, sampled between open and closed woodlands, showed greater depths and higher densities and water equivalents than the other sites sampled.

The density and depth of the snowpack, as well as the presence of ice layers, surface crusts and dust layers within the snowpack, are important factors which control the thermal properties of the snowpack and thus the effectiveness of the pack in insulating the ground surface below. As has been shown, the variety in snowpack depths and densities is large in Schefferville. Drifting and redistribution of the snow cover result in denser horizons in the snowpack. The different environments, where snow cover forms, allow for differential melting and refreezing, leading to the formation of ice layers and surface crusts which become incorporated into the snowpack.

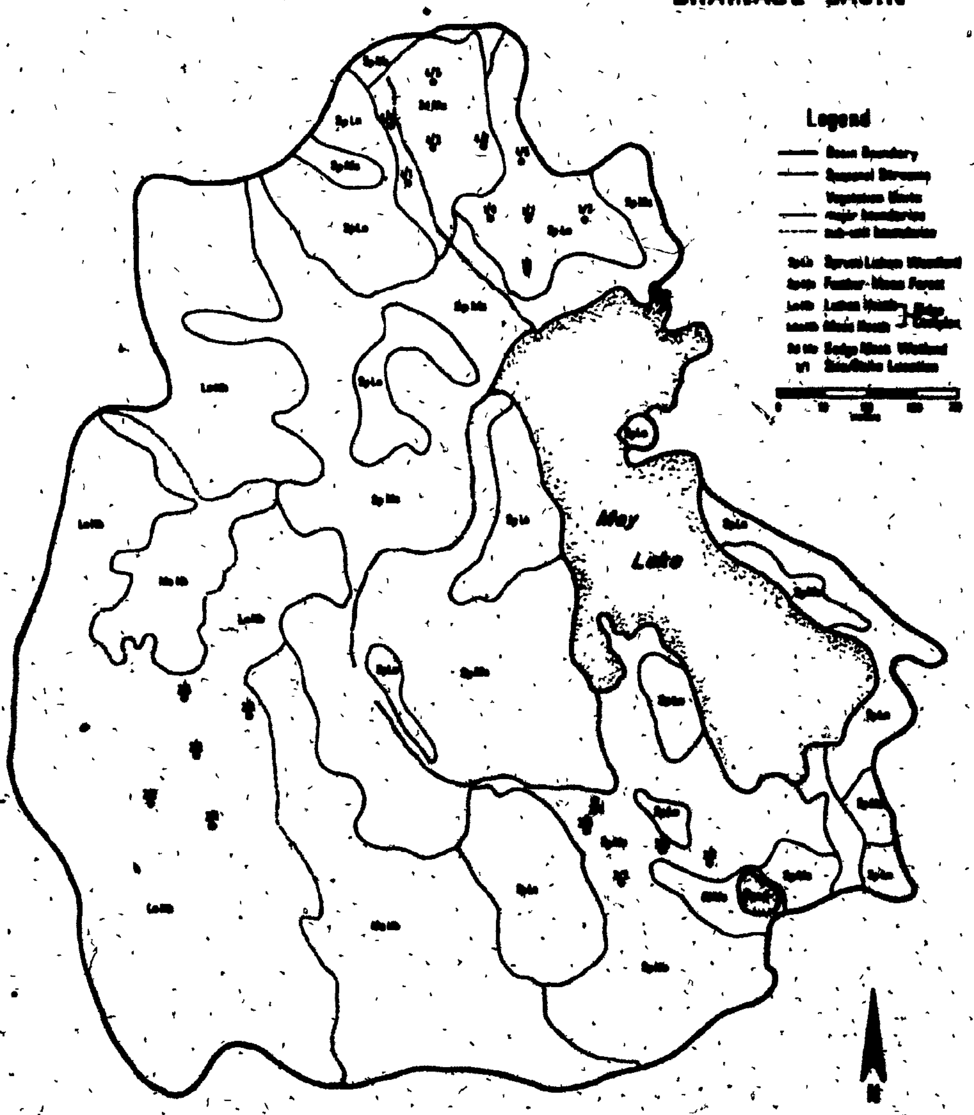
A general survey is not available on the variations in snow morphology and snow temperature changes as they relate to the various snow environments in the Schefferville area. However, it is known that, as is the case in many other snow covered areas, the ground at the base of the snowpack remains at or near 0°C as it is insulated by the snowpack above and warmed by heat conducted from the soil below. Measurements made at the base of snowpits from December to May over four years in a woodland near Schefferville showed that the snow/soil interface temperatures ranged from -3.0°C to 0.1°C with a mean value of -1.2°C. This very narrow base temperature range was maintained although air temperatures frequently are recorded below -30.0°C in the area.

There is very little information on snow chemistry in the Schefferville area. Some spring snowpack nutrient data is available from Moore (1980) which shows that the nutrient concentrations in snow samples, collected in a lichen woodland site, were very low, ranging from 0.10 mg/l for Mg to 0.97 mg/l for Na. English (per. comm.) is currently investigating the role of snow cover in the chemical budget of a drainage basin in the Schefferville region. Lewis (per. comm.) is investigating the occurrence of acid precipitation in the Schefferville area and has conducted some winter sampling. Drake and Moore (1981) found that snowpack chemistry around Schefferville appears to be affected by dust loading from the mines in the area. The effect was most pronounced to the southeast of the town where mining activity was greatest at the time. They also found that snowpack pH was lowered downwind of the town which they attributed to probable sulphate deposition from the burning of heating fuel.

This review of snow cover in the Schefferville region indicates that, although the spatial patterns of depth, density and water equivalent have been studied and their relationship to topography and vegetation cover is well established, the same has not been determined for snowpack structure, temperature regime and snowpack chemistry. These characteristics may also vary according to topography and vegetation and may be critical factors in determining the importance of the snowpack to the nutrient regime of the underlying soil body.

FIGURE 3

THE MAY LAKE DRAINAGE BASIN



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CHAPTER 3

Site Selection and Methodology

3.1 Site Selection

As indicated in Chapter 2, there are several important topographic/vegetation units in the Schefferville area. These have been identified as lichen-heath tundra, lichen woodlands, spruce-feathermoss forests and peatlands. Differences in the nutrient status of the soil between these units can be anticipated and also differences in the accumulation and composition of the snow cover. Thus it was decided to select a convenient area in which these representative units appeared for the study area.

3.1.1 Selection of the Study Area

Selection of an area for the study was dependent on three factors:

i) that the area possess representative members of the four major topographic/vegetation units in a relatively small area;
ii) that it be removed from possible sources of snowpack contamination by mine dust or from the town;
iii) that it be readily accessible because of the winter-time scope of this research.

Based on these criteria, the May Lake area, 4 km northwest of Schefferville, was selected for the study.

The May Lake catchment encompasses a 0.65 km^2 area, the long axis of which is oriented in a NW-SE direction following the major topographic axis in the Schefferville region (Figure 3). It is bordered on the southwest by a major ridge complex and mining region; immediately to the northeast is a low-lying, poorly-drained area. Three small, intermittent streams, draining the catchment, flow into May Lake from the southwest and northwest. The east and southeast border of the basin is defined by a minor ridge. The difference in elevation between the crest of this ridge and the lake is 52 m.

Although a small area, the May Lake catchment contains a variety of vegetation communities which commonly occur in the Schefferville area and which reflect the topographic variation in the region. The ridge is covered primarily by a lichen-heath tundra community which grades into moss-heath-shrub towards the western and southern edges, where the slope increases and ground hollows occur. This tundra complex covers 0.28 km^2 or 43.1 percent of the total basin area. This can be subdivided into 29.2 percent lichen-heath and 13.9 percent moss-heath-shrub. The lichen mat (Cladonia) is thin and intermittent. Where a moss ground cover occurs, it is continuous, but also thin. Trees are almost entirely absent except for a few scattered, stunted black spruce (Picea mariana). The woody perennials, blueberries (Vaccinium uliginosum, V. vitis-idaea) and Kalmia polifolia are the most commonly occurring shrubs followed by dwarf birch (Betula glandulosa) and Labrador tea (Ledum groenlandicum). The bare ground surface is very stony and cobbles are scattered widely about. In particularly exposed areas, the surface is disrupted by frost scars. Some evidence of fire was found in this area and although the date of the fire is not known, the sparsity of the charred wood suggests that it was some time ago. It is possible, then, that this ridge complex was at one time an open lichen woodland, but because of its very exposed position on this minor ridge, the woodland has not been able to regenerate and the area became populated by the current lichen-heath community.

The sheltered uplands and well-drained lowlands in the catchment are occupied by lichen woodland. In total, the woodlands cover 16.9 percent (0.11 km^2) of the drainage basin area, with open woodlands (up to 500 stems/ha) in the more exposed, upper reaches (7.7 percent of the total area) and closed woodlands (greater than 500 stems/ha) in the low-lying regions (9.2 percent). The woodlands in the May Lake catchment are typical of what is found throughout the region. The continuous lichen mat (Cladonia) is 5 to 10 cm thick and interspersed with various ericaceous shrubs. Mosses are common around the base of the trees. The most common tree species in the this area is black spruce (Picea mariana), but white spruce (P. glauca) is scattered throughout. The understory is dominated by dwarf birch (Betula glandulosa) and Labrador tea (Ledum groenlandicum).

The lower slopes, valleys and areas along-side stream channels, where the soil is moderately to poorly drained, are occupied by feathermoss forest. The forests cover 35.4 percent (0.23 km^2) of the catchment area. Here, the ground is covered by a thick (10 to 20 cm), continuous mat of various mosses (Pleurozium schreberi, Polytrichum juniperinum) interspersed with some herbs. The dominant tree species is black spruce (Picea mariana) which forms a closed canopy. White spruce (P. glauca) is found throughout. The understory is once again dominated by dwarf birch (Betula glandulosa) and Labrador tea (Ledum groenlandicum).

A small sedge-moss fen (0.03 km^2) is located at the extreme northwest end of the catchment. A similar community, but even smaller, surrounds a small pond at the southeast end. The latter is dominated by sedges (Carex spp.) and ringed by feathermoss forest. Together, these two, small wetlands comprise 4.6 percent of the total basin area. The surface cover in the sedge-moss fen is composed of both sphagnum moss and sedges (Carex spp.). Tamarack (Larix laricina) is scattered throughout as are a few stunted black spruce. The edge of the fen and small hummocks are occupied by dwarf birch (Betula glandulosa) and Labrador tea (Ledum groenlandicum). This fen occupies a very poorly-drained depression where small patches of open water frequently occur. This depression is bordered by lichen woodland.

3.1.2 Selection of the Study Sites

The vegetation cover of the basin was mapped using black and white aerial photography (1:12,000) aided by field reconnaissance. Based on airphoto interpretation and further field reconnaissance, four study sites were selected which were considered to be representative of the cover types found within the basin and the surrounding area and which incorporated minimized contamination from nearby roads, site accessibility and size. The site locations are shown in Figure 3. Site 1 was located in a closed lichen woodland at the north end of the basin. Site 2 was located to the east of the upper edge of the basin in the lichen-heath community and bordered on the moss-heath-shrub area. Site 3 was located in a feathermoss forest at the south end of the basin and bordered on a transition zone between feathermoss forest and lichen woodland. Site 4 was located the sedge-moss fen at the northwest end of the basin. Since the fen is 3 ha, it was decided to use this as a guide, to the minimum size a vegetation association should be in order to be considered for a study site.

3.2 Project Structure

The nutrient status of the organic horizons in late fall, just prior to the development of a continuous snow cover, was chosen as the base nutrient level of these horizons, since this marks the end of the growing season and uptake of nutrients by the plants. Only changes between the nutrient status of the organic horizons were measured since this is the material from which nutrients become available and which forms part of the snow/vegetation/soil interface.

Rather then measuring the bulk concentrations of the snowpack chemical parameters, the distribution of the nutrients, particulate matter and pH through the snowpack were measured in 10 cm sampling sections. This was done during three sampling periods so that changes in the distributions could be monitored and to determine whether or not the nutrients accumulated as the snowpack developed or whether they became redistributed or depleted from the snowpack. The bulk snowpack pH, nutrient and particulate matter concentrations are represented by the means of the concentrations measured in the samples removed from the snow profiles.

The snow morphology was measured during sample collection since changes in snow morphology indicate an active, rather than static, body and those changes can influence the nutrient regime of the snowpack and the environment of the snow/vegetation/soil interface. Snowpack temperature profiles were measured to determine the insulating effect of the snow cover and the temperature of the environment at the base of the snowpack.

Measurement of over-winter mass losses in plant tissues was used as a direct indicator of whether or not decomposition was occurring beneath the snowpack.

3.3 Field Methods

3.3.1 Errors and Sources of Errors

There are a number of errors associated with measuring the physical parameters of the snowpack. Most prominent of these are density, water equivalent and temperature measurements. Snowpack horizon densities were measured using snow core volume and weight measurements. Snow cores were removed using either a 250 cm^3 or 500 cm^3 metal snow core sampler. A total bulk snow sample volume of 1000 cm^3 was collected and the core samples were weighed in the field using a top-loading balance. The measurement error of the balance is ±1.0 g and the estimated volume error of the core samplers is as great as ±10.0 cm^3. Therefore, the estimated error of the density measurement ranges from ±1 to ±2 percent for the 500 cm^3 and the 250 cm^3 samplers, respectively.

The water equivalent for each horizon was calculated from the horizon depth and horizon density. Based on a depth measurement error of ±0.5 cm, the estimated error of the water equivalent ranges from ±3 to ±4 percent. The water equivalents for ice layers were calculated using a density of 0.9 g/cm^3. The bulk snowpack water equivalent is the sum of the snow horizon and ice layer water equivalents. The numerous ice layers in the snowpack and slushing at the snowpack base were consistent problems while trying to remove complete snow core samples for bulk snowpack density measurements. This method was eventually abandoned and the snowpack density values presented in section 4.2.2 have been estimated from the snowpack depth at that location and the total water equivalent.

Snow profile temperatures were measured using precalibrated, snowpack thermometers. The thermometer calibrations were checked repeatedly throughout the sampling sessions and were found to have remained consistent. The thermometers were calibrated against standard laboratory mercury thermometers in an anti-freeze solution. Measurements were calibrated at 10°C intervals from - 20°C to +10°C. The reading accuracy of the snowpack thermometers is ±0.2°C, although the actual accuracy of the instrument itself is probably between ±0.5°C and ±1.0°C.

Apart from the problems of instrument accuracy, the most obvious source of error associated with this method is the heat flow away from the exposed profile face. Therefore, the measured profile temperatures (although approximately 15 cm inside the snowpack, away from the profile face) can not be truly indicative of the undisturbed profile, but rather only approximate it. The temperatures also can not be read immediately, since the thermometer responds slowly and takes several minutes to reach a constant measurement. Therefore, due to the errors inherent in this method, snow profile temperatures measured in this manner may be used for illustrative purposes only and any conclusions based on these values are strictly tentative.

3.3.2 Sampling Procedure

The following sequence of sampling was conducted at each site:

<u>September 1980</u>:

1) Three 1x1 m soil profiles were excavated and the soils were classified according to morphological charactersitics. Profile locations were selected to include within-site surface vegetation and/or micro-topographic diversity.
2) Soil samples from each horizon were collected into plastic sampling bags for later analysis.
3) Five locations, three near to the previously excavated soil profiles and two additional ones, transecting the sites in a 'X' pattern, were selected and marked with wooden stakes of known height which would later be used for snow depth measurements. The stakes, which were numbered one to five, also marked the location of the future snow sampling locations. These locations were numbered according to the site number, followed by the stake number. Sampling locations are shown in Figure 3.
4) 2x2 m plastic sheets (0.1 mm thick) were laid over the ground surface and secured at each of the five stake locations. A numbered stake marked the corner of each sheet and the orientation of the sheet, relative to the stake, was noted. The purpose of the plastic sheets was to form a barrier between the ground/vegetation surface and the overlying snowpack, thereby removing the contact between the ground surface and the base of the snowpack.
5) Ten LFH/Ah soil samples, two from each of the five sampling locations (to a maxium depth of 10 cm), were collected for later laboratory analysis.
6) Fresh tissue samples were collected from the dominant tree and shrub species at each site. In the laboratory, the bulk tissue samples were oven dried at 65^{o}C for 24 hours and weighed out in approximately 5 g portions (exact weight was recorded) into numbered, nylon gauze litter bags with a 1mm mesh (0.5 mm

for tamarack samples). Twenty bagged samples of each species were returned to the sites from which they were collected and redistributed three m away from and around each of the plastic sheets, with four samples of each species at each stake location.

December 1980:

1) Snow depth was measured at the five stake locations at each site, on the same day.
2) Three 1x1 m snow profiles were excavated at the three stake locations near to where the soil profiles had previously been dug. Care was taken not to excavate over the plastic sheets.
3) Snow profile depth was recorded and snow profile temperatures were measured at 10 cm intervals from the snowpack base, using previously calibrated snowpack thermometers. Snow stratigraphy was recorded and snow grain size and the snow densites of each major horizon were measured.
4) Snow samples for laboratory analysis were collected in 10 cm segments down the profile, from the opposite profile face, directly into plastic sampling bags, using a plastic scoop. The snow samples were passed through a clean, large-mesh (2 mm) plastic sieve, held over the mouth of the bag, to remove any large pieces of litter which could contaminate the sample upon melting. The litter was retained and returned to the lab to be weighed and calculated with the particulate matter removed from the sample through filtering.
5) The snow samples were returned to the laboratory and stored outside in snowbanks until they could be melted, analysed for pH and filtered into clean, plastic sample bottles.

February 1981:

1) Snow depth measurements, snow profile temperatures, stratigraphy, grain size, densities and snow sample collection proceeded the same as in December, 1980.
2) Five fresh snow samples were collected from the snow surface the morning following a minor snowfall. Samples were collected directly into plastic bags using a plastic scoop.

April/May 1981:

1) Snow depth measurements were recorded on three dates during this sampling period; one previous to the onset of melt and two during the melt period.

2) Snow profiles were excavated and sampled according to the December and February sampling prodedures. However, during this sampling period, two profiles at the three snow profile stake locations were excavated: the control profiles, with a normal snow/soil interface, and the experimental profiles, excavated above one half of the plastic sheets. Although snow samples were collected from both profiles, snow stratigraphy, temperatures, grain size and density were recorded for the control profiles only.

3) Following the onset of melt, a second set of profiles were excavated, two profiles at each of the five stake locations: one with a normal snow/soil interface and one above the plastic sheet. Only snow samples from the bottom 10 cm of these profiles were collected. Snow stratigraphy, temperatures, density and grain size were not measured.

June 1981:

1) Following the melt, 20 LFH/Ah samples (to a depth of 10 cm) were collected; two from beneath each of the five plastic sheets and two adjacent to each of the sheets. The litter bags were retrieved at the same time.

3.4 Laboratory Methods

A summary of the analytical methods is presented in Table 2 and includes the analyses performed, the methods and equipment used, detection limits and equipment precision and references. The estimated precision/reproducibility of the results is ±10 percent.

The soil and organic matter samples were air dried immediately upon return to the laboratory. The mineral soil was

Table 2: Summary of analytical methods

	Analysis	Method	Equipment	Accuracy and/or Detection Limit	
Soil	pH	soil:water 1:1 determination by glass electrode	Fisher Accumet pH Meter Model 210	Acc. 0.01	Peech, 1965
	Exchangeable H	extraction with 1N NH_4OAC (pH 7.0) determination of change in pH of extract solution	Fisher Accumet pH Model Model 210	Acc. 0.01	Chapman, 1965a
	Exchangeable Bases Ca, Mg K and Na	extraction with 1N NH_4AOC (pH 7.0) determination by Atomic absorption spectrophotometry	Perkin-Elmer 403 Atomic Absorption Spectrophotometer	Detec. Limit Ca 0.05 ppm Mg 0.001ppm K 0.001ppm Na 0.01 ppm	Chapman, 1965b; Perkin-Elmer, 1976
	Cation Exchange Capacity	exchangeable H - exchangeable bases			Chapman, 1965b
	% Base Saturation	$\frac{\text{bases}}{\text{CEC}}$ x100			
	Available Phosphorus	extraction with 0.05N NH_4F and 0.1N HCl determination with molybdate-ascorbic acid	Bausch and Lomb Spectronic 70	Acc. 0.10 ug/l	Olsen and Dean, 1965
	Field Moisture Content	moisture as a percent weight of air dried soil	Mettler P1000 Balance	Acc. 1.0 mg	
Plant Tissue	Mass Loss over winter	weight difference as a percent of the fall dry weight	Mettler H10 Balance	Acc. 0.1 mg	
Snow	pH	direct determination of snow meltwater by glass electrode		Acc. 0.05	
	Base Cations Ca, Mg, K and Na	direct determination from snow meltwater by atomic absorption spectrophotometry	Perkin-Elmer 403 Atomic Absorption Spectrophotometer	Detec. Limit Ca 0.05 ppm Mg 0.001ppm K 0.001ppm Na 0.01 ppm	Perkin-Elmer, 1976
	Total Dissolved Phosphorus	Potassium persulfate digestion of filtered sample determination with ammonium molybdate ascorbic acid colorimetry	Bausch and Lomb Spectronic 100	Detec. Limit 0.03 ug/l Acc. 0.10 ug/l	Strickland and Parsons, 1968
	Particulate Matter	weight determination of particulate matter residue after filtering (assuming constant weight of filter paper)	Mettler P1000 Balance	Acc. 1.0 mg	

passed through a standard 2 mm sieve prior to chemical analysis. All further analyses were performed on the 2 mm soil fraction. The LFH/Ah and organic soil material was ground to a finer particle size prior to chemical analysis.

The snow pH measurements were performed on unfiltered, melted snow samples. A portion of the sample was removed from each sample prior to melting and placed in a glass beaker. The pH of the melting sample was monitored as the melt progressed and recorded at 0.2°C, while the sample was slush, 2.0°C, 4.0°C and then periodically until a constant pH measurement was reached. The stable pH value indicated that the melt water was in equilibrium with atmospheric CO_2 at room temperature.

The remaining snow sample melted in the resealed sample bag and, immediately following melt, was filtered through a preweighed, Whatman no. 42 filter and collected into clean, 250 ml plastic bottles. The filter papers were oven-dried at 65°C for 24 hours and reweighed. The weight difference represented the particulate matter removed from the melted sample. This amount was added to the weight of the litter previously collected from the snow sample in the field and the combined weight was adjusted to mg/l of sample. The filtered samples were refrigerated until the following analyses could be performed: Ca, Mg, K, Na and TDP. Total dissolved phosphorus content was analysed at the Schefferville station shortly after the sample had been melted. Cation analyses were performed at McGill University in Montreal.

Because of the very low nutrient concentrations anticipated, periodic checks were made for possible sample contamination from the sampling bags and sample bottles. Several sampling bags were filled with distilled, deionized water at the same time that samples were being melted and several hours later the water was transferred to sample bottles and analysed in the same manner as the snow samples. Sample bottles were also directly filled with distilled, deionized water, refrigerated and shipped with the snow samples to Montreal. Subsequent analysis indicated that both the sample bags and bottles were clean and not a source of sample contamination.

CHAPTER 4

Results

4.1 Data Presentation and Statistical Analyses

Snow and soil profile data have been presented graphically. Snow stratigraphy, temperature profiles, depths, densities and water equivalents are presented in Figures 5a to 51; the vertical distribution of the chemical parameters in the snowpack in Figures 6a to 6p. Soil profile morphology and chemical data are presented in Figures 8a to 8d.

For most purposes descriptive statistics (mean concentrations and standard deviations) are used for the snow and soil chemical data. Complete data sets for snow chemistry are found in Appendix 1 and for soil chemistry and morphology in Appendix 2. Statistical tests used include the Student's t-test, analysis of variance (Gregory, 1978 and Hammond and McCullagh, 1978) and correlation analysis (SAS Institute, 1979). The results of some of the tests are presented in this chapter; extensive results are found in Appendix 3.

Correlation analysis was used to test for relationships between the various chemical parameters measured in the snowpacks (Table 1, Appendix 1). Patterns and comparisons of intra- and inter-site variations in snowpack chemistry are based on the unweighted means and standard deviations of the chemical parameters, for which the sample size, n, is the number of 10 cm depth samples in each profile (Table 7). The Student's t-test has been applied to determine the significance of the differences between pairs of means for each chemical parameter. Differences are considered to be significant at $\alpha=0.05$.

Intra-site comparisons, between profiles sampled during the same sampling period, attempt to identify significant differences in snowpack chemistry within the same site (Table 2, Appendix 3). Inter-site comparisons identify significant differences in snowpack chemistry between the four sites during the same sampling period (Table 3, Appendix 3). Intra-site comparisons between profiles sampled in early-, mid- and late-winter identify temporal changes in snowpack chemistry within the same site (Table 4, Appendix 3). The two-tailed test significance levels have been used in the intra-site comparison of spatial variations. The one-tailed test significance levels have been used in the intra-site temporal and inter-site spatial comparisons since it is of interest to know whether or not one sample mean is significantly greater than the other. For the intra-site comparisons, this indicates a significant increase (or decrease) in mean concentrations over time. In the inter-site comparisons, this indicates at which site the mean values are significantly higher.

The influence of contact with the ground surface on the snowpack chemistry has been evaluated by comparing the snow chemistry of the control and experimental snowpacks and the chemistry of base snow samples removed from control and experimental profiles in mid-May. Comparisons, using the Student's t-test, include the effect of the soil interface within each site and between-site comparisons of the experimental and control samples.

As with the snow chemistry data, the Student's t-test has been used to compare inter-site spatial and intra-site temporal differences in soil organic horizon chemistry (Table 8, Appendix 3 and Table 19). It has also been used to assess differences in over-winter tissue mass losses, both between different species and between sites (Tables 21 and 22). Differences are considered to be significant at the $\alpha=0.05$ level.

4.2 Snow Cover in the May Lake Catchment

4.2.1 Snow Cover Accumulation

The variation in snow cover accumulation between the four

Table 3: Snow depths recorded in the May Lake catchment Winter 80/81

Date	Site	Stake Locations Snow Depths m 1	2	3	4	5	Mean m	S.D. m
10.12.80	1	0.80	0.79	0.83	0.80	0.73	0.79	0.04
21.02.81		1.20	1.07	1.17	1.16	0.99	1.12	0.09
26.04.81		1.57	1.51	1.48	1.46	1.19	1.44	0.15
19.05.81		1.01	1.08	0.85	0.80	0.77	0.90	0.14
24.05.81		0.86	0.94	0.76	0.64	0.73	0.79	0.12
10.12.80	2	0.42	0.58	0.44	0.69	0.56	0.54	0.11
21.02.81		0.52	0.31	0.23	0.72	0.34	0.42	0.20
26.04.81		0.79	0.77	0.74	1.18	0.81	0.86	0.18
16.05.81		0.38	0.40	0.38	1.07	0.72	0.59	0.31
22.05.81		0.35	0.32	0.25	0.68	0.33	0.39	0.17
10.12.80	3	0.65	1.11	0.46	0.90	0.39	0.70	0.30
21.02.81		0.89	1.29	0.83	0.87	1.13	1.00	0.20
26.04.81		1.26	1.64	1.15	1.26	1.45	1.35	0.19
19.05.81		0.88	0.95	0.90	1.18	1.07	1.00	0.13
24.05.81		0.63	0.75	0.80	1.15	0.93	0.85	0.20
10.12.80	4	0.89	0.80	0.88	0.91	0.87	0.87	0.04
21.02.81		1.11	0.94	1.01	1.15	1.09	1.06	0.08
26.04.81		1.41	1.33	1.48	1.52	1.53	1.45	0.08
19.05.81		0.72	0.69	0.78	0.92	0.91	0.80	0.11
24.05.81		0.64	0.61	0.64	0.77	0.66	0.66	0.06

Table 4: A statistical comparison (t-test) of the mean snow depths at the four study sites

Date	1 vs 2 t	1 vs 3 t	1 vs 4 t	2 vs 3 t	2 vs 4 t	3 vs 4 t
10.12.80	4.78:	0.66	3.16:	1.12	6.30!	1.26
21.02.81	7.14!	1.22	1.11	4.59:	6.82!	0.62
26.04.81	5.54!	0.83	0.13	4.19:	6.70!	1.08
19.05.81	2.04	1.17	1.26	2.73:	1.43	2.63:
24.08.81	4.30:	0.58	2.17·	3.92:	3.35:	2.03

level of significance
· 95 percent
: 99 percent
! 99.9 percent
based on the one-tailed test

df=8

Table 5: Study sites ranked according to snow depth

Date	Decreasing Snow Depth	Greatest Variation	Least Variation
10.12.80	4 > 1 > 3 > 2	site 3	sites 4, 1
21.02.81	1 > 4 > 3 > 2	3, 2	4
26.04.81	4 = 1 > 3 > 2	2	4
19.05.81	3 > 1 > 4 > 2	3	4
24.05.81	3 > 1 > 4 > 2	3	4

study sites can be seen in the varying snow depths measured at these sites over the winter. The snow depths, measured on five dates between early December, 1980 and the end of May, 1981, are presented in Table 3 and are compared statistically using the Student's t-test (Table 4). In Table 5, the study sites have been ranked according to snow depth. The sites showing the greatest and least depth variations have been identified for each measurement period.

At no time during the winter were the differences in snow depth between the woodland (site 1) and the forest (site 3) statistically significant (Table 4). Differences between the lichen-heath tundra (site 2) and the forest were significant from February until the last sampling date in May. Significant differences between the forest site and the fen (site 4) developed only after the onset of melt. Differences between sites 1 and 2 and sites 2 and 4 were significant up until melt began and once more during the latter phase of the melt. Differences between sites 1 and 4 were significant at the beginning of winter and at the end of melt.

Snow depths were shallowest at site 2 throughout the winter (Tables 3 and 5). Site 3 showed the greatest range of snow depths and, prior to snow melt, the deepest snow depths were measured at stake 2 (located near the base of a slope) at this site. In early winter, snow depths were deepest at site 4, followed by site 1. In February, the mean snow depth at site 1 was greater than at site 4 and in late April, the mean depths at these two sites were the same. Following the onset of melt, snow depths were deepest at site 3. Site 4 had the most even snow depth distribution throughout the winter. Snow depths were as consistent at site 1 during the first half of the winter, but by late winter and early melt, the variations became more pronounced.

The snowpack disappeared earliest from site 2, on or

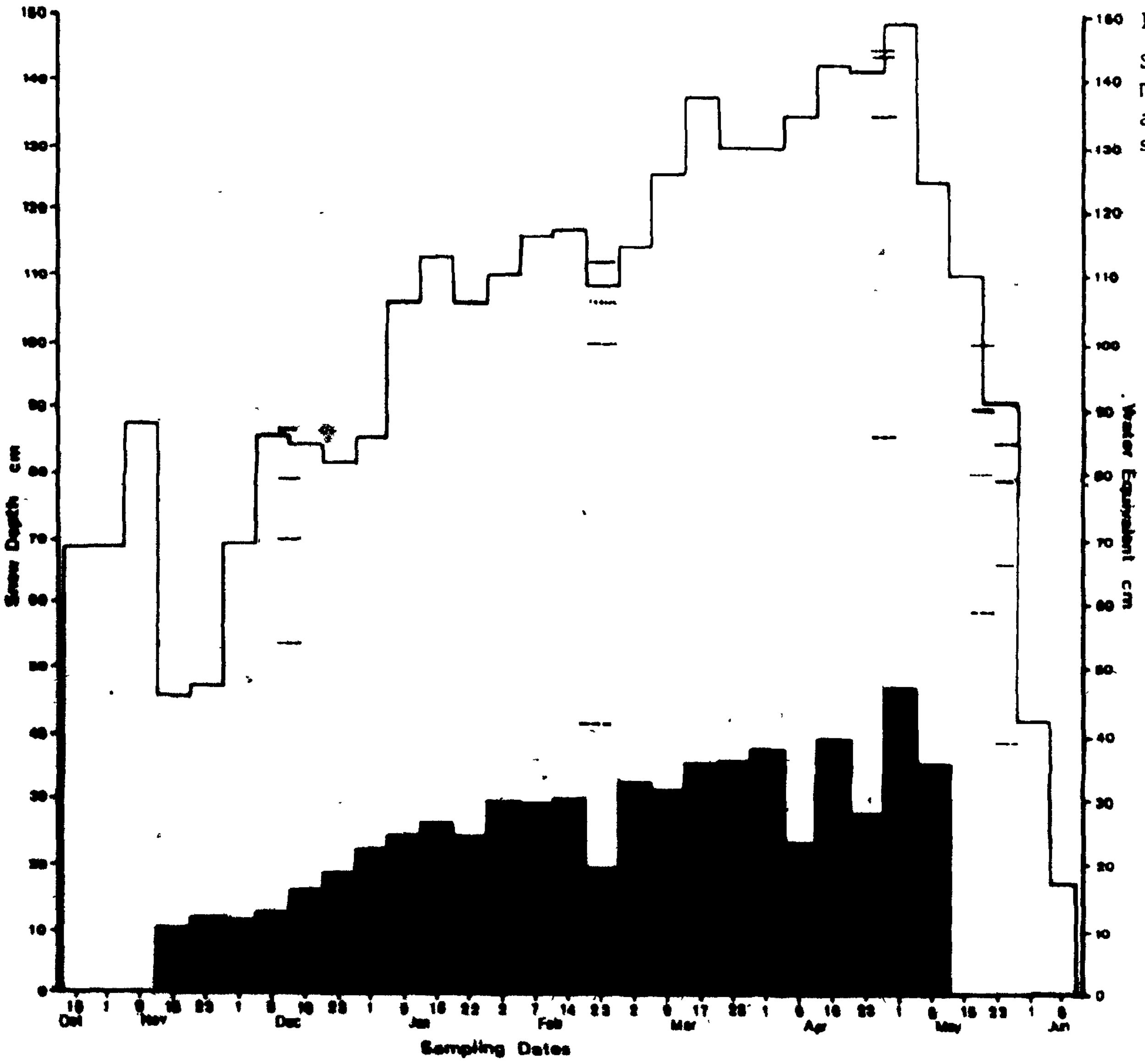


Figure 4

Snow depths and water equivalents measured during the winter 80/81 at the Schefferville 10-point snow course

——— site 1

- - - - site 2

-·-·- site 3

········ site 4

Average depths measured at the four sampling locations in the May Lake catchment during Winter 80/81 on the following dates: 10.12.80, 21.02.81, 26.04.81, 19.05.81, 24.05.81

☐ snow depth

■ water equivalent

about 28.05.81, followed by site 4 on 02/03.06.81. The wooded sites remained snow covered much longer; site 1 was, for the most part, snow free on 09/10.06, while some snow patches were still intact in the forest site, site 3, as late as 21.06.

The vegetation cover and snow accumulation patterns at the four study sites can be related to the roughness zones and snow accumulation patterns described by Granberg (1979) and discussed in section 2.6. Site 1 can be classified as a closed woodland roughness zone, where vegetation characteristics are the major surface roughness control. Snow accumulates consistently throughout the winter and variations in snow depth occur mainly around the base of trees. Site 2 is a ridge crest roughness zone, where snow removal and redistribution are more active than accumulation and where hollows and minor slopes, away from the ridge crest, act as areas of accumulation. Topography is the main surface roughness factor here, although shrub vegetation, where present, is also important in the early winter. Site 3 is a valley bottom roughness zone, where snow depth accumulation shows considerable variation. Here, topography and vegetation control surface roughness characteristics to a considerable extent. Site 4 is an open depression and, although ringed by woodland and forest, does not, itself, have any major surface roughness factors. Snow accumulation is even and shows very little variation.

In Figure 4, snow accumulation at the four study sites in the May Lake catchment has been compared with the Schefferville 10 point snow course (described in section 2.6) to see how closely the May Lake catchment reflects the snow accumulation which is often considered as representative of the standard for this environment. Site 1, followed by site 4, shows the closest agreement, on comparable dates, to the mean snow accumulation along the snow course. Site 3, and particularly site 2, have consistently lower mean snow depths for the same sampling dates. According to the graph (Figure 4), the peak, mean snow depths and water equivalents were measured on 01.05.81. Melt began sometime between 01.05 and 08.08.81. The snow depths, measured in the May Lake catchment on 26.04. 81, may therefore be considered as representative of the accumulation of the snow season since no major snowfalls occurred between 26.04 and 08.05.81.

The snowpack appears to have melted more quickly in the May Lake basin than at the snow course, although this is not an accurate comparison since the last sampling date, 24.05.81, is compared with snow depths two days earlier at the snow course (22.05.81). On the last sampling date, 08.06.81, the mean snow depth at the snow course was 17.0 cm. The complete data set (not presented here) for the snow course indicates that by 01. 06., the snow had disappeared from the string bog, one day earlier than in the fen, site 4 (McGill Subarctic Research Station Snow Course Records). At all three stake locations (7, 8 and 9), in the woodland, 13 cm of snow were recorded on 08.06; the woodland site was practically snow free on 09.06. Points 5 and 6, which may be compared to the feathermoss forest, site 3, registered snow depths of 31.4 and 33.6 cm, respectively. Although snow depth measurements are not available, the snowpack was still continuous in the forest on this date.

4.2.2 Snow Stratigraphy and Temperature

Stratigraphic and temperature profiles, densities and water equivalents for the snowpacks at the four study sites, excavated during the three major sampling seasons, are presented in Figures 5a to 5l. Snowpack densities and water equivalents increased at all sites between December and April/May. There is a certain amount of within-site variation in densities and water equivalents and the variation increases as the winter progresses. In December, snowpack densities for the profiles at site 1 (Fig. 5a) ranged from 0.22 to 0.25 g/cm^3 and water equivalents from 19.2 to 19.8 cm. In late April, this had increased to 0.34 to 0.44 g/cm^3 for density and 52.5 to 54.8 cm for water

Figures 5a to 5l
Snowpack structure and temperature profiles

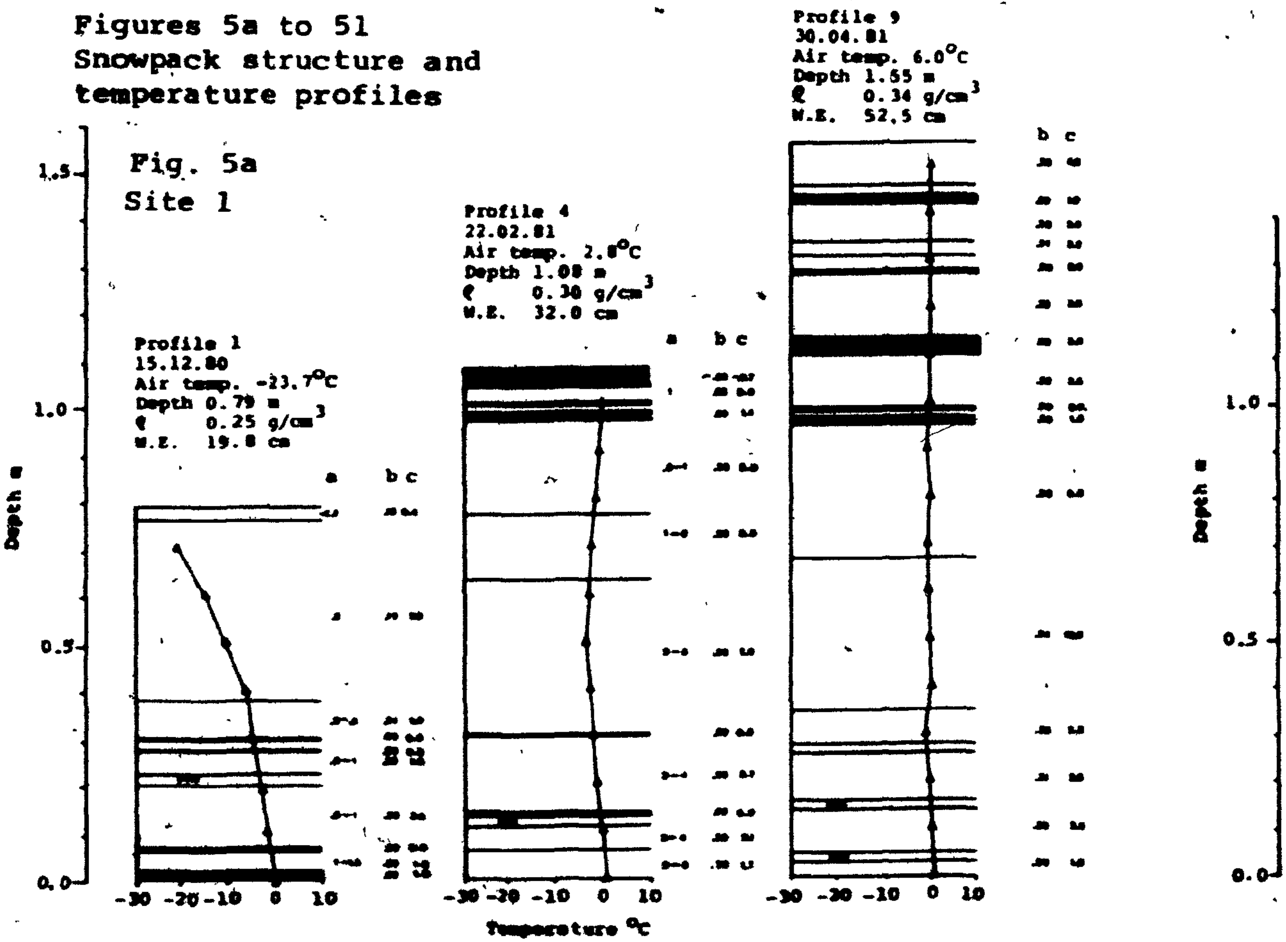


Fig. 5a
Site 1

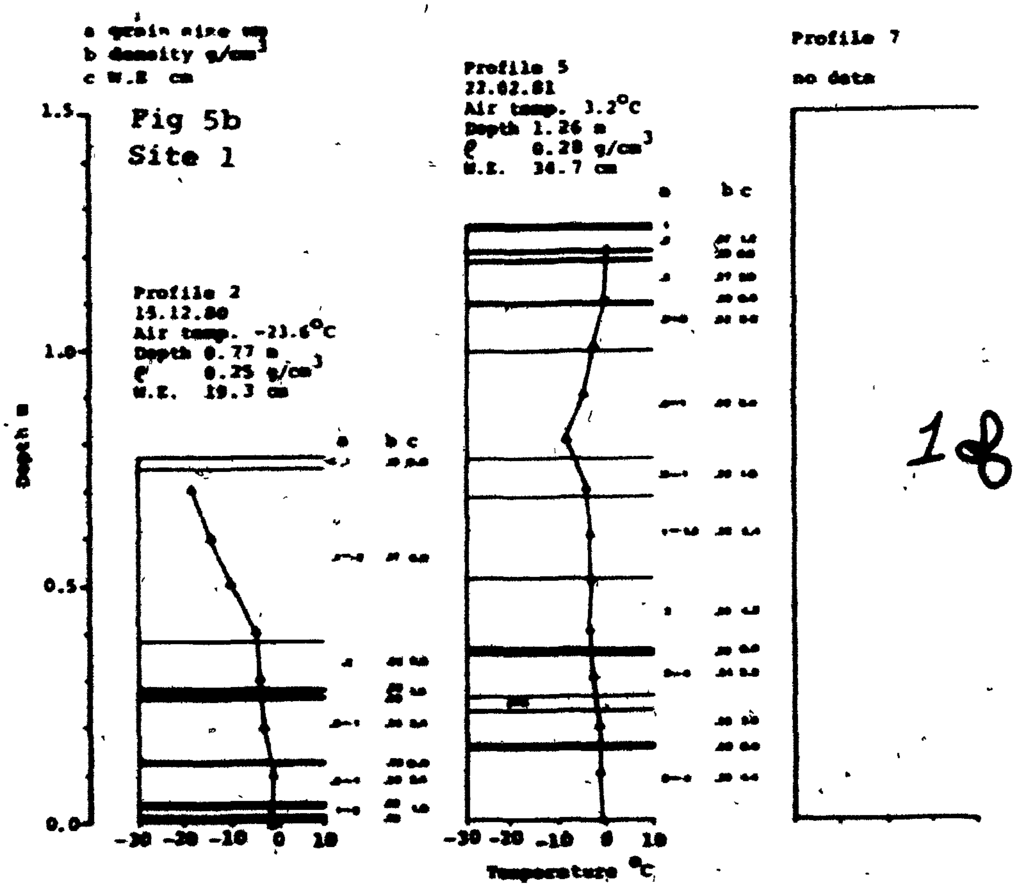
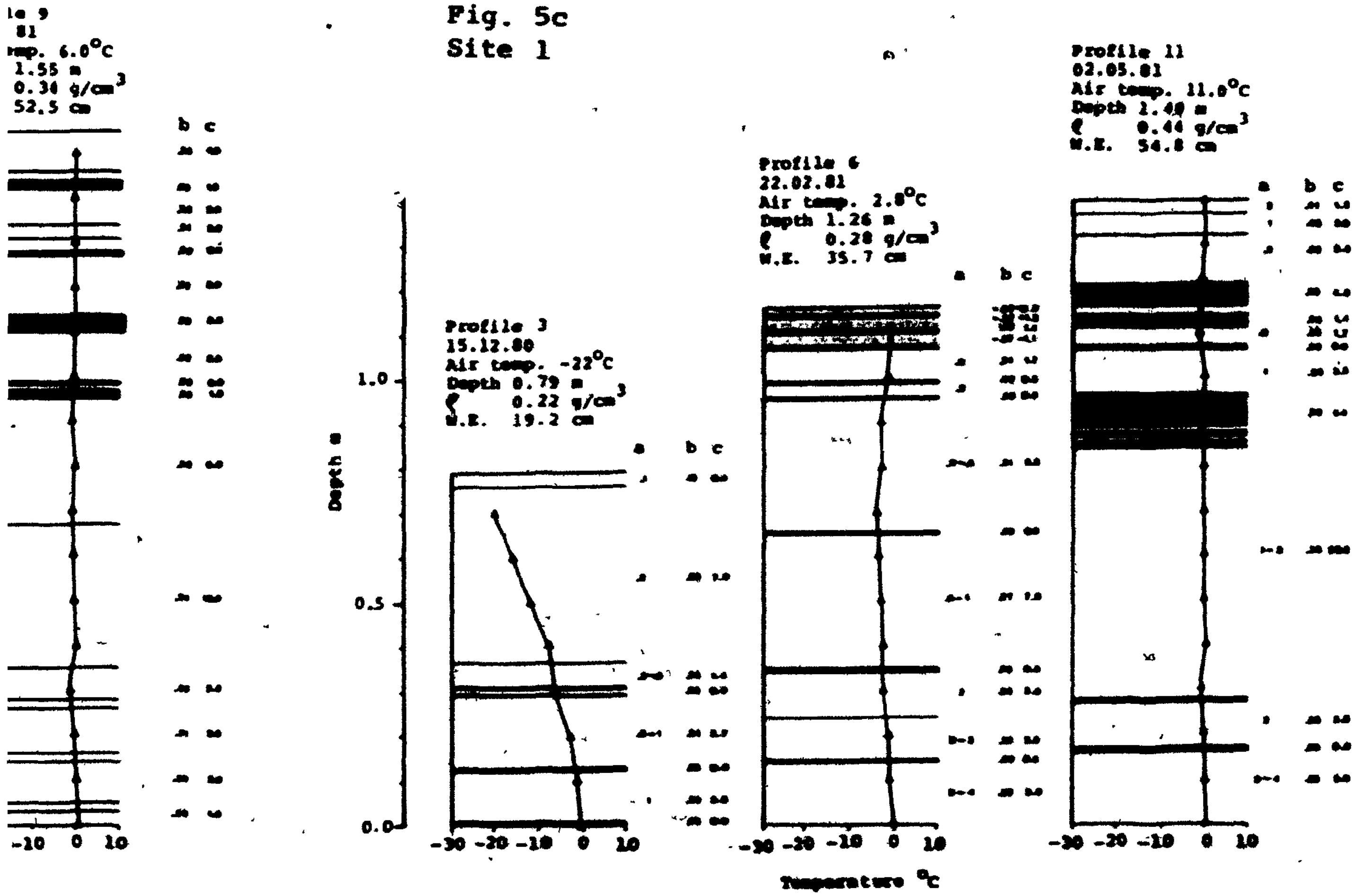


Fig 5b
Site 1

horizon boundary
buried surface crusts
ice layers
slush layer

18

Fig. 5c
Site 1



2of2

Fig. 5d
Site 2

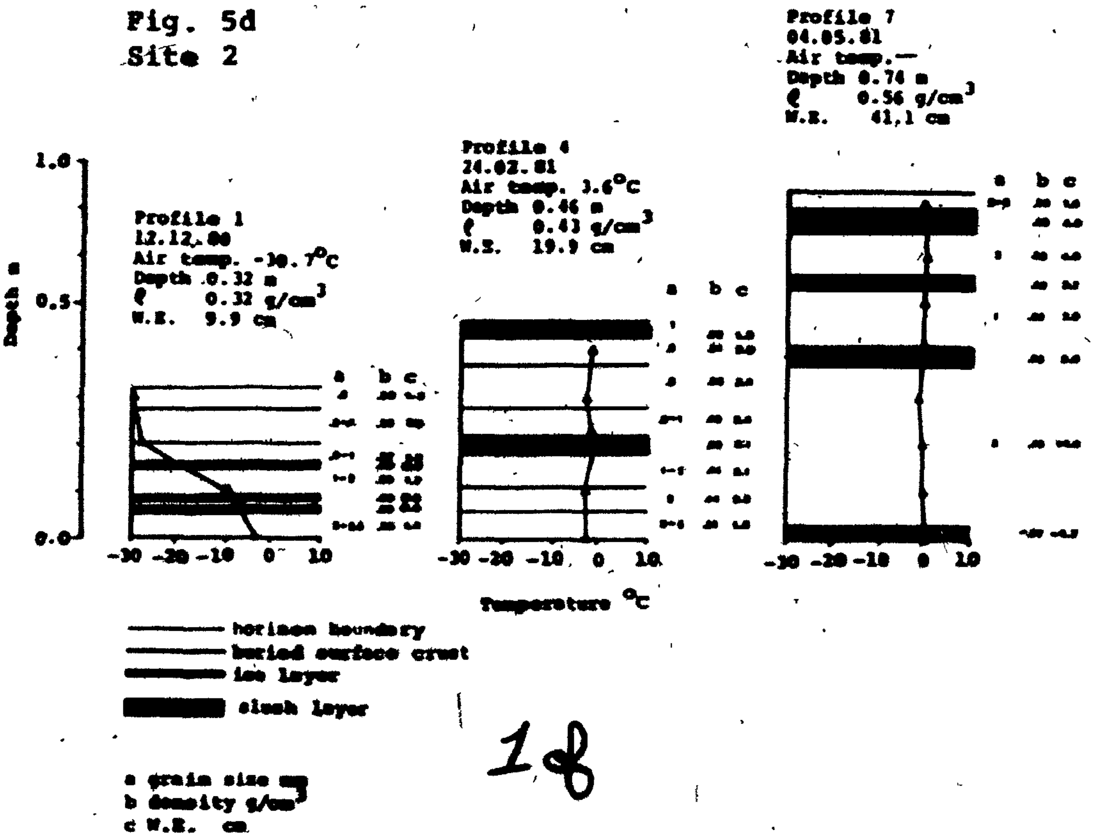


Fig. 5e
Site 2

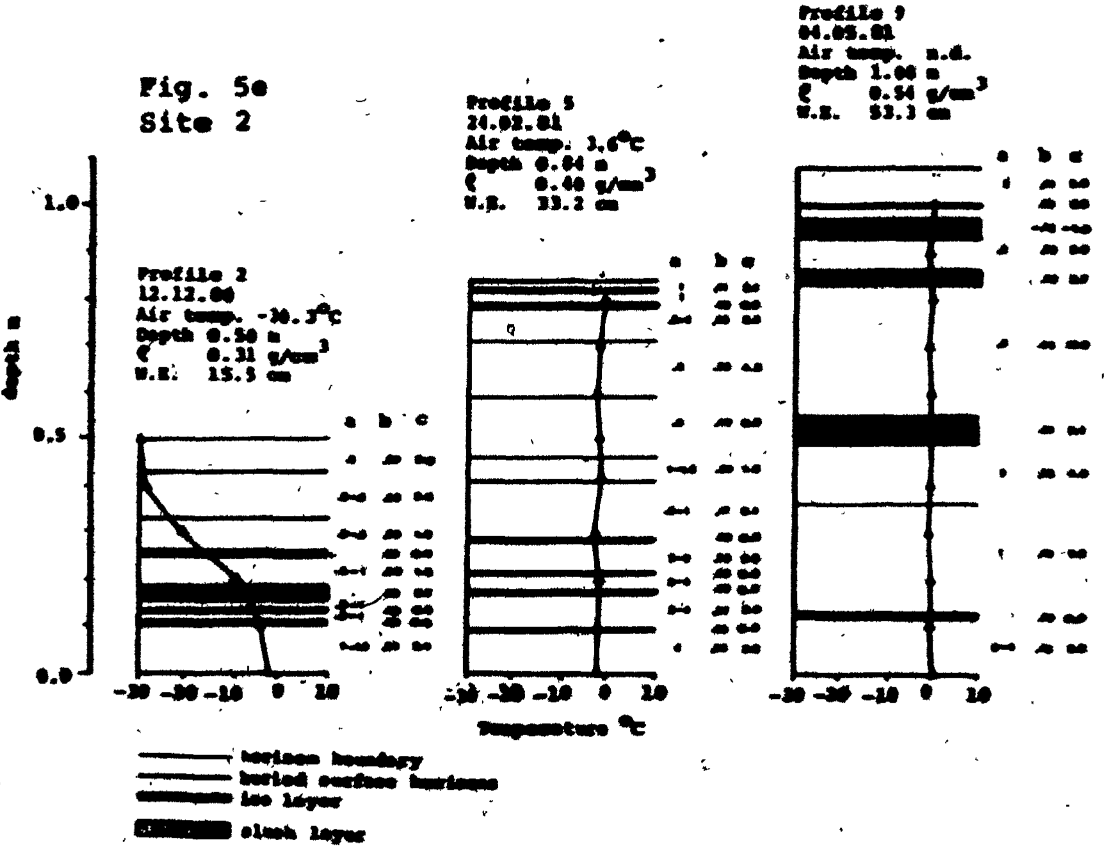


Fig. 5f

Site 2

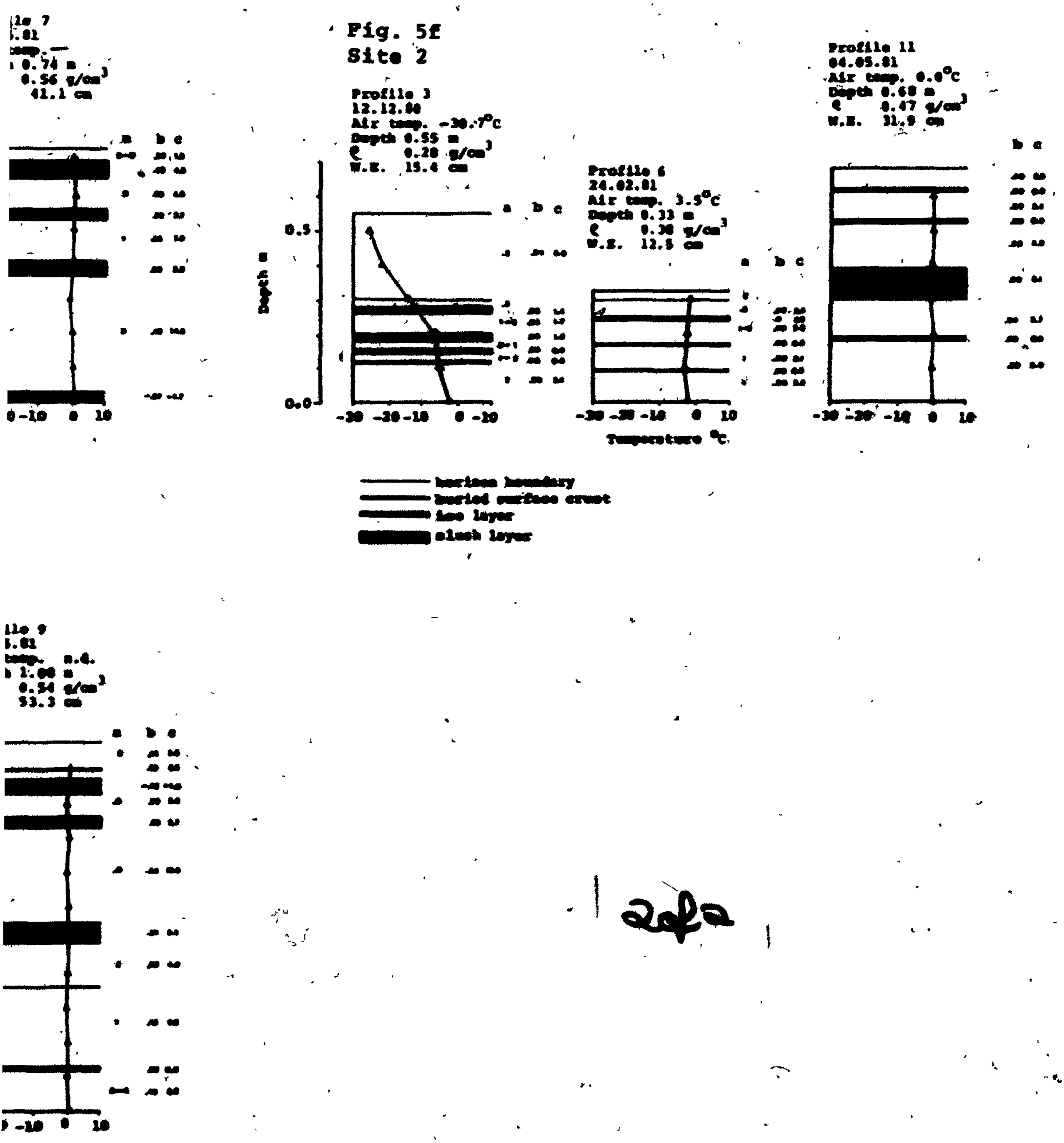


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Fig. 5g
Site 3

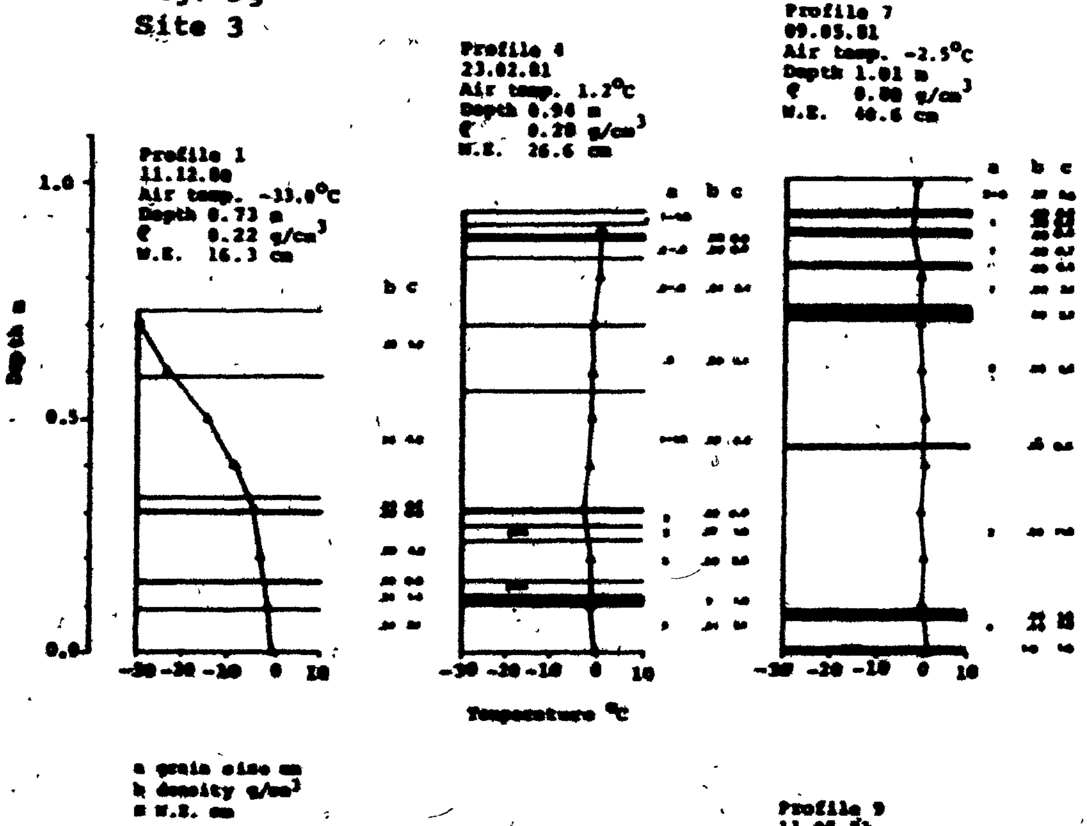
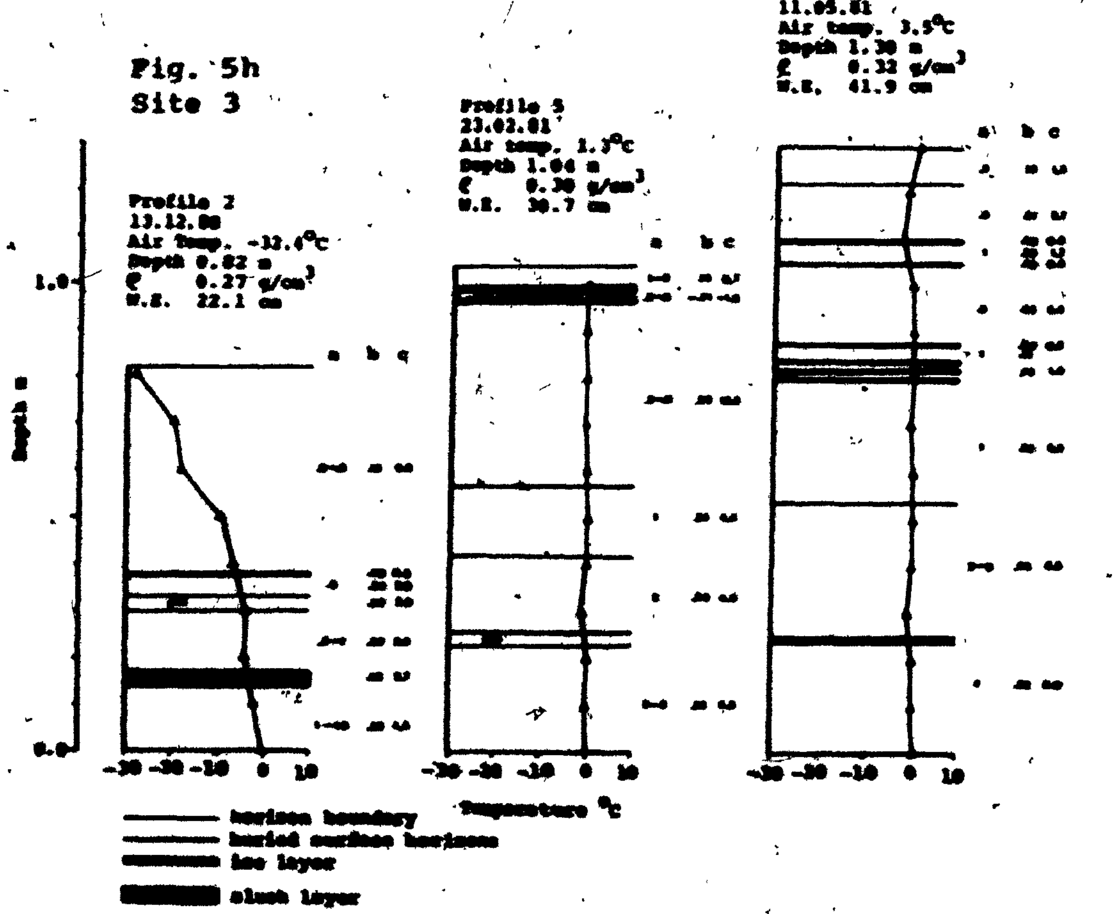


Fig. 5h
Site 3



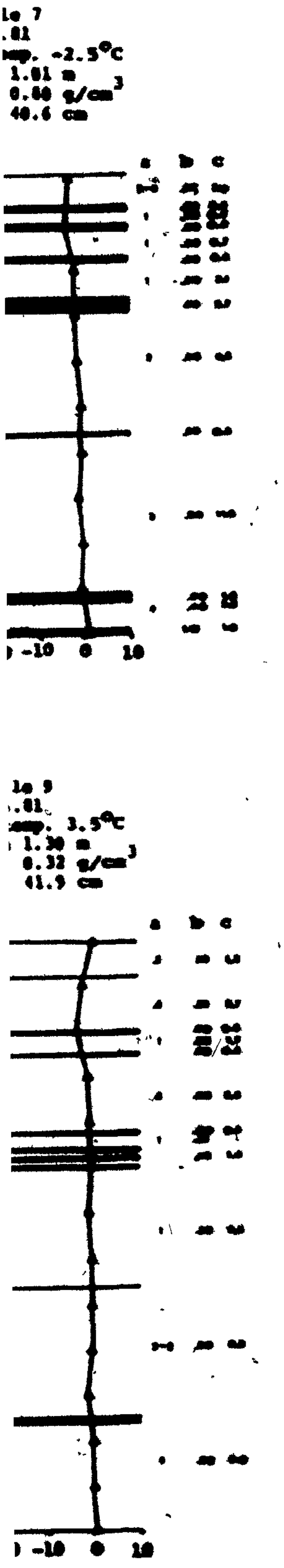


Fig. 5i
Site 3

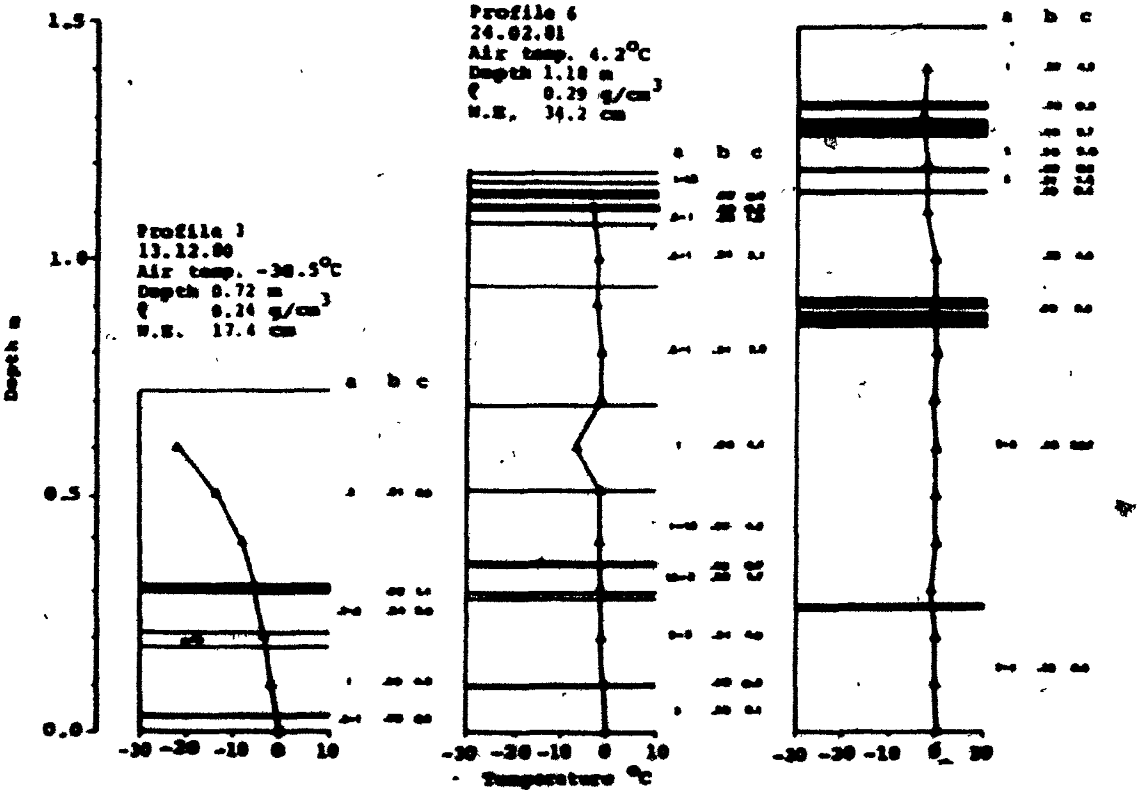


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Fig. 5j
Site 4

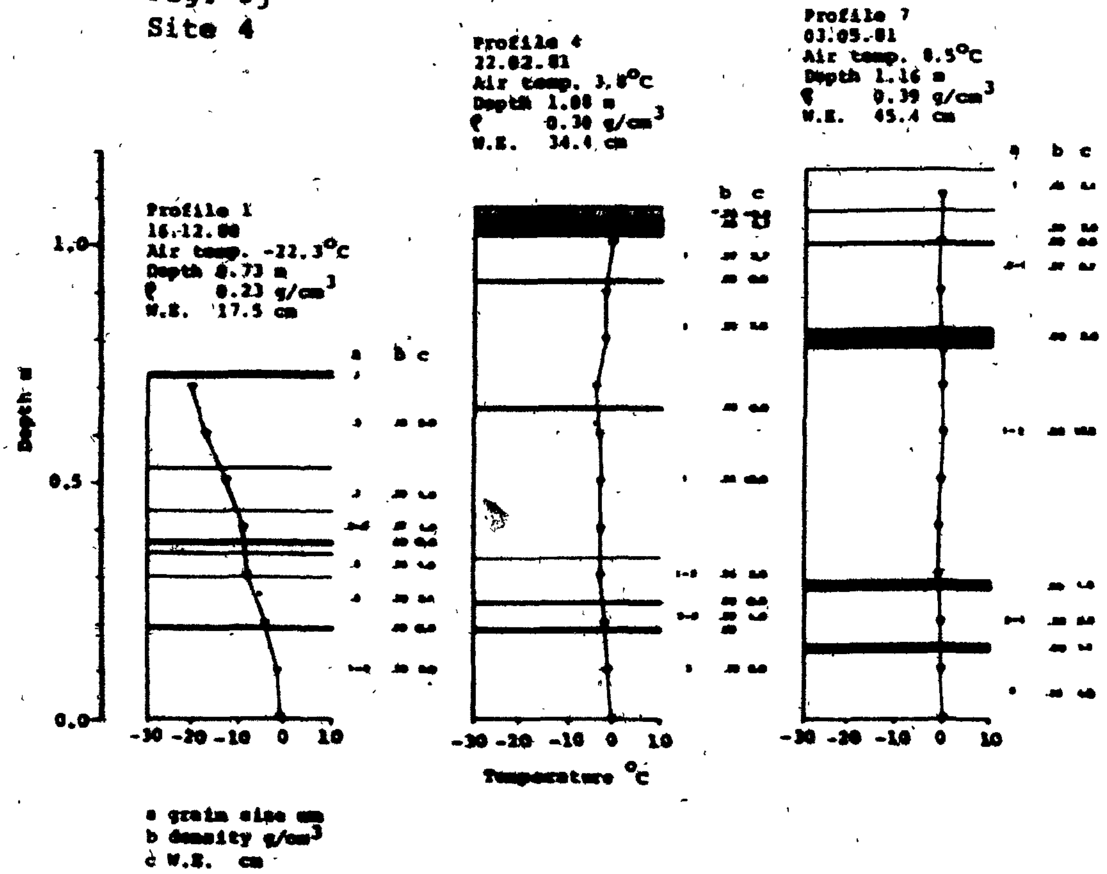


Fig. 5k
Site 4

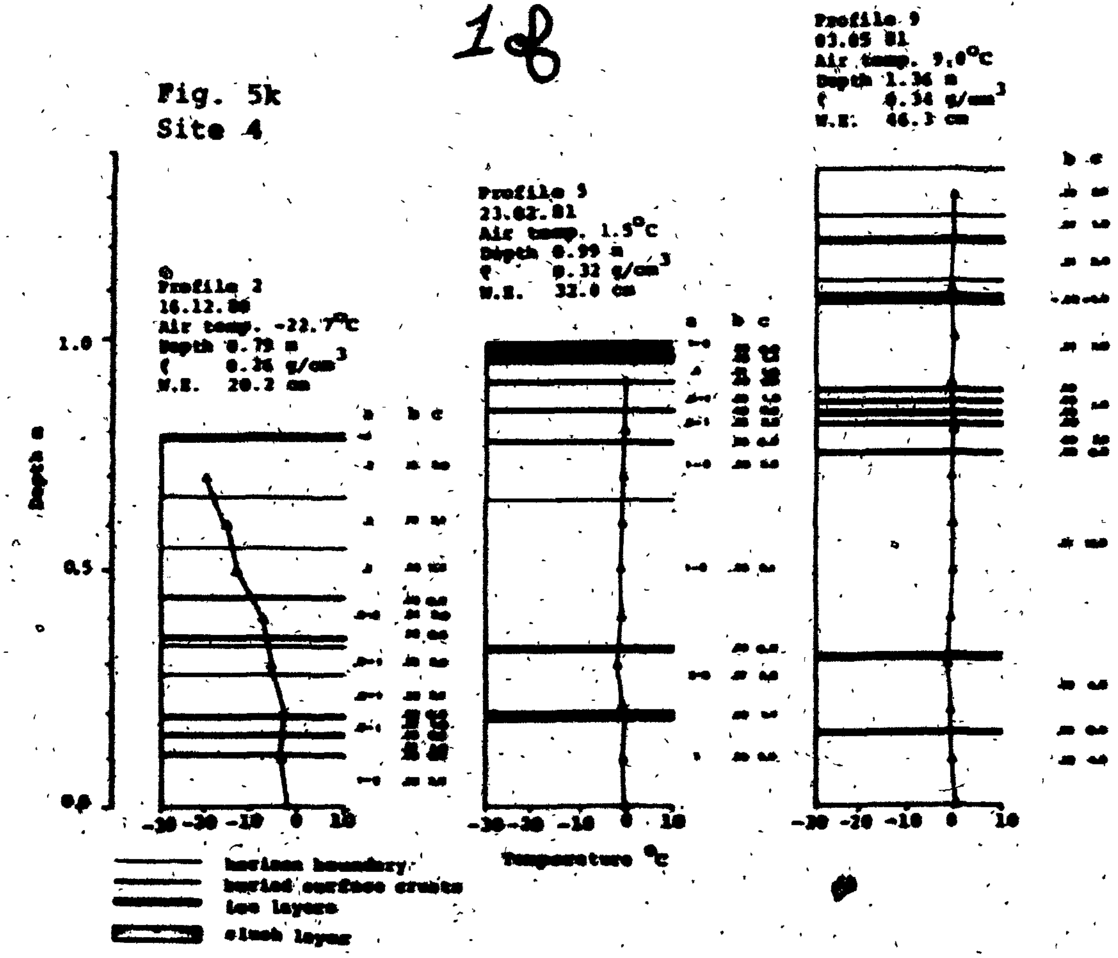
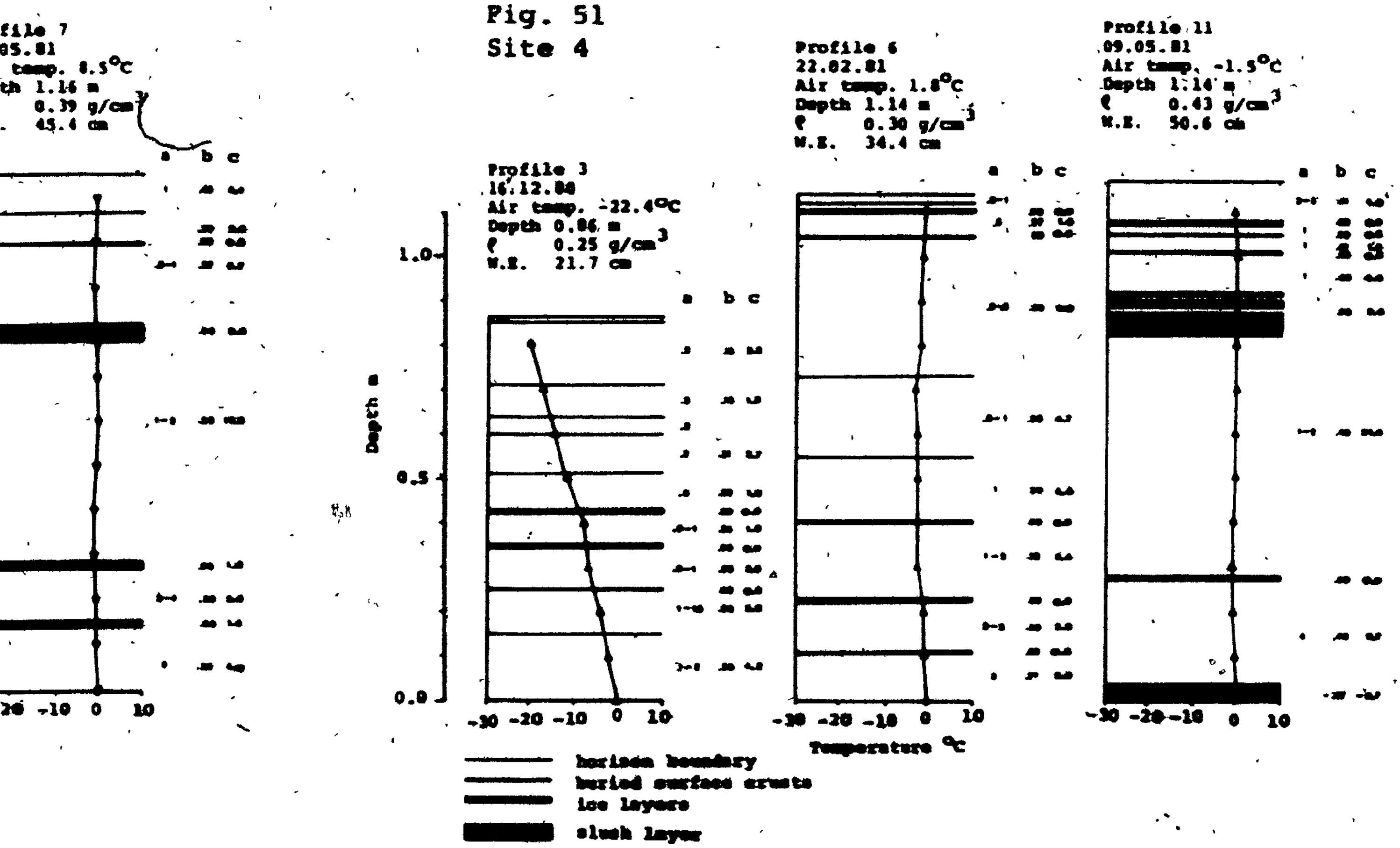
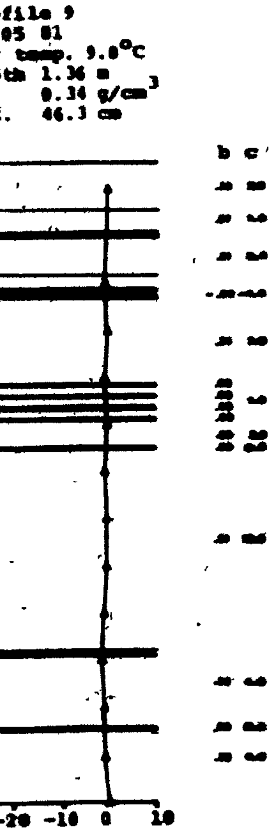


Fig. 51
Site 4





2of2

equivalent (Fig. 5c). At site 2, density values ranged from 0.28 to 0.32 g/cm^3 and water equivalents from 9.9 to 15.4 cm in December (Fig. 5d), which increased to 0.47 to 0.56 g/cm^3 for density and 31.9 to 53.3 cm for water equivalent in early May (Fig. 5f). December density and water equivalent values for the site 3 profiles ranged from 0.22 to 0.27 g/cm^3 and from 16.3 to 22.1 cm, respectively (Fig. 5g). In early May, density ranged from 0.32 to 0.40 g/cm^3 and water equivalents from 40.6 to 48.6 cm (Fig. 5i). At site 4, density values ranged from 0.23 to 0.26 g/cm^3 and water equivalent from 17.5 to 20.2 cm in December (Fig. 5j). In May, density ranged from 0.34 to 0.43 g/cm^3 and water equivalent from 45.4 to 5o.6 cm (Fig. 5l).

Snowpack densities were comparable between sites 1, 3 and 4 during the winter. At site 2, snowpack density was noticeably higher during all three sampling sessions. The mean densities (calculated from the three profiles at each site) ranged from 0.24 to 0.25 g/cm^3 at sites 1, 3 and 4, compared to 0.30 g/cm^3 at site 2 in December. The differences increased in February from 0.29 to 0.31 g/cm^3 at sites 1, 3 and 4 compared to 0.40 g/cm^3 at site 2. The difference in May was the largest; 0.35 to 0.39 g/cm^3 compared to 0.52 g/cm^3 at site 2.

Water equivalents were lowest at site 2 and although the mean water equivalents between sites 1, 3 and 4 were comparable in December, differences increased in February and, by the spring, large differences had developed between these three sites and the spring water equivalents between sites 2 and 3 were comparable. In December, the mean water equivalent values ranged from 18.6 to 19.8 cm at sites 1,3 and 4 compared to 13.6 cm at site 2. This increased to 30.5 to 34.1 cm between sites 1, 3 and 4 and 21.9 cm at site 2 in February. In May, the mean water equivalent was higher at site 1, 53.7 cm followed by site 4, 47.4 cm, site 3, 43.7 cm and site 2, 42.1 cm.

Ice layers were present in all the snowpacks and ranged in thickness from 0.5 cm (which were actually buried surface melt crusts) to layers as thick as 8.0 cm (Fig. 5f, site 2, profile 11). The majority were between 1.0 and 3.0 cm thick. During the December sampling period, an ice layer was present at the base of the snow profiles at site 1 (Figs. 5a, b and c). This did not occur at the other three sites. This may indicate that the ground surface was not frozen when the snow first began to accumulate and a slush layer formed, which was eventually buried. Low air temperatures and shallow snow depths caused the slush layer to freeze. Slush layers were also found at or near the surface of several profiles in February and once more at the snowpack base in late April/early May. The presence of ice and slush layers indicates a changing temperature regime in the snowpack.

The snowpack temperature regime is controlled by the surface air temperature and heating from the ground beneath. What is immediately apparent from all the graphs is that, while the temperature of the upper snowpack appeared to be strongly affected by the air temperatures, the temperatures of the lower snow profile, and particularly the base of the snowpack, remained remarkably consistent. Secondly, the rate of temperature increase through the snowpacks was very pronounced from the surface to approximately the centre of the snow profile and changed dramatically to a very gradual increase towards the snowpack base. This was particularly pronounced in the December snowpacks. At site 1, this gradient change occurs at 40 cm and appears to be related to horizon and density changes at 38 cm (Fig. 5a). At site 2, two gradient changes occur in the snowpacks: the first is a very gradual temperature increase between the surface and 10 cm deeper, at which point the temperature increases rapidly to 20 cm at profiles 2 and 3 (Figs. 5e and f) and to 10 cm at profile 1 (Fig. 5d). This second gradient change corresponds to major ice layers in the snowpack at these depths. At site 3, this temperature gradient is more gradual, but a gradient change can be identified at 30 cm in profile 1 (Fig. 5g), 50 cm in profile 2 (Fig. 5h) and between 30 and 40 cm in profile 3 (Fig. 5i). A minor ice layer at 30 cm in profiles 1 and 3 also appears to have some effect on this gradient change At site 4, the gradient change is at approximately 40 cm and also seems to be related to the first occurrence of ice layers (from the surface) in the snowpack at this level, as well as to density changes. The extreme air temperatures, which obviously affect the snowpack temperature regime at or near the surface, have no effect on the temperature condition at the snowpack base

The warmer air temperatures in February led to a slight warming in the upper profile sections which did not affect the lower half of the profile. In each of the February profiles, a level can be identified, at or near the profile centre, where the profile temperatures were lowest. Temperatures increased from this point toward the profile surface and toward the profile base, but at each site, the base temperatures showed very little change from December, remaining at or near 0°C. The spring profiles showed an almost isothermal temperature regime, at 0°C, in the middle snowpack sections, with very slight temperature increases of 0.1 to 0.5°C towards the surface and snowpack base.

As previously stated, the temperatures at the base of the snowpack were very similar throughout the winter and showed only small increases from December to May. If the values of the three profiles are averaged, the increases in the mean base temperatures are as follows: -7.0 to 0.9°C, site 1; -2.4 to 0.3°C, site 2; -0.6 to 0.7°C, site 3 and -0.8 to 0.5°C at site 4. Considering the magnitude of the air temperature changes experienced throughout the winter, the environment at the snowpack base appears very constant.

Only small temperature differences were apparent between sites 1, 3 and 4; base temperatures were lower at site 2 by 1.6 to 1.8°C in December. A temperature range of 0.5°C occurs in May between the four sites. The lower temperatures at site 2 in December are most probably related to the shallower snow depths and the higher snowpack densities at this site, leading to increased heat loss. A second factor may be the absence of a vegetation mat. Site 2 is the only site which does not have a continuous ground cover. At site 1, the ground is protected by a continuous lichen mat and at sites 3 and 4 by moss. In summer, these ground covers insulate the ground beneath from the warmer air temperatures and the soil temperatures remain relatively low. In winter, these vegetation covers retard the effective transfer of heat away from the ground through the snowpack and act themselves as a heat reservoir, thus maintaining a constant temperature at the snowpack base near $0^{\circ}C$.

The presence of ice layers in the snowpack possibly have some role in preventing heat loss from the bottom snowpack section and their presence could be an important factor in maintaining a constant temperature regime at the snow/vegetation/soil interface. At the same time, their presence would inhibit the ventilation of the snowpack, leading to a buildup of gases, such as CO_2, should respiration be occurring. This possibility was, however, not measured in this study.

4.3 Snowpack Chemistry

4.3.1 The Distribution of the Chemical Parameters in the Snowpack

The vertical distribution of the chemical parameters measured in the snowpack in December, February and April/May is shown in Figures 6a to 6p. It can be seen that snowpack chemistry varies with depth and that strong peaks in concentrations are apparent. In some instances, the various parameters, particularly the cations, show simultaneous increases of comparable magnitudes.

Because of the variation in sampling location and sampling times, pH, cation, phosphorus and particulate matter concentrations show a considerable range of values. pH values range from 4.0 to 5.5; the majority of pH(1) values fall within

Figures 6a to 6p: Vertical distribution of the chemical constituents in the snowpacks

Fig. 6a

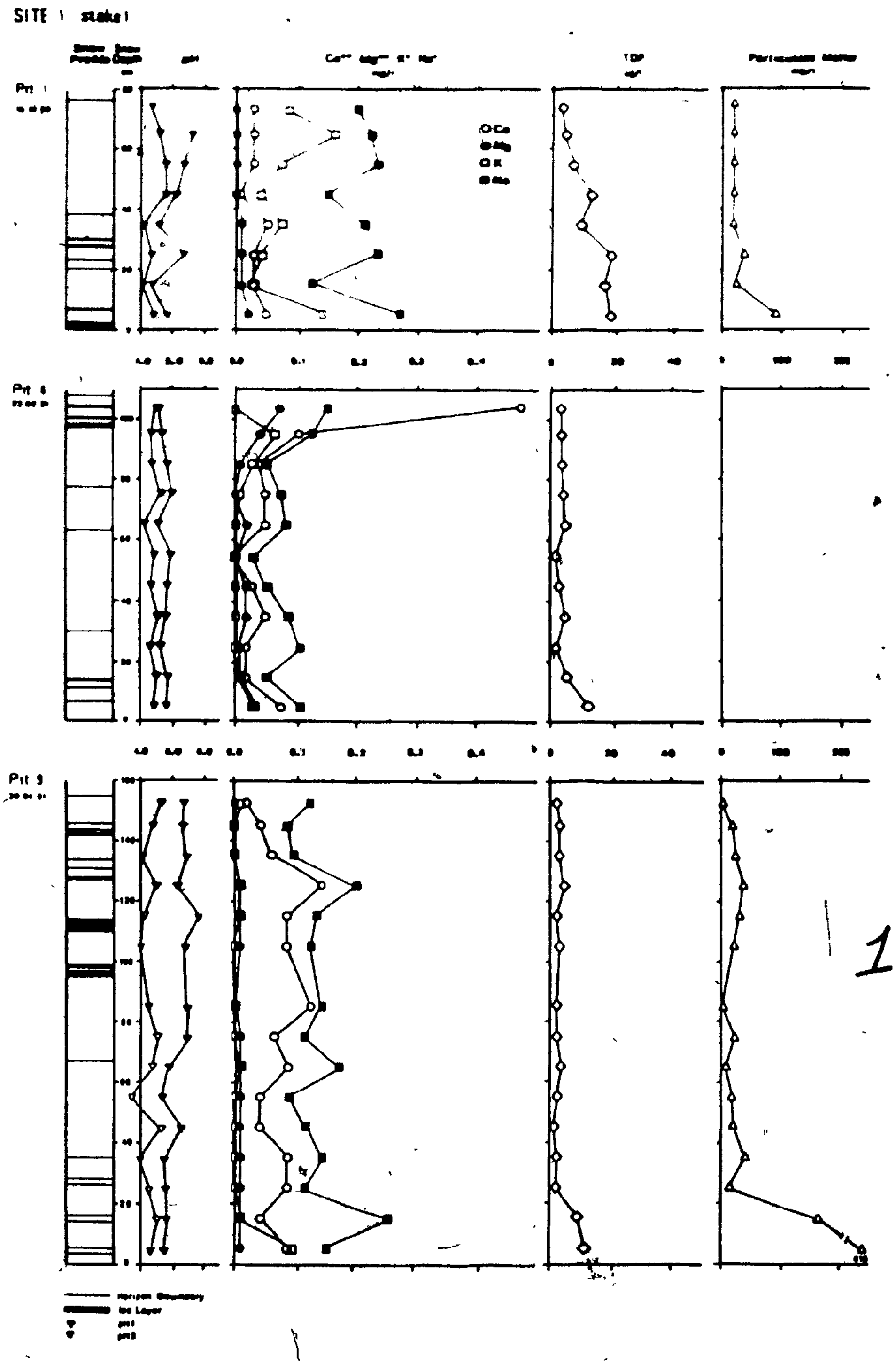


Fig. 6

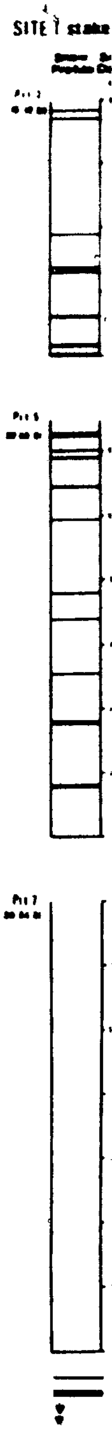
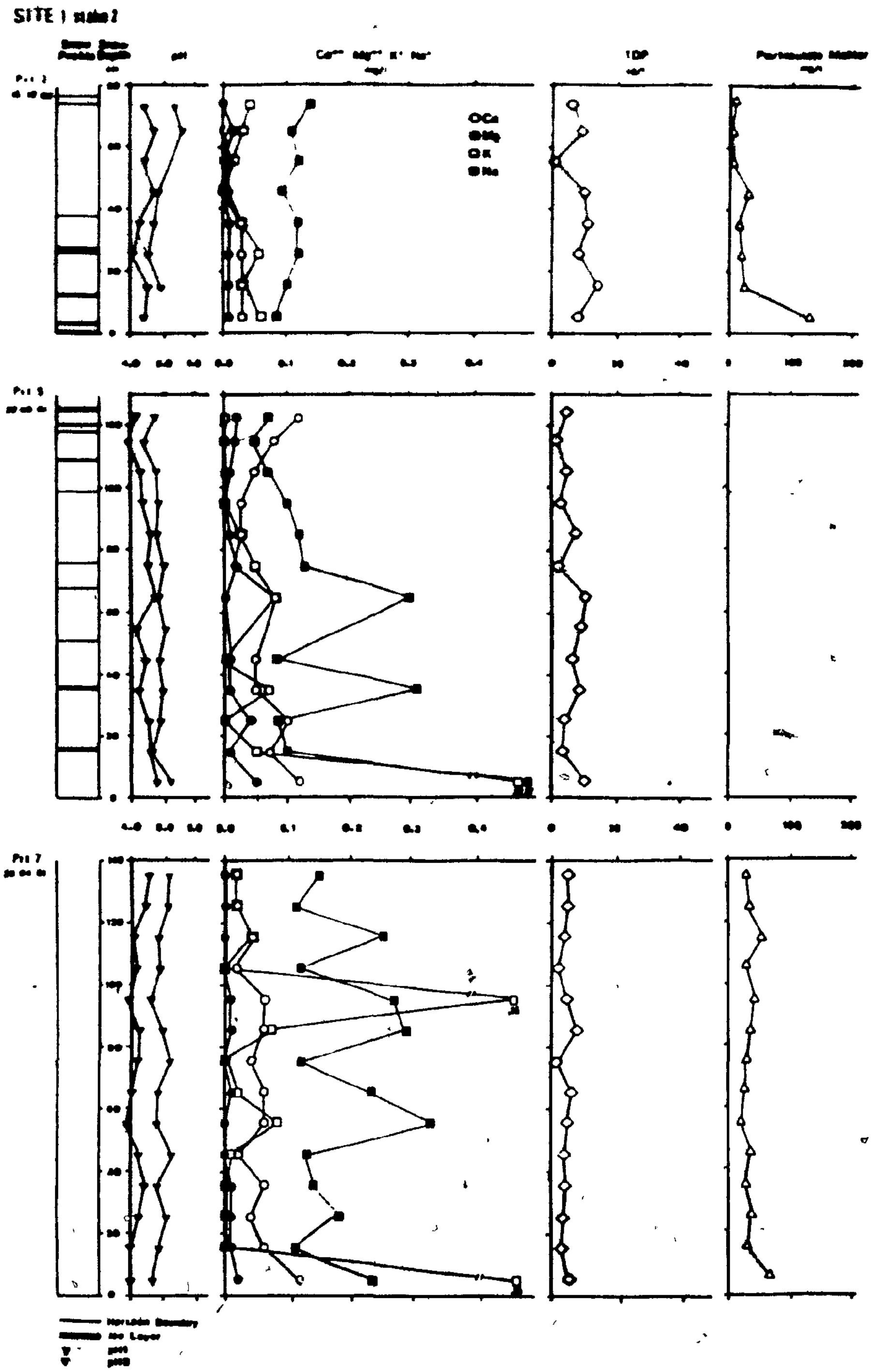


Fig. 6b

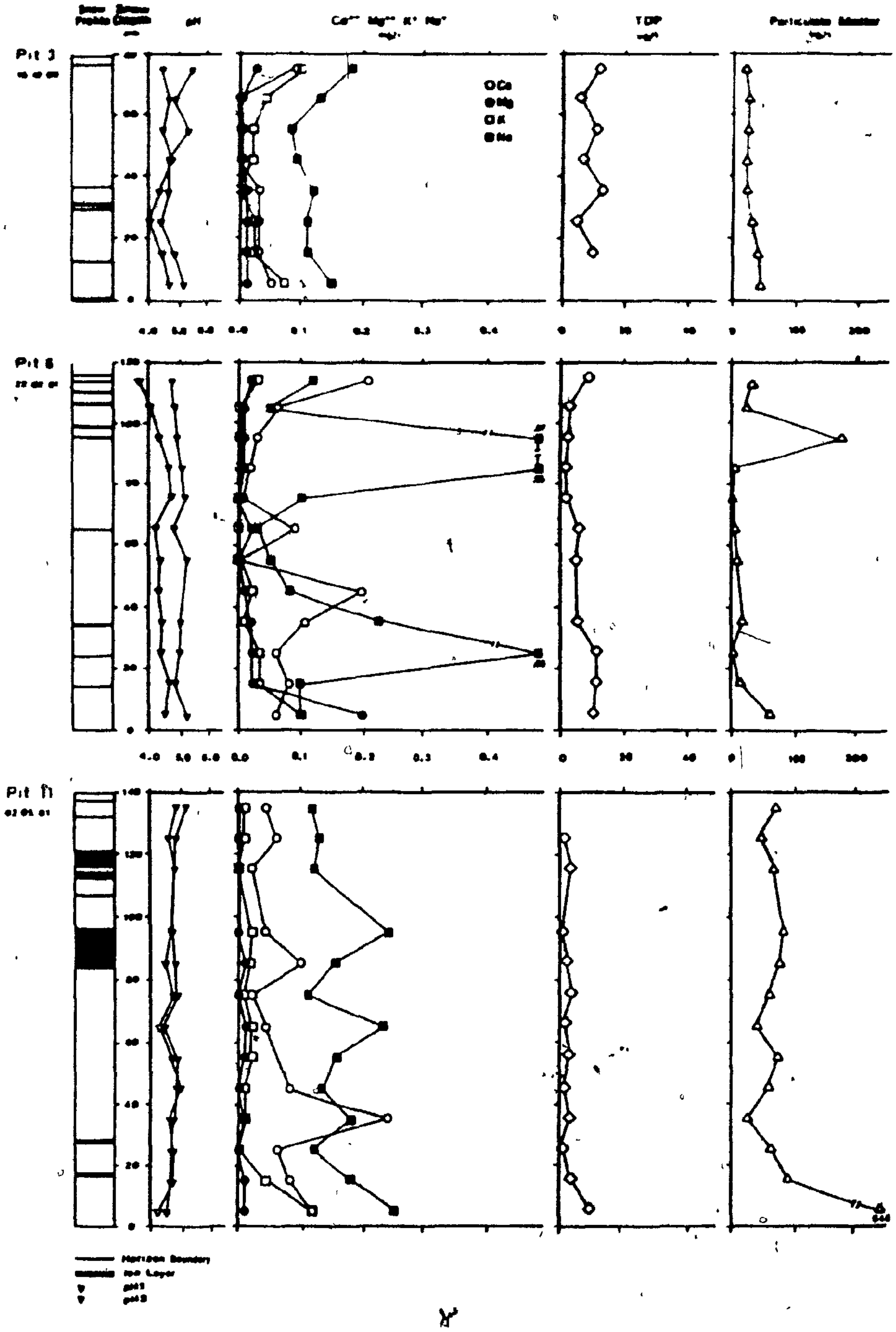

SITE 1
pH
TDP
Particulate Matter
OCa
Mg
K
Na
Pit 2
Pit 5
Pit 7
0.0
0.1
0.2
0.3
0.4
0
20
40
0
100
200
Horizon Boundary
Ice Layer

2of2

18

Fig. 6c

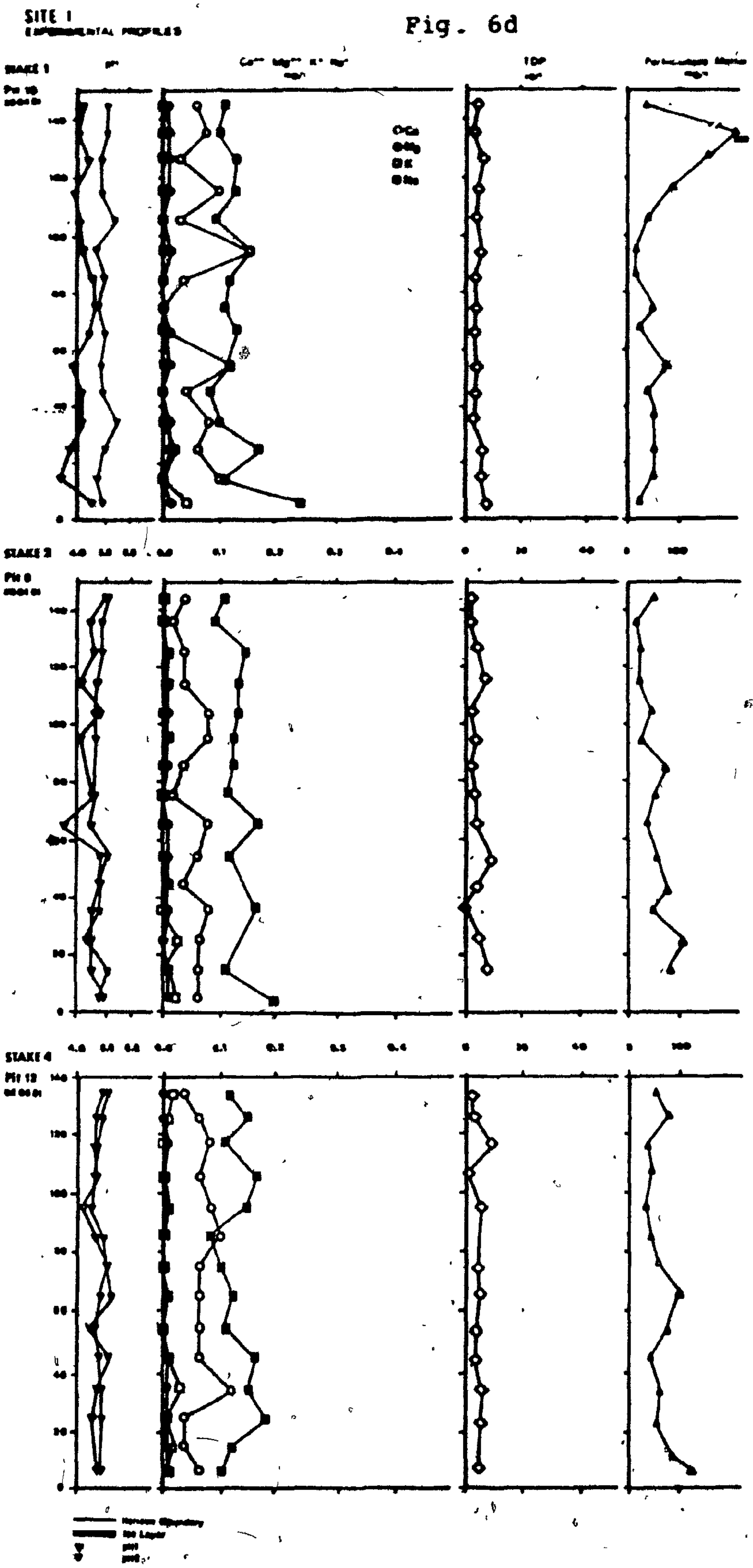
SITE 1 stake 4



Particulate Matter
0
100
200

2of2

Fig. 6d



SITE 1
EXPERIMENTAL PROFILES
STAKE 1
pH
TDP
Particulate Matter
O Ca
Mg
K
Na
STAKE 2
STAKE 4
0.0
0.1
0.2
0.3
0.4
0
100
140
120
100
80
60
40
20
0
pH

Fig. 6e

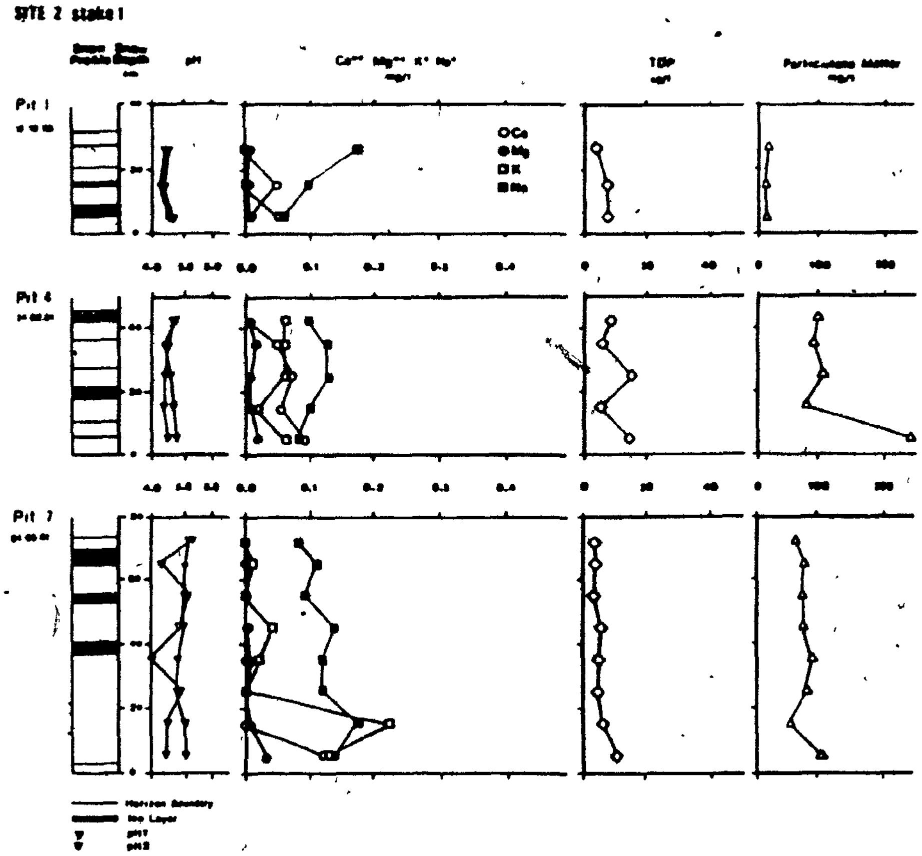

SITE 2 stake 1
Snow Profile
Snow Depth cm
pH
Ca++ Mg++ K+ Na+ mg/l
TDP ug/l
Particulate Matter mg/l
Pit 1
Pit 4
Pit 7
Ca
Mg
K
Na
4.0 5.0 6.0
0.0 0.1 0.2 0.3 0.4
0 20 40
0 100 200
Horizon Boundary
Ice Layer
pH1
pH2

Fig. 6f

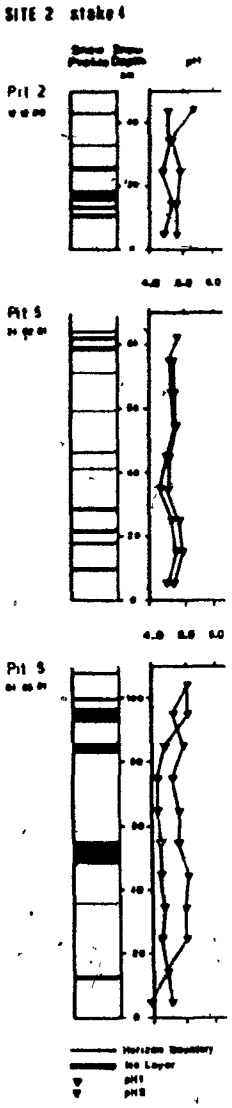
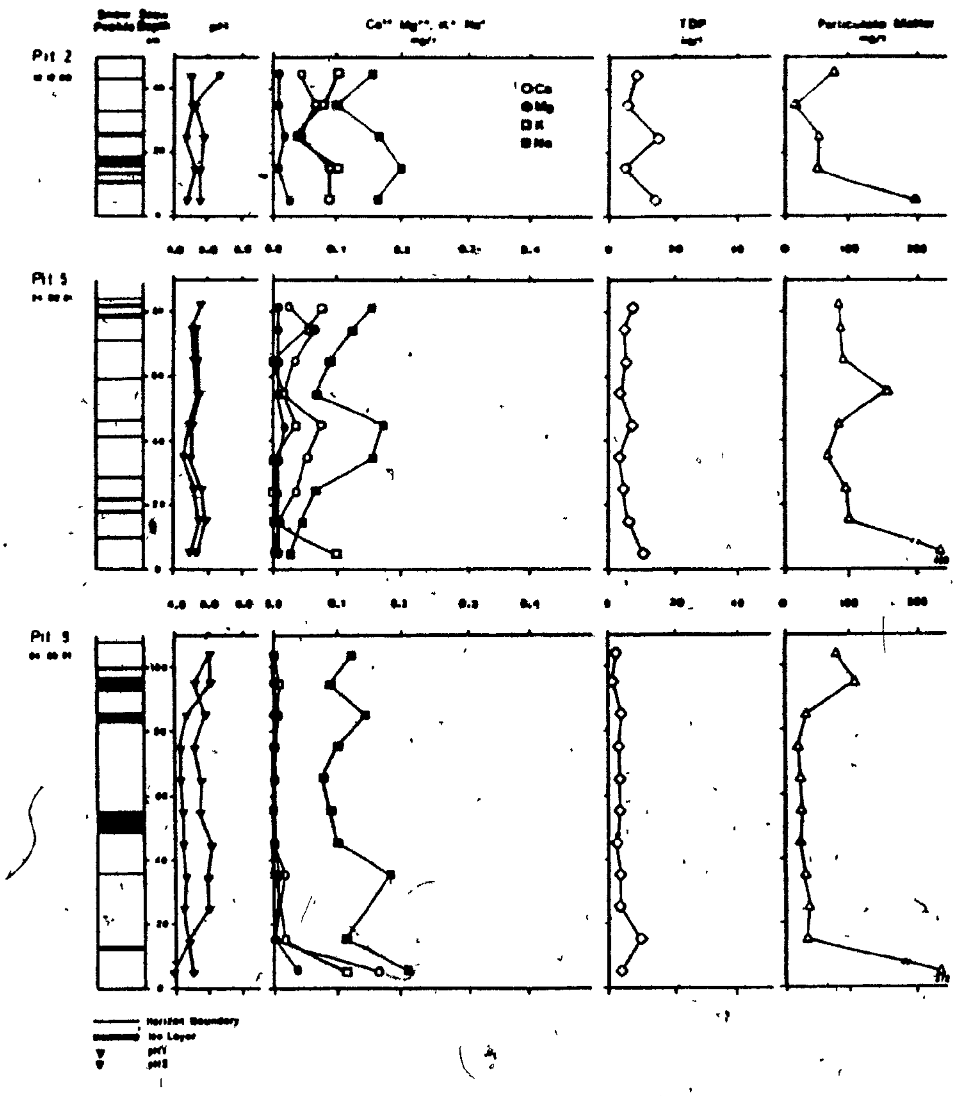

SITE 2 stake 4
Snow Profile
Snow Depth cm
pH
Pit 2
Pit 5
Pit 5
4.0 5.0 6.0
Horizon Boundary
Ice Layer
pH1
pH2

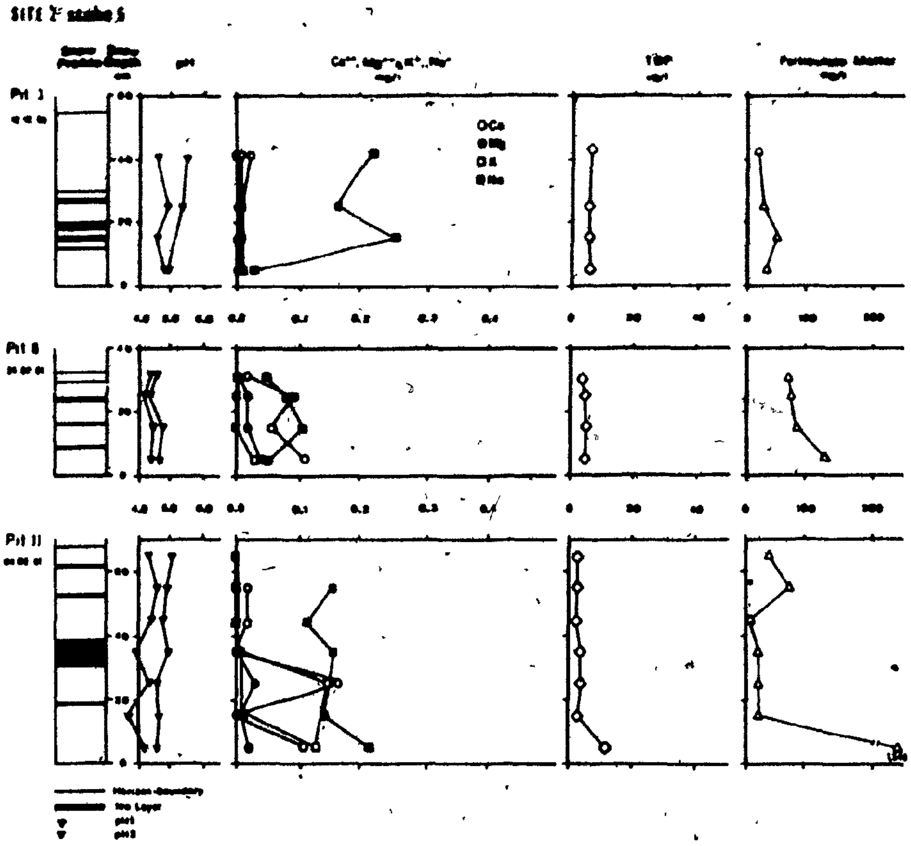
Fig. 6f

SITE 2 stake 4



2of2

Fig. 6g


Pit 1
Pit 8
Pit 11
pH
Ca
Mg
K
Na
mg/l
Particulate Matter
4.0
5.0
6.0
0.0
0.1
0.2
0.3
0.4
0
20
40
0
100
200
Horizon Boundary
Ice Layer
pH1
pH2

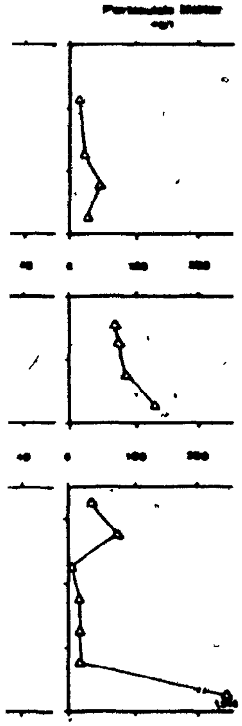
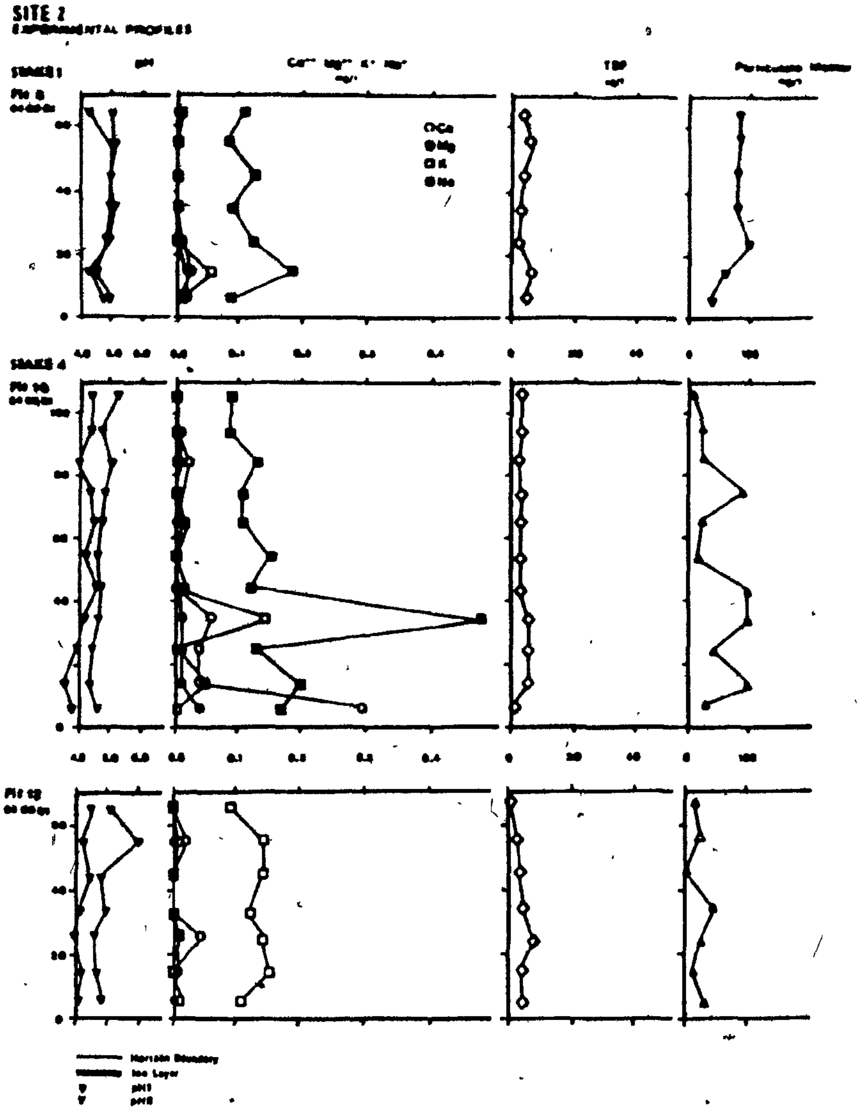

Particulate Matter
mg/l
0
100
200

Fig. 6h


SITE 2
EXPERIMENTAL PROFILES
STAGE 1
STAGE 4
pH
TDP
mg/l
Particulate Matter
mg/l
Ca
Mg
K
Na
0
20
40
60
80
100
4.0
5.0
6.0
0.0
0.1
0.2
0.3
0.4
0
20
40
0
100
Horizon Boundary
Ice Layer
pH1
pH2

2of2

Fig. 6i

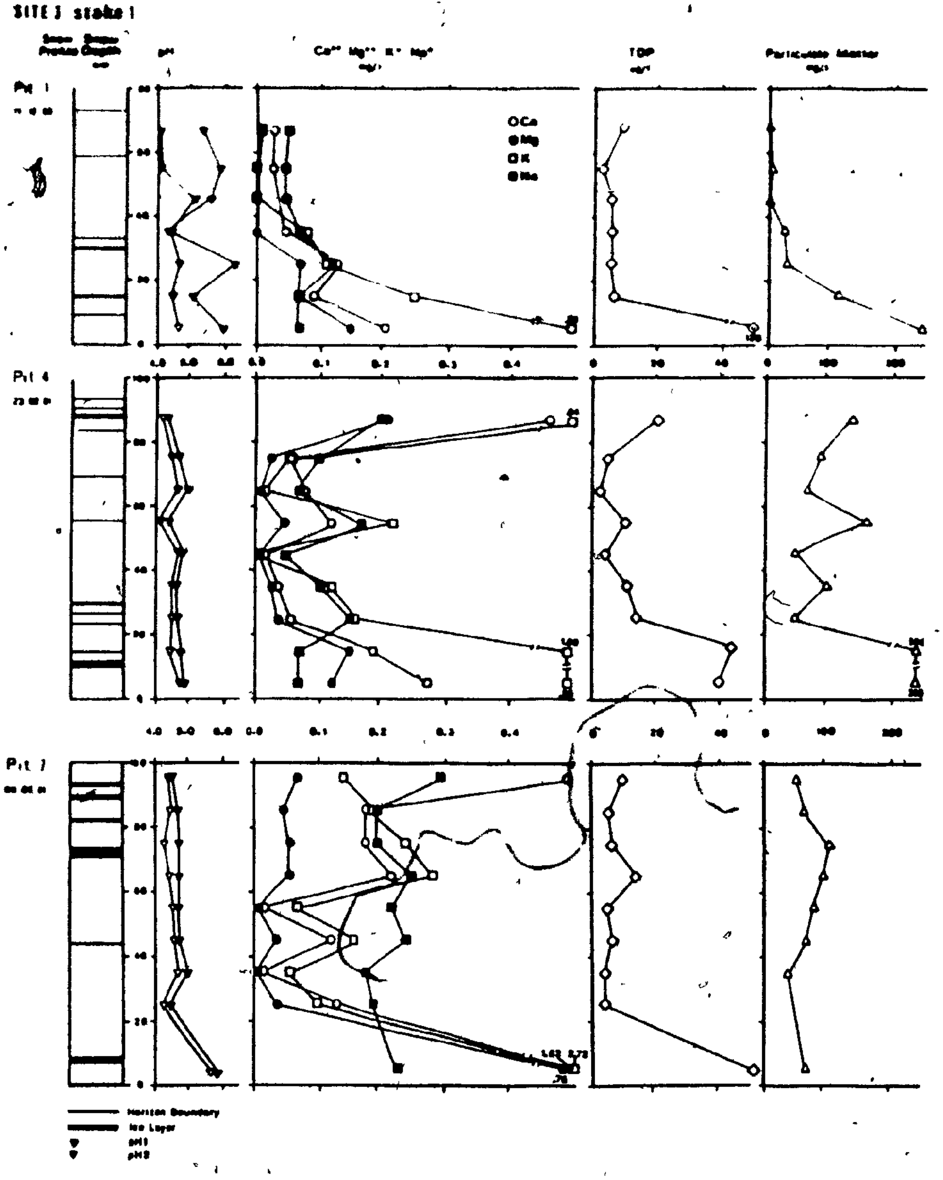

SITE 3 stake 1
Snow Profile
Snow Depth cm
pH
Ca++ Mg++ K+ Na+ mg/l
TDP
Particulate Matter mg/l
Pit 1
Pit 4
Pit 7
OCa
●Mg
□K
■Na
Horizon Boundary
Ice Layer
pH1
pH2

Fig. 6j

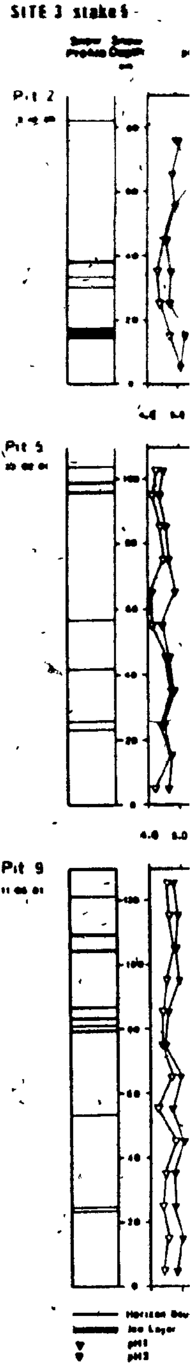
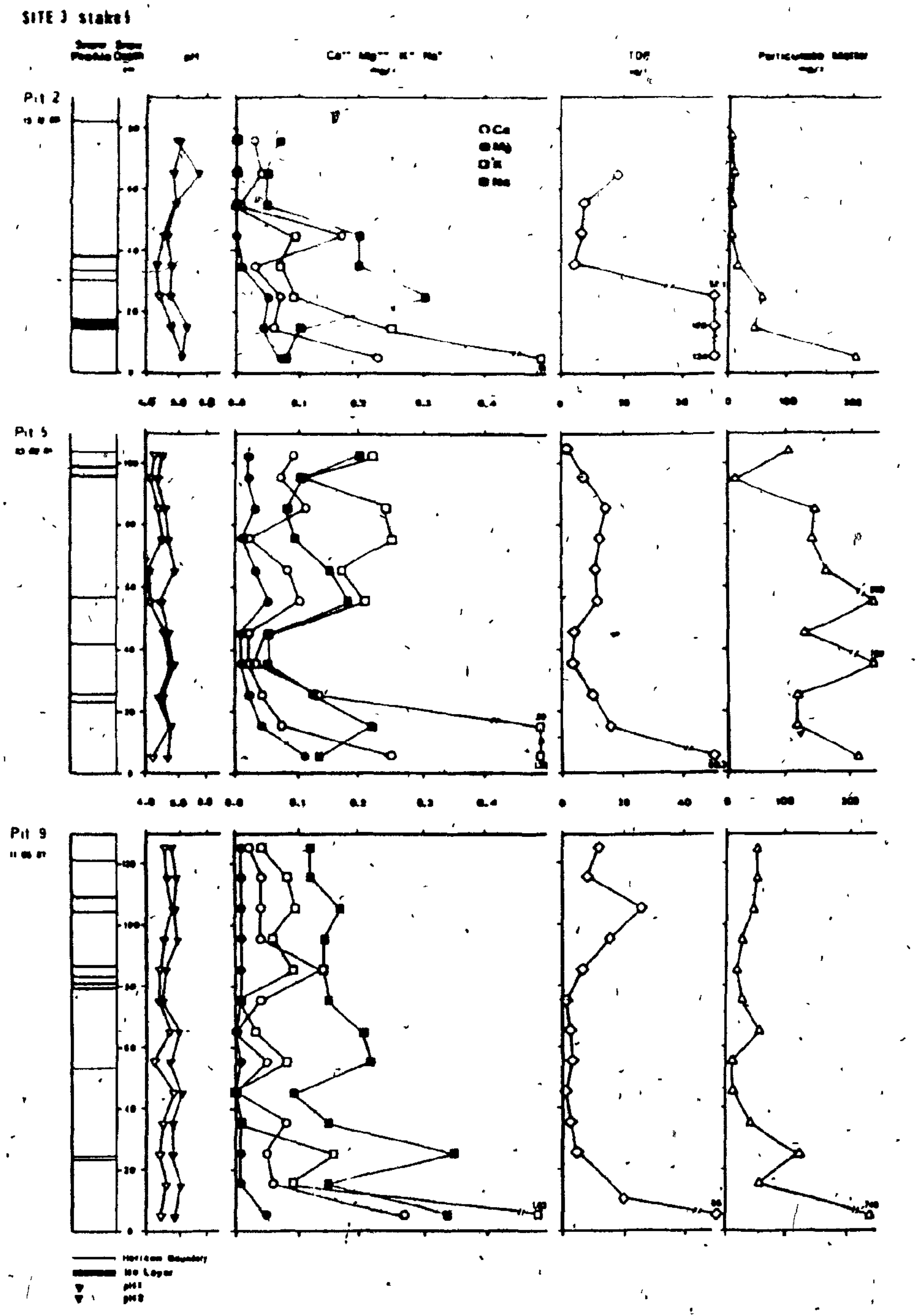

SITE 3 stake 5
Snow Profile
Snow Depth cm
Pit 2
Pit 5
Pit 9
Horizon Boundary
Ice Layer
pH1
pH2

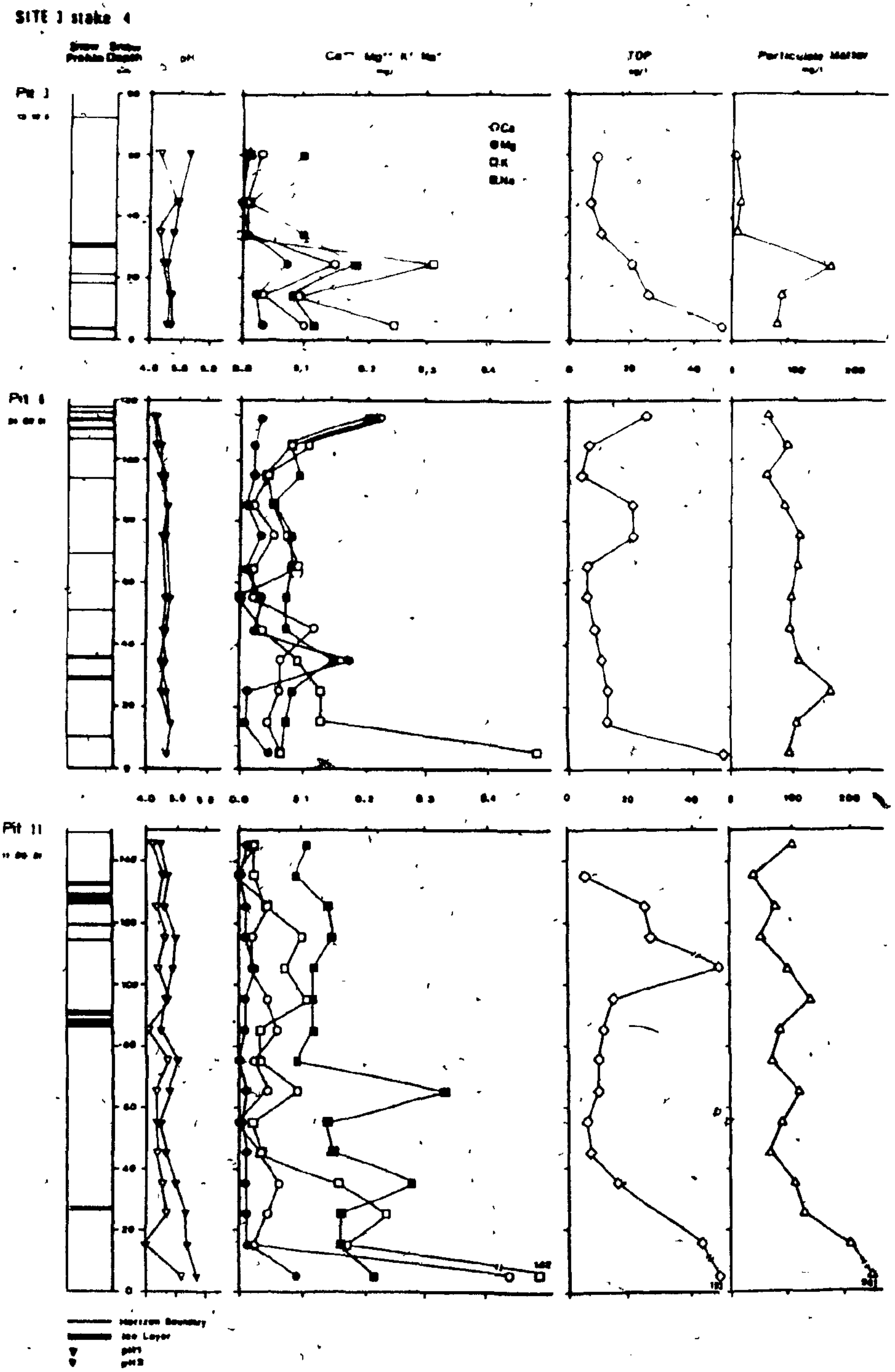
Fig. 6j

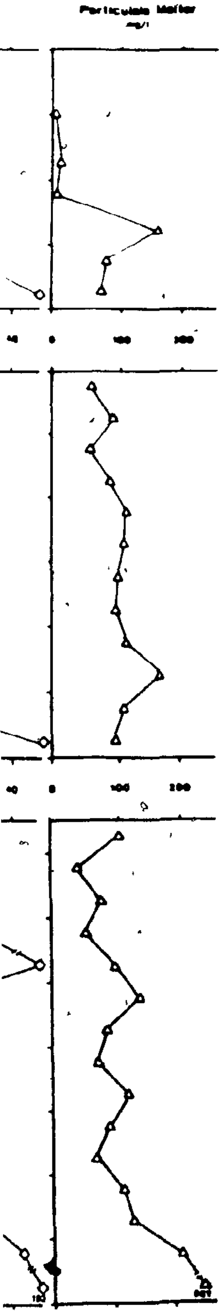


SITE 3 stake5
Snow Profile
Snow Depth
cm
pH
Ca++ Mg++ K+ Na+
mg/l
mg/l
Particulate Matter
mg/l
Pit 2
Pit 5
Pit 9
Ca
Mg
K
Na
4.0
5.0
6.0
0.0
0.1
0.2
0.3
0.4
0
10
20
30
100
200
Horizon Boundary
Ice Layer
pH1
pH2

2of2

Fig. 6k

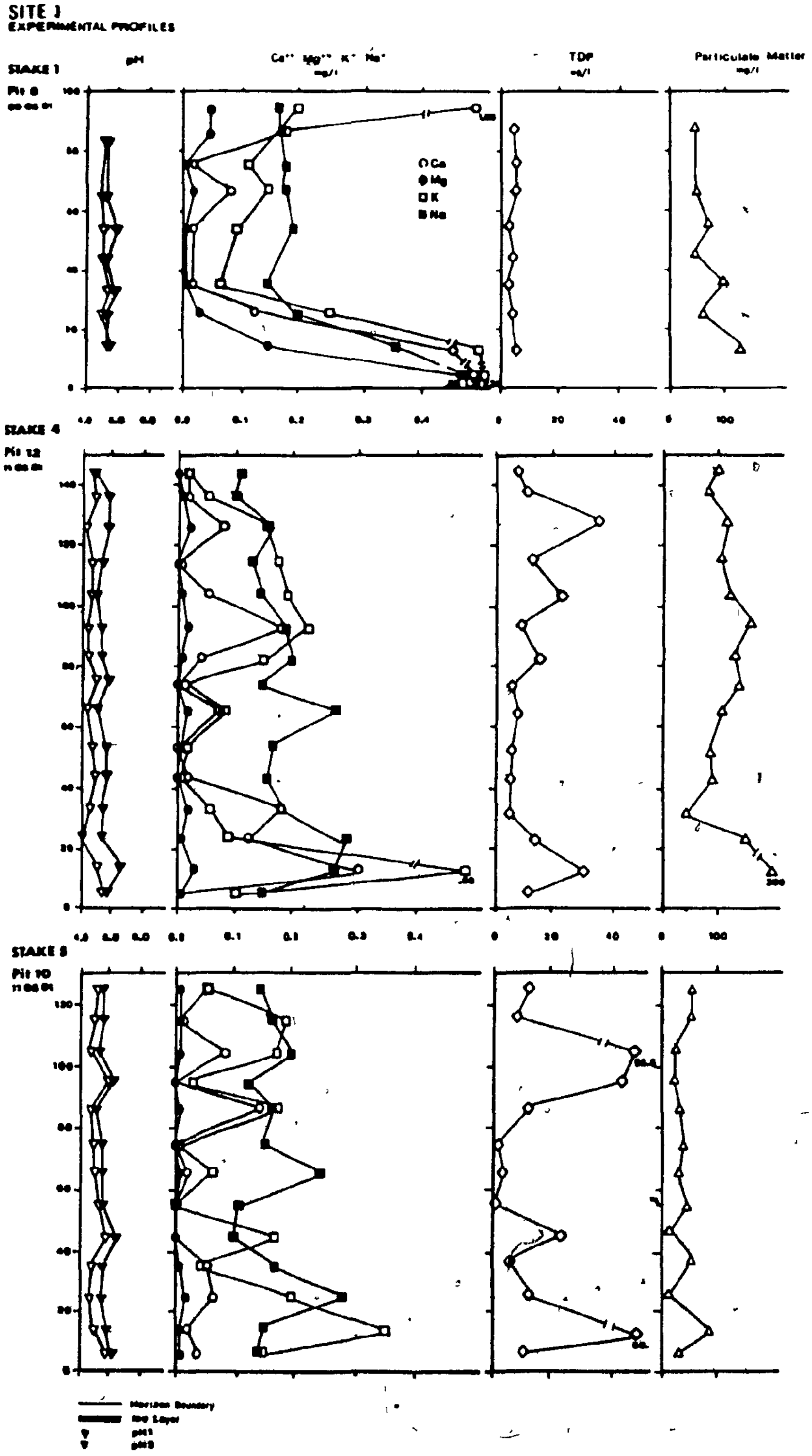

SITE 3 stake 4
Snow Profile
Snow Depth
cm
pH
Ca⁺⁺ Mg⁺⁺ K⁺ Na⁺
mg/l
TDP
mg/l
Particulate Matter
mg/l
Pit 3
Pit 8
Pit 11
○Ca
●Mg
□K
■Na
0
20
40
60
80
100
120
140
4.0
5.0
6.0
0.0
0.1
0.2
0.3
0.4
0
20
40
0
100
200
Horizon Boundary
Ice Layer
pH1
pH2



Particulate Matter
mg/l
0
100
200

Fig. 61

2of2



SITE 1
EXPERIMENTAL PROFILES
STAKE 1
Pit 8
pH
Ca++ Mg++ K+ Na+
mg/l
TDP
mg/l
Particulate Matter
mg/l
○ Ca
● Mg
□ K
■ Na
4.0
5.0
6.0
0.0
0.1
0.2
0.3
0.4
0
20
40
0
100
STAKE 4
Pit 12
STAKE 5
Pit 10
0
20
40
60
80
100
120
140
Horizon Boundary
Ice Layer
pH1
pH2

Fig. 6m

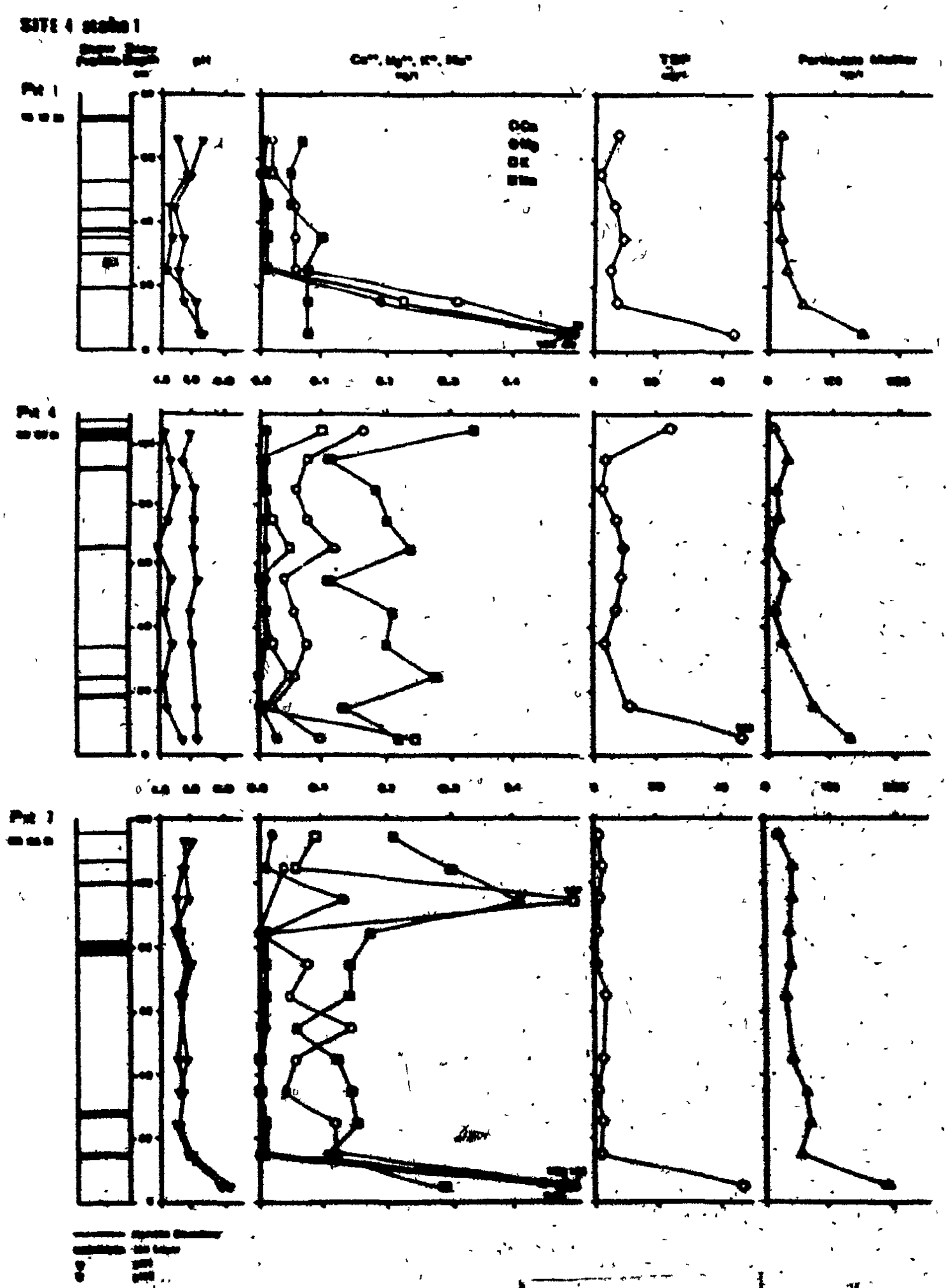

SITE 4 stake 1
pH
Ca++, Mg++, K+, Na+
TSP
Particulate Matter
Pit 1
Ca
Mg
K
Na
Pit 4
Pit 7

Fig. 6n

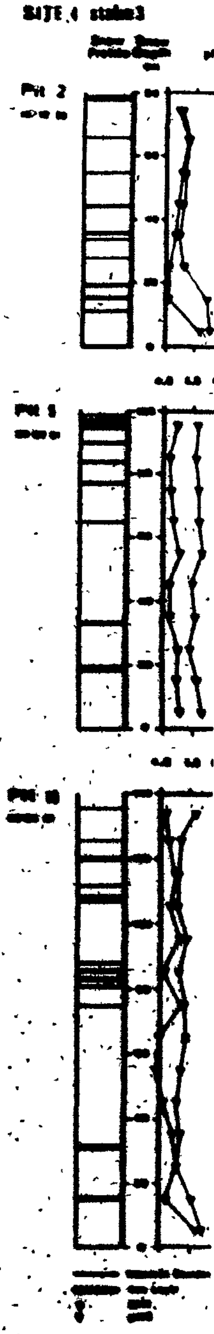

SITE 4 stake3
Pit 2
Pit 5

Fig. 6n

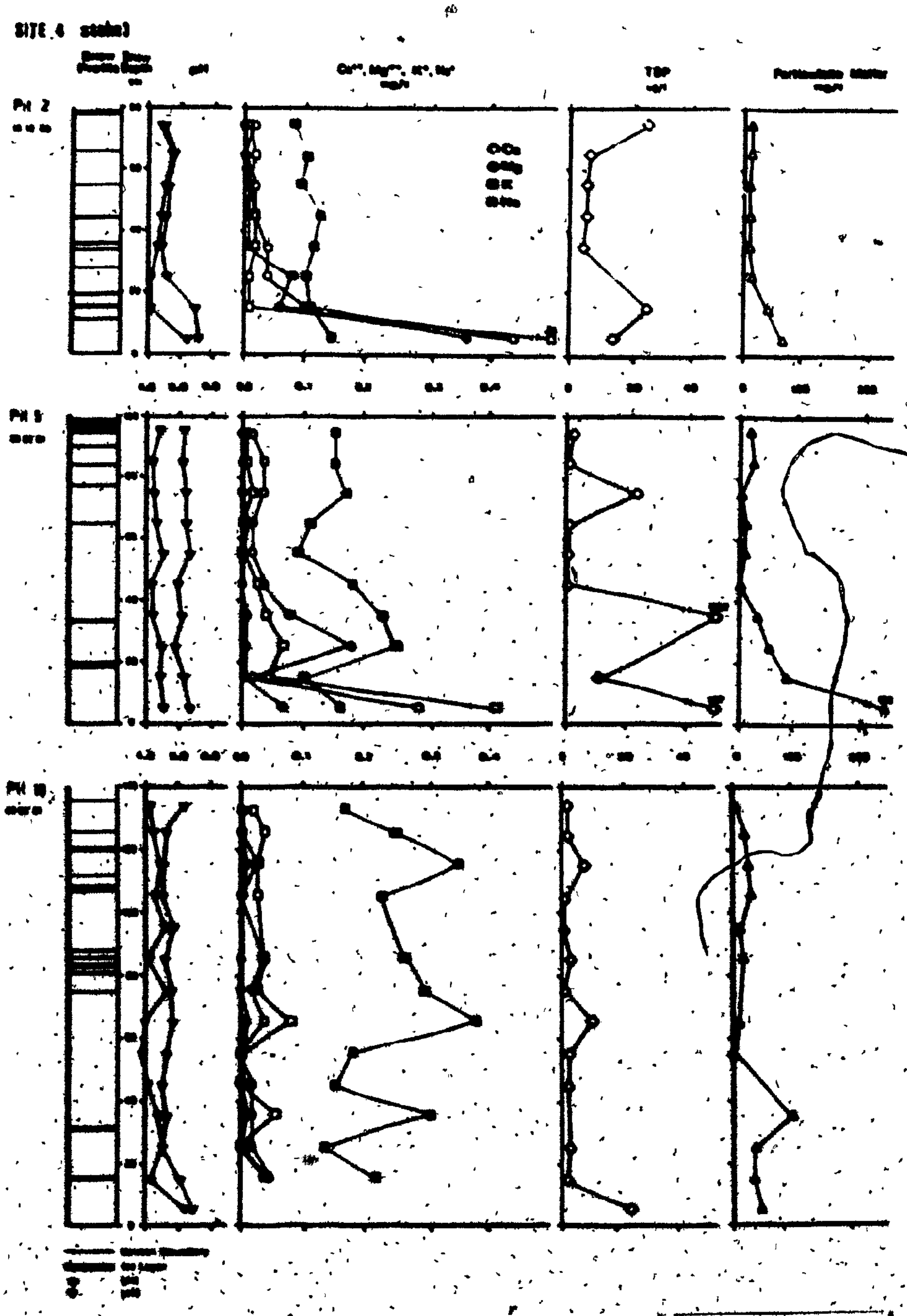
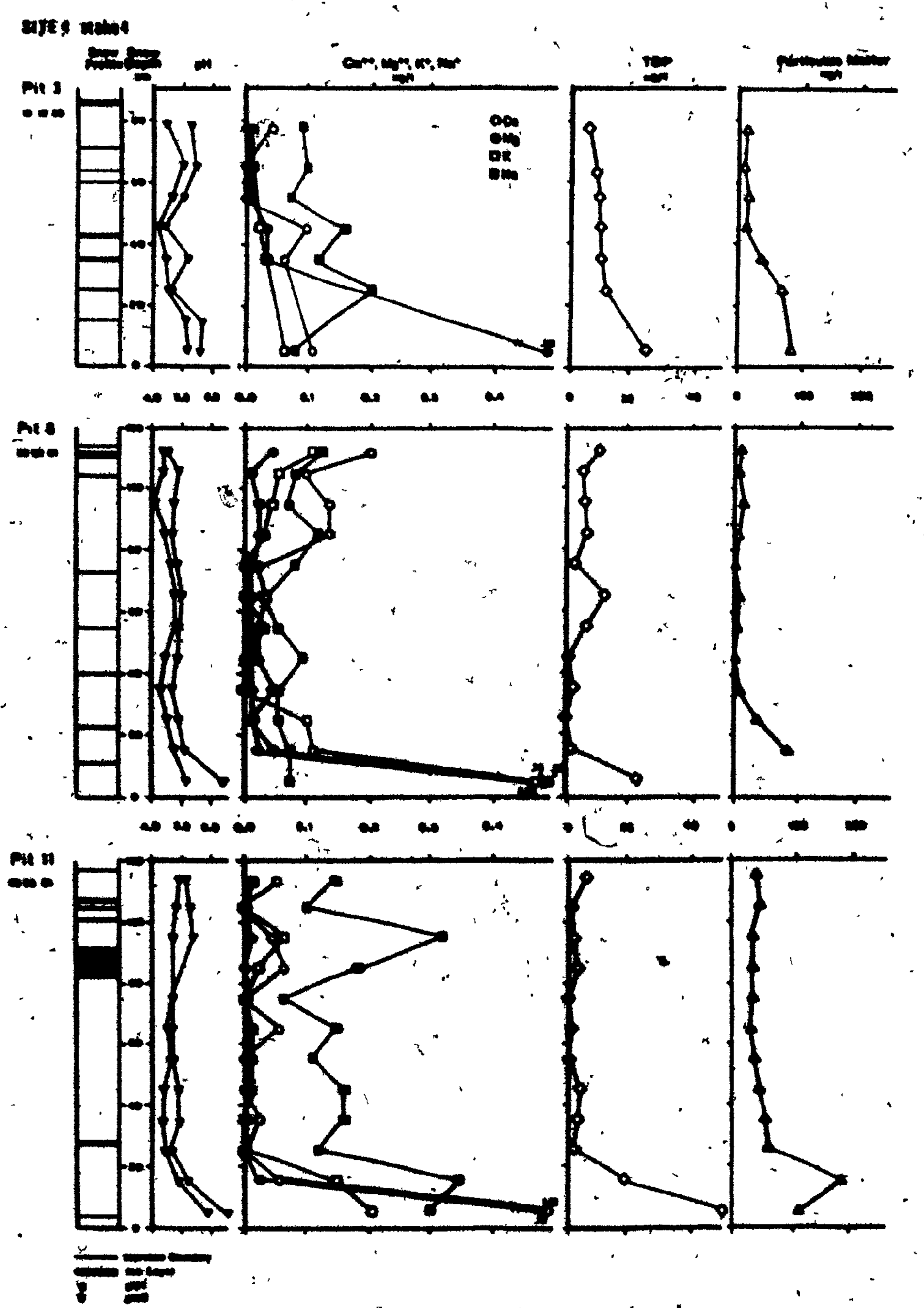
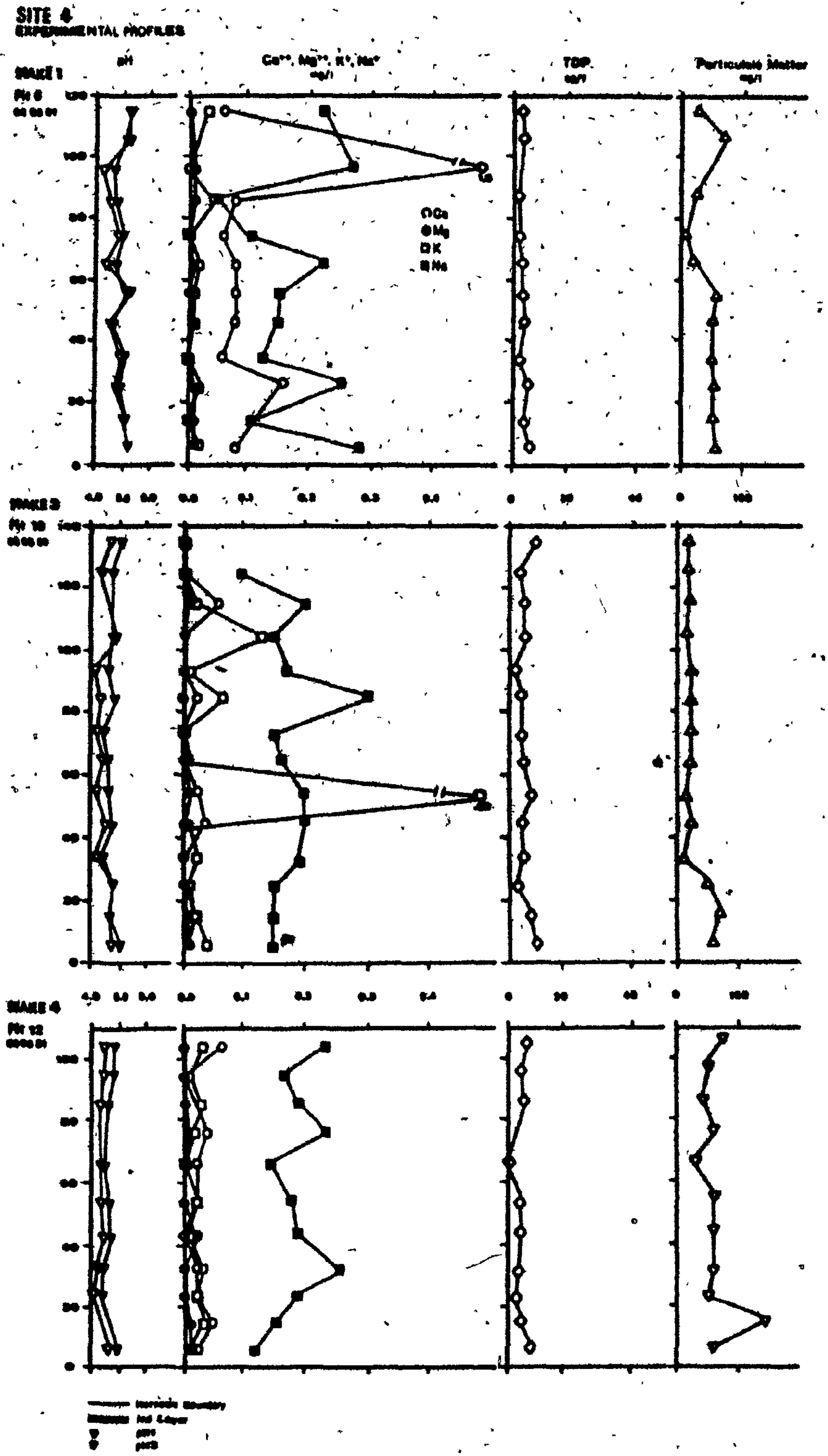


Fig. 6o


Pit 3
Pit 8
Pit 11
Snow Profile
Snow Depth cm
pH
Ca++, Mg++, K+, Na+ mg/l
Ca
Mg
K
Na
TDP
Particulate Matter mg/l
4.0
5.0
6.0
0.0
0.1
0.2
0.3
0.4
0
20
40
0
100
200


Particulate Matter
mg/l
100
200
100
200

Fig. 6p


SITE 4
EXPERIMENTAL PROFILES
pH
Ca++, Mg++, K+, Na+
mg/l
TDP
mg/l
Particulate Matter
mg/l
○Ca
●Mg
□K
■Na
120
100
80
60
40
20
0
0.0
0.1
0.2
0.3
0.4
0
20
40
0
100

2of2

the lower range of 4.0 to 4.5 and pH(2) values between 4.5 and 5.5. Cation and phosphorus concentrations are extremely low and often near the detection limit of the methods used. Of the four cations, Na is present in the highest concentrations, generally ranging from 0.1 to 0.3 mg/l, although occasional peaks in the order of 1.0 mg/l occur. Magnesium concentrations are consistently low, normally around 0.01 mg/l and rarely exceed 0.05 mg/l. Potassium concentrations were found to be highly variable. Large sections of the profiles frequently did not contain measureable amounts of K, but concentrations were also often measured at 0.2 mg/l and some peaks of 1.0 to 2.0 mg/l were measured. Ca also shows considerable variation, ranging from 0.01 to 1.0 mg/l. Total dissolved phosphorus was most commonly present in concentrations between 1 and 10 ug/l, but peaks of up to 100 ug/l in some profiles were measured. Particulate matter content was extremely variable, ranging from 1 to 1000 mg/l, however, the majority of values can be seen to fall between 1 and 100 mg/l.

The two pH values, presented in Figures 6a to 6p, are the pH of the melting snow, as slush, at 0.2°C, pH(1) and the pH of the snow meltwater in equilibrium with atmospheric CO_2 concentrations at room temperature, pH(2). The pH(2) value will be referred to in later discussions as the pH of the sampled snow, since it was measured under conditions comparable to other studies and is, therefore, a value representative of methods in standard use. However, pH(1) is more representative of the conditions found in nature, particularly in spring, when slush is present in, or at the base of, the snowpack and the temperature of the meltwater at the base of the snowpack is near 0°C.

pH(1) values are lower than pH(2) (by, in general, 0.5 pH units) and the two distribution patterns parallel one another throughout the profiles. pH is lower in the middle section of the profiles and increases toward the base of the snowpacks. This increase is seen to be most pronounced at site 4, where it was measured in every profile sampled (Figs. 6m, n and o). Surface pH(2) values range from 4.5 to 5.4 and base values from 5.0 to 6.5. An increase can also be seen in the spring profiles, 7 and 11, at site 3 (Figs. 6i and k, respectively) and at the base of profiles 1 (Fig. 6i) and 2 (Fig. 6j) sampled in December. For the remainder of the profiles at site 3, pH changes were minimal. At sites 1 and 2, the majority of the profiles show a slight decrease in the pH at the base of the snowpack. Exceptions to this are seen in profiles 1 and 4, site 2 (Fig. 6e) and profiles 1 (Fig. 6a) and 3 (Fig. 6c), site 1, sampled in December and a slight increase in the February profile, 5 (Fig. 6b), also at site 1.

Common distribution patterns frequently occur and the cations and peaks in concentrations serve to accentuate these similarities. Since Mg concentrations show the least tendency to vary through the profile and concentrations remain very low, the distribution patterns do not appear to be similar to those of the other cations. The profiles which do show very similar distribution patterns for all four cations are found at site 3, profiles 1, 4 and 7 (Fig 6i) and profiles 3 and 6 (Fig. 6k). The cations in profiles 3 (Fig. 6c) and 4 (Fig. 6a), site 1 also have very similar distribution patterns. Calcium and K parallel one another closely in all of the site 3 profiles and this can also be seen at site 4 in profiles 1 and 4 (Fig. 6m) and 5 (Fig. 6n). Sodium distributions are also often similar to those of Ca and K and at site 1, it is Ca and Na, rather than Ca and K, that show the most similar patterns. This can best be seen in the spring profiles, 7, 9 and 11.

Marked increases in concentrations occur periodically in the profiles and often correspond to peaks in particulate matter concentrations. This is most pronounced in the profiles at site 3, where all four cations and TDP frequently parallel increases in particulate matter. Profiles 1 and 4, site 3 (Fig. 6i) show this well. In profile 4, pH decreases in response to increases in particulate matter. In the same profile, the slightly higher particulate matter concentration at the surface is paralleled by higher cation and TDP concentrations and by a lower pH. In sample interval 40-50 cm, a decrease in particulate matter is paralleled by increases in TDP and cation concentrations and an increase in pH. Other examples at site 3 include profile 7 (Fig. 6i), where the cations and TDP concentrations increase in sample interval 60-70 cm, just below the increase in particulate matter at sample interval 70-80 cm and at profiles 3 and 11 (Fig. 6k), where the four cations and particulate matter increase at levels 20-30 cm and 60-70 cm. Cation and particulate matter distribution patterns are very similar in profile 5 (Fig 6j) and in profile 9 (Fig. 6i), K, Na and particulate matter at 60-70 cm is followed by an increase in all four cations at 50-60 cm.

At site 1, the only examples of corresponding increases in particulate matter and the cations include profile 1, 20-30 cm, followed by decreases at 10-20 cm, and profile 9, where the distribution of Ca and Na follow that of particulate matter reasonably well and where pH shows an inverse distribution pattern (Fig. 6a). At profile 7 (Fig 6b), Na has an erratic distribution pattern which does not reflect any obvious changes in particulate matter. The sudden increase in K also appears to be unrelated to particulate matter. A peak in Na concentration at profile 6 (Fig. 6c) 90-100 cm, corresponds to a peak in particulate matter, but there are no corresponding increases evident in the other cations.

At site 2, profile 4 (Fig. 6e), particulate matter, K Ca and TDP distributions are similar. At profile 7 (Fig. 6e), increases in K and Na at 10-20 cm appear unrelated to the other curves. Curiously, particulate matter decreases at this level, the opposite trend to what is normally found. At profile 5 (Fig. 6f), the increase in particulate matter at 50-60 cm is followed by an increase in cations and TDP at 40-50 cm. This lag is also seen in profile 9 (Fig. 6f), where particulate matter increases at 90-100 cm and Na and TDP at 80-90 cm. The other elements do not respond. In the same profile, at 30-40 cm, Na shows another strong increase and Ca and Mg also increase slightly, but this is not seen in particulate matter. Similarly, increases in K, Na and Ca in profile 11, 20-30 cm (Fig. 6g) occur independently. At site 4, several strong concentration increases occur (ie. profile 4, 60-70 cm and 7, 90-100 cm (Fig. 6m); profile 5, 20-30 cm and 9, 60-70 cm and 10-20 cm (Fig. 6n) and profile 11, 90-100 cm (Fig. 6o)) although there are no obvious, corresponding increases in particulate matter.

Cation and TDP concentrations increase at the base of many of the profiles. The magnitude of these increases varies considerably but is most pronounced in the spring profiles at site 3. In the majority of cases, particulate matter concentrations also increase. Exceptions to this pattern do occur. In many of the profiles sampled in December and February at sites 1, 2 and 3, Na concentrations decreased at this level. At site 4, this is seen only once, in the December profile, 3 (Fig. 6o). Magnesium shows the least tendency to change. Potassium, followed by Ca, shows the most dramatic increases at this level. Increases in K concentrations are in the order of 1-2 mg/l at site 3 in the spring. Ca concentrations range from 0.5 to 1.5 mg/l. In profile 7, site 4 (Fig. 6m), K increases to 2 mg/l and Ca and Mg to 1.5 mg/l. Sodium also shows an increase, but increases in the other spring profiles are modest. Increases at sites 1 and 2 do not exceed 0.6 mg/l for K.

Changes in pH at the snowpack base are not consistent. Increases were measured at all sites (Site 1, profiles 1 (Fig. 6a), 5 (Fig. 6b) and 3 and 6 (Fig. 6c); site 2, profiles 1 and 4 (Fig. 6e) and 9 (Fig. 6f); site 3, profiles 1, 4 and 7 (Fig. 6i) and 11 (Fig. 6k) and site 4, profiles 1, 4 and 7 (Fig. 6m), 2,5 and 9 (Fig. 6n) and 6 and 11 (Fig. 6o)) but occur predominantly at site 4. In these examples, the cation concentrations also show relatively large increases at the snowpack base, in comparison to the remaining cases, where decreases in pH at this level occur.

The distribution patterns for the various parameters measured, as illustrated in Figures 6a to 6p, can be summarized as follows: snow pH lies predominantly in the range of 4.5 to 5.5, the lowest pH values normally occurring in the middle layers of the snowpack. Cation and TDP concentrations are low. Sodium is present in the highest, Mg in the lowest, concentrations at all sites throughout the winter, but all the parameters show variable concentrations throughout the snowpack. Peaks in cation and TDP concentrations in the snow profiles at sites 1 and 2 are small in comparison to those at sites 3 and 4. These increases frequently correspond to increases in particulate matter in the snow profiles at the same sampling levels. This effect is most pronounced in the profiles at site 3, where particulate matter concentrations are also the largest. The greatest variations in the concentration distributions of the cations, TDP and particulate matter also occur at site 3. Sodium distributions have the most erratic pattern, which is apparent at all sites and in all the snowpacks sampled. The particulate matter concentrations at sites 1 and 4 are reasonably consistent throughout the snowpack, but at site 4, cation concentrations change considerably, regardless of this consistency. Phosphorus concentrations are comparatively stable throughout the snowpacks at sites 1 and 2, whereas concentrations vary in the snowpacks at sites 3 and 4, the greatest variations occurring at site 3. Calcium, Mg, K, TDP and particulate matter increase considerably at the base of the snowpack, the effect being most pronounced at sites 3 and 4 and least at sites 1 and 2. Although increases in Na concentrations do occur, they are not as pronounced as for the other parameters and, in many of the profiles, Na concentrations decrease.

The relationships between the parameters, as suggested by the many similar distribution patterns, were tested using

Table 6: Correlations (probability = 0.05) common to the three profiles in each site, during each sampling period

Site	December r (Fig)	February r (Fig)	April/May control profiles	April/May experimental profiles
1	- -	-		-
2	- -	-	Mg:pm 0.57(6e), 0.85(6f), 0.99(6g) K:Na 0.87(6e), 0.73(6f), 0.91(6g)	-
3	Ca:Mg 0.97(6i), 0.66(6j), 0.95(6k) Ca:K 0.88(6i), 0.82(6j), 0.98(6k) Ca:pm 0.85(6i), 0.75(6j), 0.89(6k) Mg:K 0.92(6i), 0.85(6j), 0.92(6k) Mg:pm 0.92(6i), 0.91(6j), 0.95(6k) K:pm 0.98(6i), 0.97(6j), 0.91(6k)	-	Ca:K 0.70(6i), 0.88(6j), 0.98(6k) Mg:K 0.99(6i), 0.96(6j), 0.97(6k)	Mg:Na 0.99(6l), 0.78(6l), 0.58(6l)
4	Ca:pm 0.99(6m), 0.94(6n), 0.85(6o) Mg:K 0.99(6m), 0.97(6n), 0.94(6o) Mg:pm 0.99(6m), 0.90(6n), 0.91(6o) K:pm 0.99(6m), 0.86(6n), 0.98(6o)	Mg:K 0.79(6m), 0.98(6n), 0.99(6o) K:pm 0.86(6m), 0.99(6n), 0.61(6o)	Ca:Mg 0.99(6m), 0.63(6n), 0.99(6o) Mg:K 0.86(6m), 0.66(6n) 0.80(6o) Mg:P 0.99(6m), 0.68(6n) 0.94(6o)	H1:H2 0.92(6p), 0.74(6p) 0.88(6p)

correlation analysis. The results are presented in Table 1, Appendix 3. Although there are numerous examples of significant correlations, parameters are only considered to be correlated where there is a high probability of correlation between the same parameters at all three profiles sampled. These examples are summarized (with corresponding Figures) in Table 6. The level of significance is at least 95 percent.

What is immediately apparent from the results presented in Table 6 is that there are no common patterns of correlation at site 1 during the entire winter and that correlations, common to all three profiles, only become apparent in the spring at site 2. There are significant correlations between Ca, Mg and K in the three profiles at site 3 and between these cations and particulate matter at sites 3 and 4. In February, only Mg and K and K and particulate matter were found to be correlated. There was only a slight increase in the number of correlations in the spring snowpack, and with the exception of Mg and Na at site 3 and H(1) and H(2) (pH 1 and 2) at site 4, there are no other common patterns for the control profiles.

The similarities shown by many of the distribution patterns (outlined above) at site 3, in the early winter, are supported by these significant correlations, suggesting that the concentrations of the chemical constituents in the snowpack are related and that the cations appear to be strongly related to particulate matter. In addition, as seen in Table 1, Appendix 3, there are also significant correlations between Ca, Mg and K and between K and particulate matter in one February profile, 4, at site 3, as is suggested by the distribution patterns in Figure 6i. Interestingly, the distribution patterns in the profiles at site 4 do not suggest the strong relationships between many of the parameters which become apparent from the high correlation coefficients.

At sites 1 and 2, relatively few of the relationships suggested by the graphs are supported by high correlation coefficients. However, as is apparent from some of the distributions at site 1, and as can be seen in Table 1, Appendix 3, there is a correlation between Na and the other cations in several of the profiles. The examples include profile 4 (Fig. 6a), Ca and Na (r=0.76) and Mg and Na (r=0.85); profile 5 (Fig. 6b), K and Na (r=0.97) and profile 3 (Fig. 6c) Ca and Na (r=0.88) and K and Na (r=0. 85). At site 2, the similar distributions at profile 5 (Fig. 6f) do indicate moderate correlations between Ca and Na (r=0. 79), Mg and Ca (r=0.69) and Mg and Na (r=0.71). The cations and particulate matter are correlated for the spring profiles 9 and 11.

Although the distribution patterns for pH(1) and (2) suggest that there is a strong relationship between these two values, relatively few of these examples are supported by high correlation coefficients. At site 4, the two measurements were found to be correlated in all three experimental profiles. Also of importance are the correlations at two of the December profiles, 1 and 2, at site 1 (r=0.90 and 0.83) and the February profiles, 5 and 6, at site 2 (r=0.91 and 0.99) and 4 and 6, site 3 (r=0.89 and 0.76).

4.3.2 Changes in Distribution During the Winter

It can be expected that the vertical distribution of the chemical constituents in the snowpack will change as the winter progresses for the following reasons: new precipitation inputs of different chemistries, depending on synoptic conditions; additions of litter to the snowpack and litter decomposition and leaching; snow/soil interactions which will particularly affect the lower snowpack sections and snow metamorphosis, as evidenced by changing snow densities, crystal sizes and ice lenses (section 4.2.2). The decrease in the number of common correlation patterns (Table 6) at sites 3 and 4 after December may be as a result of the changing nutrient and/or particulate matter distributions in the snowpack.

pH, cation, TDP and particulate matter distributions do change as the winter progresses. The changes are, however, often inconsistent, not only between sites, but also within the same site and common patterns are not always easily discernible. There do not appear to be any large, overall changes in the snowpack pH at site 1 during the winter, with the exception of sampling location 1 (Fig. 6a), where pH increases from February to May (from a range of 4.5-5.0 to 5.0-5.5) in the upper and middle profile sections. No major shifts in pH are obvious between February and May, with the exception of decreases in the base sample values from 5.1 to 4.6. At site 2, pH decreases between December and February at stake locations 1 and 5 (Figs. 6e and g), whereas there is little apparent change at stake location 4 (Fig. 6f). In May, pH shows obvious increases throughout the profiles at all three sampling locations; the range of values increases from an overall 4.3 to 4.8 in February to 4.4 to 5.2 in May.

At site 3, the very erratic December pH distribution at sampling location 1 (Fig. 6i), with very large variations, becomes more uniform in February and, with the exception of a large increase in the base sample (4.3 to 5.0), very little change occurs between February and May. At the other two sampling locations, pH values are generally less than 5.0 throughout the profile during the winter, although the increase, measured in the lower profile section at profile 7, also occurred in profiles 6 and 11 (Fig. 6g), increasing from 4.6 to 5.7.

Snow pH increases from December to February at sampling locations 1 (Fig. 6m) and 3 (Fig. 6n), site 4. This is followed by slight, overall decreases in May. At location 4 (Fig. 6o), pH values become more uniform in February, compared to December, although a large increase in the base sample from 4.5 to 6.5 occurs. The overall pH distribution does not, however, exceed 5.0, being lower than the other two February profiles. Little change is apparent between the February and May profiles at this stake location.

There is a general increase in Ca concentrations in the profiles at site 1 over the winter, although depletions at certain levels between February and May do occur. This is particularly noticeable in the surface layer concentrations. At site 2, Ca concentrations are considerably higher in the profiles at stake location 4 (Fig. 6f), than at the other sampling locations, throughout the winter. These concentrations decrease between December and February, whereas those at stake locations 1 and 5 increase. By May, Ca has been depleted from the upper profile sections at all three sampling locations.

At site 3, comparatively high Ca concentrations are seen in the surface snow layers in Figures 6i and 6k in February. The only large increases in Ca concentrations between February and May occur at stake location 1 (Fig. 6i) and this increase is, once again, very pronounced in the surface sample (0.46 to 1.84 mg/l). There is an increase of the same magnitude (0.27 to 1.82 mg/l) in the base sample. Calcium concentrations are very low in the upper and middle section of the December snowpack at all profiles sampled at site 4, with only slight increases in the lower depths. The concentrations change very little throughout the winter, although higher Ca concentrations are seen in the February profiles (Figs 6m and 6o).

Magnesium concentrations are very low at all sites and do not change appreciably during the winter. At site 1, Mg is absent from the upper section of the snowpack (80-40 cm) and present in only very small concentrations (0.02 mg/l) in the lower profile sections. A slight increase occurs by February in the lower profiles (particularly noticeable in the base sample at profile 6 (Fig. 6c)), but concentrations otherwise remain low (0.05 mg/l). By May, Mg appears to have been depleted from the snowpack at this site. Magnesium concentrations are practically negligible throughout the winter in the snowpacks at site 2, showing no appreciable increases from December to May. In comparison to the other cations in the profiles at site 3, Mg concentrations are low, but noticeably higher than the concentrations at the other three sites. Magnesium is absent from the upper sections of all three December profiles but shows definite increases in the lower half of the profiles. These concentrations are higher than those measured in either February or May. In the February and May profiles at stake location 1 (Fig. 6i), concentrations decrease toward the middle of the profile and increase in the lower section. This pattern is not evident at locations 4 and 5, where concentrations at all depths remain very low. Magnesium concentrations do not exceed 0.01 mg/l at most sampling levels in the snowpack at site 4 throughout the winter, with the exceptions of the samples from the base of the profiles.

Although present in measureable amounts in the December snowpack at site 1, K is noticeably depleted from the February profiles, being totally absent from the upper and middle profile sections. Only negligible addition of K occurs between February and May (from 0.00 t0 0.02 mg/l) and this is limited to only a few sampling intervals, although at level 90-100 cm, profile 7 (Fig. 6b), a very large increase to 0.55 mg/l occurs. Potassium also becomes depleted from the profiles at sampling locations 4 and 5 (Figs. 6f and g), site 2, although concentrations increase in the profiles at stake location 1 (Fig. 6e). There are also large increases in K concentrations at the base of the profiles sampled in May. At site 3, K does not appear to become depleted from the snowpack. However, concentrations are higher in the upper and lower profile sections than in the middle section in February and decrease at one sampling location in May. Changes are not apparent at stake locations 1 and 4. Potassium concentrations are very low in the upper and middle profile sections at site 4 and this pattern does not noticeably change from December to May.

Because of the great variability in Na concentrations throughout the profiles, it is difficult to identify patterns of change. At sites 1, 2 and 4, Na concentrations remain higher than the other cations through the winter. Concentrations remain very variable and no apparent overall shifts toward higher or lower concentrations occur at sites 1 and 2. At site 4, an increase occurs from December to May. At site 3, K concentrations frequently exceed those of Na at many sampling levels during December and February, but, in May, increases in Na concentrations at all three profile locations occur so that Na concentrations eventually exceed those of K.

Phosphorus concentrations show a tendency to decrease from December to May at sites 1, 2 and 4 and become more uniform in the profile as the winter progresses. At site 3, TDP distributions show a strong pattern of depletion in the centre profile sections which becomes more pronounced between December and February and which is accentuated by the very large concentrations in the snowpack base samples.

Changes in particulate matter distributions in the profiles are most likely due to the large degree of within-site variability of this parameter. Particulate matter may also be redistributed in the snowpack through transport with percolating meltwater. At site 1, particulate matter concentrations are reasonably consistent throughout the winter, showing some increased variability in the May profiles. Concentrations appear to become more variable between December and February in the site 2 snowpacks. Particulate matter distribution is very variable at site 3, particularly in the February profiles, which also show general increases in concentration compared to the December values. This variability decreases somewhat by May and overall concentrations also appear to decrease. Concentration patterns remain the same throughout the winter at site 4; low concentrations in the upper and middle profile sections and increasing in the lower profile sections.

Table 7: The bulk chemical composition of the snowpack expressed as the mean of n 10 cm depth samples from each profile

Site	Date	Stake No/ Profile	pH(1) (n)	pH(2) (n)	Ca (n)	Mg (n)	K (n)	Na (n)	TDP (n)	p.m. (n)
					mg/1	mg/1	mg/1	mg/1	ug/1	mg/1
1	15.12.80	1/1	4.41±0.27(8)	4.98±0.42(7)	0.033±0.013(8)	0.006±0.010(8)	0.078±0.048(8)	0.204±0.047(8)	11.5±6.04(8)	31.6±24.8(8)
	15.12.80	2/2	4.39±0.20(8)	5.01±0.44(6)	0.020±0.013(7)	0.008±0.007(8)	0.033±0.020(8)	0.108±0.022(8)	7.81±3.71(8)	31.5±41.2(8)
	15.12.80	4/3	4.48±0.23(8)	4.94±0.39(8)	0.033±0.027(8)	0.006±0.005(8)	0.036±0.033(8)	0.121±0.032(8)	8.63±3.25(7)	27.3±8.78(8)
1	22.02.81	1/4	4.42±0.12(11)	4.78±0.14(11)	0.082±0.132(11)	0.021±0.020(11)	0.018±0.030(11)	0.080±0.035(11)	5.28±2.87(11)	nd
	22.02.81	2/5	4.32±0.23(13)	4.73±0.21(13)	0.066±0.034(12)	0.017±0.015(12)	0.075±0.174(12)	0.195±0.260(12)	5.42±2.84(13)	nd
	22.02.81	4/6	4.34±0.26(12)	5.08±0.18(11)	0.077±0.069(12)	0.018±0.054(12)	0.018±0.028(12)	0.235±0.256(12)	6.30±3.85(11)	33.5±51.2(11)
1	30.04.81	1/9	4.26±0.28(15)	5.09±0.30(15)	0.069±0.032(15)	0.007±0.005(15)	0.009±0.023(15)	0.134±0.045(15)	3.99±2.82(15)	57.0±106 (15)
	30.04.81	2/7	4.11±0.17(14)	4.83±0.20(14)	0.048±0.027(14)	0.006±0.006(14)	0.097±0.194(14)	0.190±0.076(14)	3.97±1.49(14)	37.1±11.7(14)
	02.05.81	4/11	4.60±0.19(13)	4.72±0.19(13)	0.075±0.060912)	0.005±0.005(13)	0.022±0.031(13)	0.164±0.049(13)	2.63±2.29(13)	106 ± 164 (13)
1	30.04.81	1/10	4.18±0.31(15)	5.00±0.22(15)	0.067±0.043(14)	0.006±0.005(15)	0.004±0.011(15)	0.126±0.039(15)	3.59±1.10(15)	63.1±62.3(15)
	30.04.81	2/8	4.53±0.36(14)	4.81±0.20(14)	0.053±0.021(15)	0.008±0.005(15)	0.006±0.070(15)	0.137±0.029(14)	2.68±2.09(14)	50.8±27.0(14)
	02.05.81	4/12	4.68±0.28(13)	4.75±0.19(13)	0.066±0.023(14)	0.006±0.005(14)	0.010±0.010(14)	0.124±0.032(14)	3.41±2.25(12)	61.7±27.9(11)
2	12.12.82	1/1	4.40±0.14(3)	4.52±0.12(3)	0.020±0.026(3)	0.010±0.000(3)	0.025±0.035(3)	0.110±0.062(3)	5.73±2.47(3)	14.7±0.57(3)
	12.12.80	4/2	4.47±0.12(5)	4.84±0.29(5)	0.068±0.018(5)	0.016±0.009(5)	0.075±0.030(4)	0.136±0.073(5)	9.68±4.78(5)	76.6±70.3(5)
	12.12.80	5/3	4.72±0.17(4)	5.26±0.32(3)	0.010±0.000(4)	0.000±0.000(4)	0.013±0.005(4)	0.165±0.100(4)	6.32±0.27(4)	3.10±14.1(4)
2	24.02.81	1/4	4.45±0.12(5)	4.62±0.13(5)	0.056±0.029(5)	0.014±0.006(5)	0.052±0.018(5)	0.110±0.021(5)	9.63±4.77(5)	137 ± 89.4(5)
	24.02.81	4/5	4.56±0.15(9)	4.65±0.15(8)	0.040±0.025(9)	0.010±0.005(9)	0.033±0.039(9)	0.108±0.050(9)	6.13±2.34(9)	129 ± 105 (9)
	24.02.81	5/5	4.32±0.09(4)	4.55±0.17(4)	0.070±0.039(4)	0.023±0.013(4)	0.008±0.015(4)	0.070±0.025(4)	4.93±0.73(4)	92 ± 27.5(4)
2	04.05.81	1/7	4.65±0.45(8)	4.97±0.14(8)	0.021±0.045(8)	0.006±0.011(8)	0.053±0.081(8)	0.123±0.032(8)	5.06±2.27(8)	83.4±14.6(8)
	04.05.81	4/9	4.38±0.37(11)	4.77±0.22(11)	0.023±0.056(9)	0.006±0.013(10)	0.016±0.034(10)	0.121±0.043(10)	3.49±0.94(11)	61.6±75.7(11)
	04.05.81	5/11	4.19±0.32(7)	4.78±0.20(7)	0.050±0.065(6)	0.042±0.083(6)	0.040±0.062(7)	0.152±0.036(5)	4.68±3.53(7)	248± 575 (7)
2	04.05.81	1/8	4.80±0.28(7)	4.88±0.29(7)	0.009±0.011(7)	0.007±0.011(7)	0.011±0.022(7)	0.110±0.037(7)	4.11±1.12(7)	74.9±22.0(7)
	04.05.81	4/10	4.14±0.32(11)	4.75±0.26(11)	0.045±0.089(10)	0.010±0.011(11)	0.020±0.043(11)	0.159±0.105(11)	3.74±1.12(11)	48.6±36.5(11)
	04.05.81	5/12	4.21±0.20(7)	5.02±0.44(7)	0.009±0.016(7)	0.003±0.005(7)	0.004±0.005(7)	0.127±0.021(7)	4.13±1.90(7)	20.9±12.5(7)

Site	Date	Stake No/ Profile	pH(1) (n)	pH(2) (n)	Ca (n)	Mg (n)	K (n)	Na (n)	TDP (n)	pm (n)
					mg/1	mg/1	mg/1	mg/1	ug/1	mg/1
3	11.12.80	1/1	4.57±0.44(7)	5.45±0.63(7)	0.090±0.070(6)	0.043±0.057(7)	0.204±0.353(7)	0.069±0.025(7)	23.1±46.3(7)	71.2±95.4(7)
	13.12.80	5/2	4.64±0.28(8)	4.90±0.33(8)	0.086±0.078(8)	0.023±0.031(8)	0.176±0.308(8)	0.131±0.091(8)	50.4±57.4(7)	42.9±69.6(8)
	13.12.80	4/3	4.56±0.23(6)	4.84±0.27(6)	0.055±0.057(6)	0.023±0.025(6)	0.110±0.134(6)	0.098±0.055(6)	21.0±17.1(6)	56.2±61.1(6)
3	23.02.81	1/4	4.49±0.24(9)	4.68±0.21(9)	0.144±0.143(9)	0.072±0.071(9)	0.310±0.345(9)	0.109±0.052(9)	17.2±15.5(9)	176 ± 166 (9)
	23.02.81	5/5	4.36±0.23(11)	4.60±0.15(11)	0.077±0.067(11)	0.034±0.029(11)	0.315±0.381(11)	0.125±0.058(11)	13.6±16.1(11)	194 ± 186 (11)
	24.02.81	6/4	4.50±0.16(10)	4.56±0.16(11)	0.060±0.056(12)	0.035±0.046(12)	0.119±0.127(12)	0.090±0.042(12)	13.7±12.8(12)	89.2±35.7(12)
3	09.05.81	1/7	4.60±0.41(9)	4.82±0.38(9)	0.503±0.755(9)	0.122±0.240(9)	0.462±0.869(9)	0.206±0.034(9)	12.0±15.0(9)	72.3±23.9(8)
	11.05.81	[illegible]	4.49±0.15(13)	4.77±0.19(13)	[illegible]	0.012±0.012(13)	0.136±0.222(13)	0.120±0.220(13)	14.7±22.9(13)	95.5±196 (13)

2	04.05.81	1/8	4.80±0.28(7)	4.88±0.29(7)	0.009±0.011(7)	0.007±0.011(7)	0.011±0.022(7)	0.110±0.037(7)	4.11±1.12(7)	74.9±22.0(7)
	04.05.81	4/10	4.14±0.32(11)	4.75±0.26(11)	0.045±0.089(10)	0.010±0.011(11)	0.020±0.043(11)	0.159±0.105(11)	3.74±1.12(11)	48.6±36.5(11)
	04.05.81	5/12	4.21±0.20(7)	5.02±0.44(7)	0.009±0.016(7)	0.003±0.005(7)	0.004±0.005(7)	0.127±0.021(7)	4.13±1.90(7)	20.9±12.5(7)

Site	Date	Stake No/ Profile	pH(1) (n)	pH(2) (n)	Ca (n)	Mg (n)	K (n)	Na (n)	TDP (n)	pm (n)
					mg/l				ug/l	mg/l
3	11.12.80	1/1	4.57±0.44(7)	5.45±0.63(7)	0.090±0.070(6)	0.043±0.057(7)	0.204±0.353(7)	0.069±0.025(7)	23.1±46.3(7)	71.2±95.4(7)
	13.12.80	5/2	4.64±0.28(8)	4.90±0.33(8)	0.086±0.078(8)	0.023±0.031(8)	0.176±0.308(8)	0.131±0.091(8)	50.4±57.4(7)	42.9±69.6(8)
	13.12.80	4/3	4.56±0.23(6)	4,84±0.27(6)	0.055±0.057(6)	0.023±0.025(6)	0.110±0.134(6)	0.098±0.055(6)	21.0±17.1(6)	56.2±61.1(6)
3	23.02.81	1/4	4.49±0.24(9)	4.68±0.21(9)	0.144±0.143(9)	0.072±0.071(9)	0.310±0.345(9)	0.109±0.052(9)	17.2±15.5(9)	176 ± 166 (9)
	23.02.81	5/5	4.36±0.23(11)	4.60±0.15(11)	0.077±0.067(11)	0.034±0.029(11)	0.315±0.381(11)	0.125±0.058(11)	13.6±16.1(11)	194 ± 186 (11)
	24.02.81	6/4	4.50±0.16(10)	4.56±0.16(11)	0.060±0.056(12)	0.035±0.046(12)	0.119±0.127(12)	0.090±0.042(12)	13.7±12.8(12)	89.2±35.7(12)
3	09.05.81	1/7	4.60±0.41(9)	4.82±0.38(9)	0.503±0.755(9)	0.122±0.240(9)	0.462±0.869(9)	0.206±0.034(9)	12.0±15.0(9)	72.3±23.9(8)
	11.05.81	5/9	4.48±0.15(13)	4.77±0.18(13)	0.120±0.220(13)	0.012±0.012(13)	0.136±0.272(13)	0.120±0.220(13)	14.7±22.9(13)	95.5±196 (13)
	11.05.81	4/11	4.40±0.29(15)	4.83±0.36(6)	0.057±0.108(15)	0.014±0.022(15)	0.189±0.401(15)	0.167±0.065(15)	33.5±50.9(13)	156 ± 234 (15)
3	09.05.81	1/8	4.60±0.11(7)	4.78±0.12(7)	0.437±0.650(9)	0.089±0.152(9)	0.424±0.703(9)	0.269±0.228(9)	5.68±1.90(8)	72.0±28.7(7)
	11.05.81	5/10	4.56±0.25(13)	4.83±0.18(13)	0.045±0.044(13)	0.009±0.006(13)	0.125±0.097(13)	0.164±0.049(13)	23.7±28.9(13)	33.2±22.1(13)
	11.15.81	4/12	4.34±0.20(.5)	4.75±0.20(15)	0.078±0.086(15)	0.012±0.009(15)	0.129±0.137(15)	0.174±0.057(15)	13.3±10.2(15)	120 ± 60.7(14)
4	16.12.80	1/1	4.65±0.44(7)	4.86±0.39(7)	0.187±0.208(7)	0.119±0.223(7)	0.273±0.539(6)	0.073±0.018(7)	12.2±14.4(7)	41.4±49.2(7)
	16.12.80	3/2	4.40±0.36(8)	4.76±0.41(8)	0.084±0.143(8)	0.118±0.122(8)	0.118±0.292(8)	0.194±0.261(8)	12.7±8.13(7)	24.4±22.3(8)
	16.12.80	4/3	4.63±0.37(8)	5.10±0.45(8)	0.052±0.048(6)	0.100±0.211(6)	0.026±0.021(5)	0.117±0.047(7)	11.4±6.76(7)	34.3±28.9(7)
4	22.02.81	1/4	4.28±0,22(11)	5.07±0.15(10)	0.078±0.038(11)	0.010±0.008(11)	0.047±0.073(11)	0.201±0.069(11)	14.2±16.0(10)	34.0±39.5(10)
	23.02.81	3/5	4.38±0.16(10)	5.14±0.13(10)	0.074±0.087(10)	0.012±0.024(10)	0.064±0.124(10)	0.159±0.052(10)	26.8±45.7(9)	84.6±186 (10)
	23.02.81	4/6	4.45±0.25(12)	4.87±0.46(12)	0.108±0,147(12)	0.078±0.215(12)	0.275±0.821(12)	0.078±0.029(12)	6.51±6.86(12)	18,9±23.7(11)
4	03.05.81	1/7	4.86±0,38(11)	4,92±0.45(11)	0.616±1.280(10)	0.143±0.429(12)	0.302±0.677(12)	0.182±0.097(12)	6.36±13.5(11)	56.5±46.1(11)
	09.05.81	3/9	4.37±0.34(14)	4.80±0.26(14)	0,020±0.018(12)	0.003±0.005(12)	0.031±0.024(12)	0.242±0.078(12)	4,58±5.46(13)	28.4±26.9(12)
	03.05.81	4/11	4.68±0.43(11)	5.06±0.55(11)	0.123±0.328(12)	0.084±0.207(12)	0.039±0.066(12)	0.179±0.091(12)	7.93±14.5(12)	60.1±42.3(12)
4	03.05.81	1/8	4.82±0.34(12)	4.93±0.20(12)	0.258±0.557(10)	0.006±0.005(11)	0.014±0.014(11)	0.179±0.076(11)	2.86±1.09(11)	36.3±23.6(11)
	09.05.81	3/10	4.46±0.26(13)	4.96±0.22(13)	0.011±0,017(14)	0,003±0.003(14)	0.061±0.137(14)	0.175±0.047(13)	4.66±2.67(14)	26.0±154 (14)
	03.05.81	4/12	4.29±0.16(9)	4.64±0.18(9)	0.025±0.020(10)	0.005±0.007(11)	0.019±0.010(11)	0.183±0.040(11)	4.19±1.73(10)	57.1±32.6(11)

4.3.3 Intra-Site Variability in Snowpack Chemistry

The mean pH, cation and particulate matter concentrations for each profile are presented in Table 7. The within-site differences between mean concentrations were assessed using the t-statistic. The results are presented in Table 2, Appendix 3. For the majority of comparisons, the resultant t-statistics are very low and significant differences are not apparent, indicating that, in general, within-site differences in snow chemistry are minor. There are, however, some between-profile differences which are significant at at least the 95 percent level.

Significant differences at site 1 include mean K and Na concentrations in December, mean pH(2) values in February and mean pH(1) and (2) and Na concentrations in April. Differences in mean pH(1) and (2) in the experimental profiles are also significant. At site 2, parameters which show some significant differences include pH, K and particulate matter in December, K, Na and TDP in February and pH in May. Differences in particulate matter concentrations and mean pH(1) are significant at the experimental profiles. Other than significant differences between all three experimental profiles for particulate matter and TDP, the mean values for the chemical parameters at site 3 are comparable during the three sampling periods. The only exception is pH(2) in December. Differences between mean December Na concentrations were found to be significant as well as differences between mean pH(1) values and between mean particulate matter concentrations in February and May. Between the experimental profiles, mean pH(1) and (2) and TDP are all significantly different.

The nutrient content of the snowpack has been calculated in kg/ha from the mean profile concentrations and the snowpack water equivalents. These values are given in Table 8. Since nutrient contents account for the varying water equivalents of the snowpacks at the sampling locations, they should remove some of the variability, shown by the mean concentrations, if differences in water equivalents are causing these variations. It is, however, clear from Table 8 that within-site variability still remains, even when nutrient contents are expressed in absolute amounts. For example, at site 1, K contents ranged from 0.06 to 0.15 kg/ha, as measured at the three December profiles, 0.06 to 0.15 kg/ha in February and 0.05 to 0.12 kg/ha in April. Na contents ranged from 0.26 to 0.84 kg/ha in February and particulate matter from 113 to 581 kg/ha in April. At site 2, large differences were seen in Mg, which ranged from 0.03 to 0.13 kg/ha in April, K ranging from 0.02 to 0.12 kg/ha in December and 0.01 to 0.10 kg/ha in February and particulate matter from 15 to 119 kg/ha in December, 115 to 488 kg/ha in February and 328 to 791 kg/ha in May. Phosphorus contents ranged from 0.04 to 0.11 kg/ha in December at site 3, but the largest variations at site 3 occurred in the spring: Ca, 0.50 to 2.0 kg/ha; Mg, 0.05 to 0.50 kg/ha; K, 0.6 to 1.9 kg/ha; TDP 0.05 to 0.16 kg/ha and particulate matter, 294 to 758 kg/ha. Particularly large variations occurred, also in the spring, at site 4: Ca, 0.09 to 2.80 kg/ha; Mg, 0.01 to 0.07 kg/ha; K, 0.14 to 1.37 kg/ha and TDP, 0.04 to 0.21 kg/ha.

4.3.4. Inter-Site Variability in Snowpack Chemistry

Inter-site comparisons are concerned with the following considerations:

i) whether or not a pattern of consistently higher concentrations in all three profiles at one site can be identified:
ii) whether or not the mean values are consistently higher (or lower) at any one site throughout the winter and
iii) whether the differences between the sites are significant.

The t-statistics for these comparisons are found in Table 3, Appendix 3.

Table 9: Inter-sits comparisons of snowpack chemistry showing a) the general between-site relationship and b) the individual between-site comparisons for each parameter

December	a) general relationship	b) between-site comparisons 9/9	8/9	7/9	6/9	5/9
pH1	3>2=4>3>1	3>1		4>1	2>1 3>2	4>2 4>3
pH2	1>3>2>4				1>2 1>3 1>4 3>2 3>4	2>4
Ca	3>4>1>2	3>1* 4>1	3>2 4>2			1>2 3>4
Mg	4>3>2>1	3>1 4>1 3>2 4>2 4>3			2>1	
K	3>4>1>2	3>1 3>2 4>2		1>2	4>1	3>4
Na	2>1>4>3		2>3	1>3	1 4 4>3	2>1 2>4
TDP	3>4>1>2	3>1 3>2 4>2 3>4	4>1	1>2		
PM	3>4>2>1	3>1 3>4			2>1 4>1 3>2	4>2

February	a) general relationship	b) between-site comparisons 9/9	8/9	7/9	6/9	5/9
pH1	3>2>4>1		3>1 3>4		2>4	2>1 4>1 3>2
pH2	4>1>3>2	1>2* 1>3* 4>2* 4>3‡	4>1			3>2
Ca	4>1>3>2		1>2 3>2		4>1 4>3	1>3
Mg	3>1>4=2	3>1 3>2		1>2	1>4 3>4	4=2
K	3>4 1>2	3>1‡ 3>2‡	4>2 3>4	4>1		1>2
Na				1>2 4>2	1>3 1>4 3>2 4>3	
TDP	4>3>2>1		4>2			2>1 4>3
PM	3>4>2>1				3>2	2>1 3>1 4>1

May	a) general relationship	b) between-site comparisons 9/9	8/9	7/9	6/9	5/9
pH1	4>3>2>1		4>1	4>2	2>1 3>1 3>2 4>3	
pH2	4>1>3=2		4>2 4>3			1>2 1>3 4>1 3=2
Ca	4>3>1>2	3>2	1>2	3>1 4>1	4>2	4>3
Mg	4>3>2>1	3>1		3>2	4>1 4>2	2>1 4>3
K	3>4>2>1	3>1 3>2		4>1 4>2 3>4		2>1
Na	4>3>1>2	3 2* 4 2*	1>2	3>2 4>1	4>3	
TDP	3>4>1>2	3>1 4>1 3>2 3>4		4>2	1>2	
PM	3>2>1>4	2>4 3>4		2>1 3>1	1>4	3>2

significant differences (α=0.05) between
= 9 comparisons
: 8 comparisons
: 7 comparisons

Table 9 (compiled from Table 3, Appendix 1) describes the relationships between the four sites for each parameter during the three different sampling periods. The generalized comparisons on the left organize the sites in order of decreasing mean pH, cation and particulate matter concentrations. On the right, this comparison is broken down to show how this generalized relationship is determined. Six between-site comparisons are possible: site 1 vs 2, 3 and 4; site 2 vs 3 and 4 and site 3 vs 4. By referring to these comparisons in Table 3, Appendix 1, it was determined (on the basis of a majority out of the nine between-profile comparisons), at which site a given parameter had the highest mean value. The optimal situation occurs where all nine comparisons indicate higher mean values at the profiles at one site. This, however, seldom occurs because of the intra-site spatial variations in snowpack chemistry, outlined in the preceding sections.

For the samples in question, it can only be interpreted, with any certainty, that a given parameter is present in significantly higher concentrations in the profiles at one site when all nine comparisons show significantly higher concentrations at one site. Of the comparisons in Table 9, this situation occurs once. It has been indicated whether seven, eight or nine of the comparisons are significantly greater at one site.

With reference to Table 9, the majority of comparisons indicate that mean pH(1) values at sites 2, 3 and 4 are greater than at site 1 and greater at site 3 than at site 2. The pattern is not as clear between sites 2 and 4 and sites 3 and 4. In February, the majority of comparisons indicate lower mean pH(1) in the snowpack at site 4 than at sites 2 and 3, whereas in spring, pH is higher at site 4 than at sites 2 and 3.

Between December and May, there is a general increase in the number of occurrences where mean pH(1) is significantly higher in the snowpack at one site compared to another site (Table 3, Appendix 3). With the exception of site 2 vs 3, this trend is seen in all the other between-site comparisons. However, the number of significantly higher values at one site are too few to consider differences in mean pH(1) as being, in general, significant.

Mean pH(2) show the opposite pattern to pH(1). The majority of comparisons are consistently higher at site 1 than at sites 2, 3 and 4, higher in December at site 3 than at sites 2 and 4 and at site 2 than at site 4. This pattern continues through the winter. In February, the mean pH(2) of the snowpack is highest at site 4. This is maintained into spring.

The occurrences of a significantly higher mean pH(2) at any one site increase between December and February. During the February sampling period, the mean pH(2) of the snowpack at sites 1 and 4 is significantly higher than at sites 2 and 3 and significantly higher in five of the eight comparisons at site 4 than at site 1. Little difference between sites 2 and 3 is apparent. The significant differences are not maintained in May.

Calcium, Mg, K, TDP and particulate matter show a common pattern in December; mean concentrations for these parameters are higher for the majority of comparisons at sites 3 and 4 than at sites 1 and 2. For many comparisons, mean values at site 3 are greater than at site 1 or 2 in all nine between-profile comparisons. This also occurs for comparisons between sites 4 and 2 and sites 4 and 1, although not as frequently, where all nine comparisons indicate the largest mean values at site 4. Sodium shows the opposite pattern; higher mean Na concentrations occur at sites 1 and 2 than at sites 3 and 4. When pH(2) is interpreted in terms of H ion concentrations, then the same pattern also partially applies; higher H ion concentrations in the snowpack at sites 3 and 4 than at site 1 and higher H ion concentrations at site 4 than at site 2.

Comparisons between sites 1 and 2 and between sites 3 and 4 are not as consistent. Higher mean Ca, K and TDP concentrations are more prevalent at site 1 compared to site 2 and at site 3 than at site 4. Particulate matter concentrations are also higher at site 3 than at site 4. Higher K and Na concentrations occur at site 2 compared to site 1 and at site 4 compared to site 3. The comparisons in Table 9 show that the above described patterns are largely maintained throughout the winter with a few reversals between sites 1 and 2 and sites 3 and 4. In February, the dominance of one site over the next is noticeably less for certain comparisons, particularly for Ca and Mg. In April/May, the comparisons of mean Na concentrations agree with those of the other elements.

Within this overall pattern, there are few examples of significantly greater concentrations at any given site. Where significant differences do occur, they are generally significantly higher at site 3 (Table 9). The most notable examples are the following: in December, Ca is present in significantly higher mean concentrations in the snow profiles sampled at site 3 than at site 2. Mean K concentrations are likewise significantly higher in the snow from profiles at site 3 than at either sites 1 or 2 in February. Mean Na concentrations are significantly higher in the snowpacks at sites 3 and 4 compared to site 2. The number of differences, where mean TDP concentrations are significantly higher at site 3 compared to site 1, increase from December to February and are maintained in spring. Mean pH(2) is significantly higher in February at site 1 and 4 compared to sites 2 and 3, indicating higher (although not necessarily significantly higher) H ion concentrations at sites 2 and 3 compared to sites 1 and 4.

To see if the general patterns described above and seen in Table 9 would also apply when combined mean values are compared, the mean values for pH, Ca, Mg, K, Na, TDP and particulate matter were derived by combining the three mean values from the profiles sampled during each sampling period. The results are

Table 10: Combined snowpack mean nutrient concentrations (in mg/l) and amounts (in kg/ha), calculated for each parameter from the means of the three profiles sampled at each site.

Date	Site	W.E. cm	N(1)	N(2)	Ca	Mg	K	Na	TDP	p.m.
			mg/l (kg/ha)							
15.12.80	1	19.4	0.037(0.072)	0.011(0.021)	0.029(0.055)	0.007(0.013)	0.049(0.095)	0.144(0.281)	9.31(0.018)	30.1 (59.5)
22.02.81		34.1	0.044(0.150)	0.015(0.051)	0.075(0.255)	0.022(0.077)	0.037(0.127)	0.170(0.590)	5.66(0.019)	33.5 (119.6)
30.04.81		53.7	0.048(0.258)	0.013(0.074)	0.064(0.386)	0.006(0.021)	0.042(0.084)	0.163(0.801)	3.53(0.018)	66.7 (346.9)
12.12.80	2	13.6	0.030(0.041)	0.014(0.020)	0.033(0.047)	0.009(0.012)	0.038(0.053)	0.137(0.191)	7.24(0.010)	41.1 (60.9)
24.02.81		21.9	0.036(0.079)	0.025(0.052)	0.050(0.110)	0.016(0.030)	0.031(0.074)	0.093(0.213)	6.90(0.015)	119.3(272.0)
04.05.81		42.1	0.039(0.016)	0.015(0.064)	0.031(0.123)	0.018(0.063)	0.036(0.144)	0.132(0.545)	4.41(0.018)	131.0(487.4)
11/13.12.80	3	18.6	0.026(0.048)	0.009(0.020)	0.077(0.136)	0.030(0.054)	0.163(0.304)	0.099(0.191)	31.5(0.062)	56.8 (102.8)
23.02.81		30.5	0.036(0.110)	0.025(0.076)	0.096(0.286)	0.047(0.139)	0.245(0.722)	0.108(0.327)	14.8(0.045)	153.1(456.3)
09/11.05.81		43.7	0.032(0.140)	0.016(0.069)	0.227(0.940)	0.049(0.204)	0.263(1.122)	0.184(0.799)	20.1(0.091)	107.9(483.9)
16.12.80	4	19.8	0.028(0.055)	0.012(0.023)	0.108(0.203)	0.095(0.186)	0.139(0.257)	0.128(0.257)	12.1(0.024)	33.4 (61.5)
22/23.02.81		33.6	0.043(0.145)	0.009(0.033)	0.087(0.292)	0.033(0.113)	0.129(0.436)	0.146(0.489)	15.8(0.052)	45.8 (150.7)
03/09.05.81		47.4	0.023(0.107)	0.012(0.057)	0.253(1.171)	0.070(0.329)	0.124(0.570)	0.201(0.951)	6.29(0.094)	48.3 (230.7)

Table 11a: The between-site relationships of the combined mean nutrient concentrations

	W.E.	H(1)	H(2)	Ca	Mg	K	Na	TDP	pm
December	4>1>3>2	1>2>4>3	2>4>1>3	4>3>2>1	4>3>2>1	3>4>1>2	1>2>4>3	3>4>1>2	3>2>4>1
February	1>4>3>2	1>4>2=3	3=2>1>4	4>3>1>2	3>4>1>2	3>4>1>2	1>4>3>2	4>3>2>1	3>2>4>1
April/May	1>4>3>2	1>2>3>4	3>2>1>4	4>3>1>2	4>3>2>1	3>4>1>2	4>3>1>2	3>4>2>1	2>3>1>4

Table 11b: The between-site relationships of the combined mena nutrient amounts

	W.E.	H(1)	H(2)	Ca	Mg	K	Na	TDP	pm
December	4>1>3>2	1>4>3>2	1>2=3>4	4>3>1>2	4>3>2>1	3>4>1>2	1>4>2>3	3>4>1>2	3>4>2>1
February	1>4>3>2	1>4>3>2	3>2>1>4	4>3>1>2	3>4>2>1	3>4>1>2	1>4>3>2	4>3>1>2	3>2>4>1
April/May	1>4>3>2	1>2>3>4	1>3>2>4	1>4>3>2	4>3>1>2	3>4>1>2	4>1>3>2	3>4>2>1	2>3>1>4

presented in Table 10 and the relationships between the four sites in Table 11a. The agreement between the general relationships in Tables 9 and 1 is good. Where discrepancies do occur, they are usually reversals between the second and third highest values or between sites 1 and 2 as the lowest value. Most importantly, the basic pattern of the highest concentrations occurring in the snowpack at sites 3 and 4 and the lowest at sites 1 and 2 is maintained. Included in this table are the mean H ion concentrations which show particularly close concentrations between the four sites. Hydrogen ion concentrations were all close to 0.01 mg/l in December (0.008 to 0.014 mg/l), showed a slightly larger range in February (0.009 to 0.025 mg/l), being the same at sites 2 and 3, where concentrations were also the highest, and decreasing in concentration by May to 0.012 to 0.016 mg/l.

The combined means of the nutrient contents, in kg/ha, have also been calculated and are also presented, with the mean concentrations, in Table 10. As is the case with mean concentrations, the mean nutrient contents are greatest in the snowpacks at sites 3 and 4 and least at sites 1 and 2. The exception is Na, where concentrations and absolute amounts were highest at site 1 in December and February. The between-site relationships are presented in Table 11b. In spite of accounting for the varying water equivalents, there is little difference in the between site relationships of the nutrient concentrations and absolute amounts.

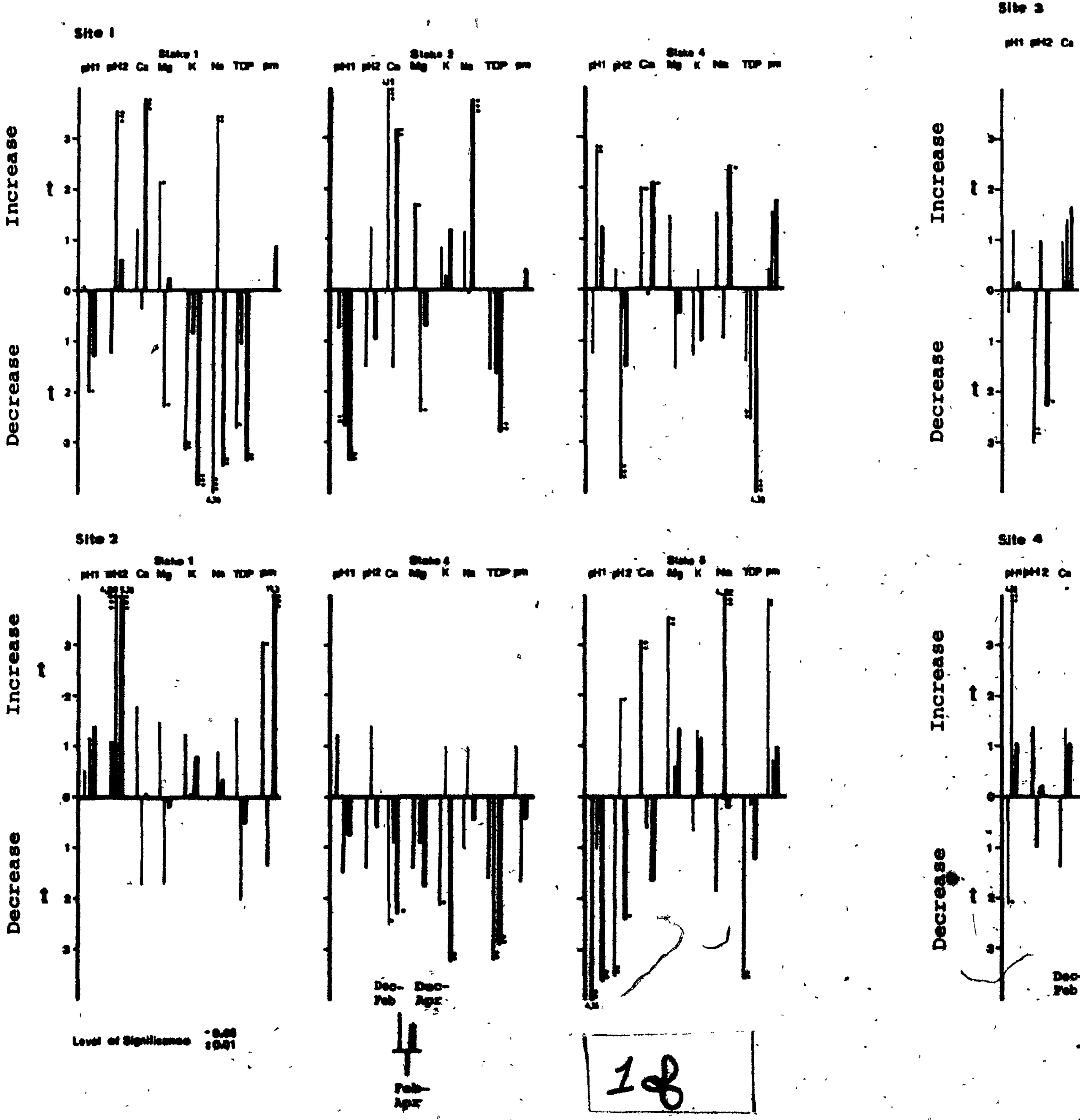
In December, the H ion content was the same at the four sites (0.02 kg/ha). Differences increased by February (0.03 to 0.08 kg/ha) and were once again very similar in spring (0.06 to 0.07 kg/ha). Between-site differences were most pronounced for the cations. Calcium ranged from 0.05 to 0.20 kg/ha in December, 0.11 to 0.29 kg/ha in February and 0.12 to 1.17 kg/ha in May. Magnesium contents ranged from 0.01 to 0.19 kg/ha in December to 0.03 to 0.14 in February to 0.02 to 0.33 hg/ha in May. With the exception of Mg in February (where contents were higher at site 3), the largest amounts of Ca and Mg were contained in the snowpack at site 4. Mean amounts were lowest for Ca at site 2 and Mg at site 1. Mean K contents were consistently higher at site 3 and least at site 2. In December, amounts ranged from 0.05 to 0.30 kg/ha, in February from 0.07 to 0.72 kg/ha and in May from 0.08 to 1.12 kg/ha. Mean Na contents were higher during December and February at site 1. Amounts ranged from 0.19 to 0.28 kg/ha in December and from 0.21 to 0.59 kg/ha in February. In May, the highest mean value occurred at site 4 and the range was from 0.55 to 0.95 kg/ha. The phosphorus content of the snowpack was very similar at sites 1 and 2 and was the same during February and May (0.02kg/ha). The mean TDP contents at sites 3 and 4 were 0.05 kg/ha in February and 0.09 kg/ha in May. Particulate matter content was practically the same at sites 1, 2 and 4 in December; 59.5 kg/ha at site 1, 60.9 kg/ha at site 2 and 61.5 kg/ha at site 4. The mean content of the snowpack at site 3 was 103 kg/ha. In February, the amounts ranged from 120 to 456 kg/ha, being greatest at site 3. Mean values in May ranged from 231 to 487 kg/ha and were very close at sites 2 and 3, 487 and 484 kg/ha, respectively.

If nutrient inputs were equal at all four sites, the higher water equivalents at site 1 and the lower water equivalents at site 2 should lead to higher nutrient amounts at site 1 and higher nutrient concentrations at site 2. This, however, is not the case. Both concentrations and amounts are consistently lower at sites 1 and 2. This suggests that inputs from atmospheric, litter and/or underlying vegetation sources are less at sites 1 and 2 than at sites 3 and 4, where both mean concentrations and mean amounts are consistently greater.

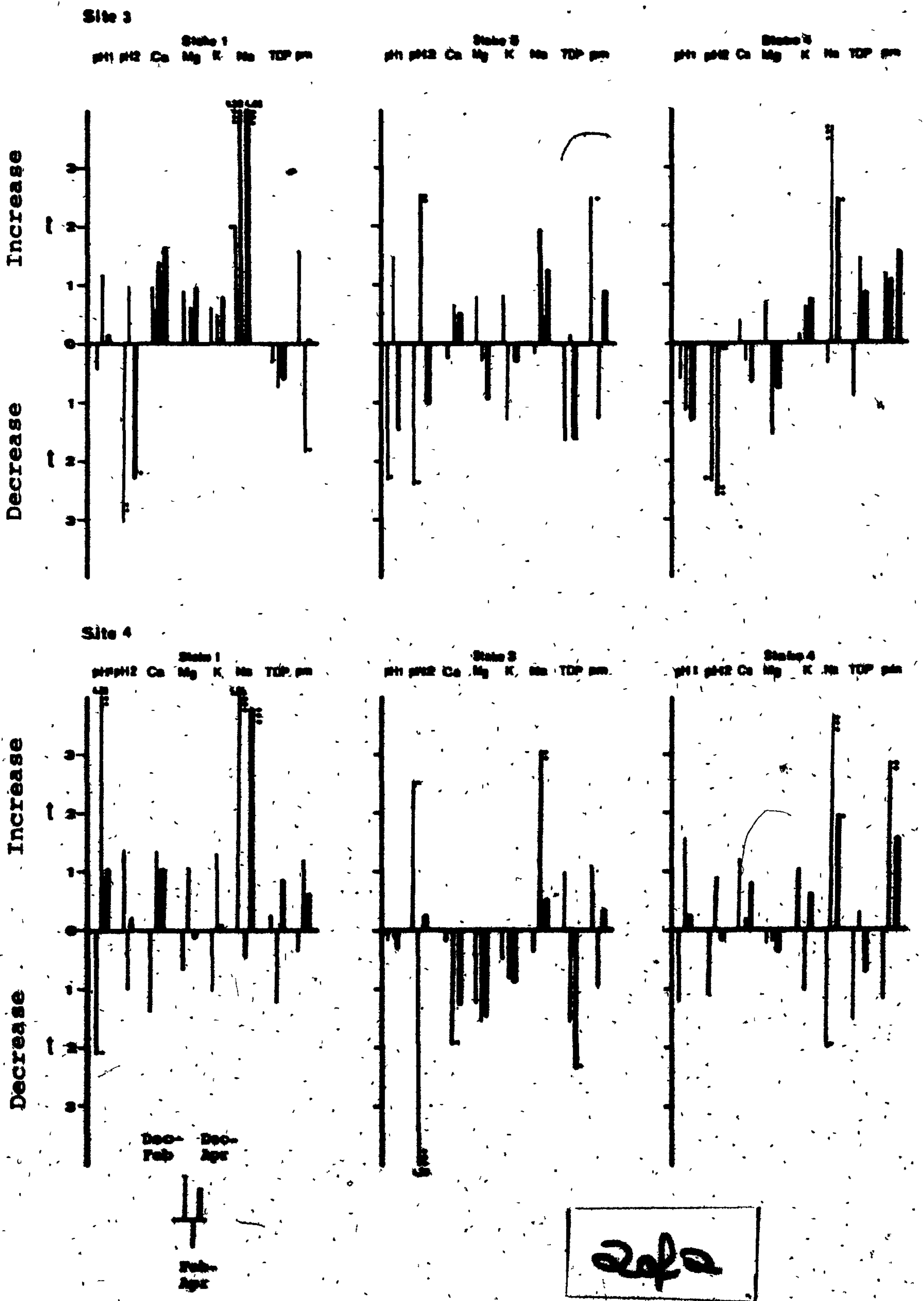
4.3.5 Intra-Site Temporal Differences in Snowpack Chemistry

The temporal differences in mean pH, cation and particulate matter concentrations in the snowpack within each site have been evaluated using the t-statistic. The results are given in

Figure 7 Temporal changes in snowpack chemistry



18


Site 3
Stake 1
pH1 pH2 Ca Mg K Na TOP pm
Stake 3
pH1 pH2 Ca Mg K Na TOP pm
Stake 5
pH1 pH2 Ca Mg K Na TOP pm
Increase
t
3
2
1
0
1
2
3
Decrease
t
Site 4
Stake 1
pH1 pH2 Ca Mg K Na TOP pm
Stake 3
pH1 pH2 Ca Mg K Na TOP pm
Stake 4
pH1 pH2 Ca Mg K Na TOP pm
Increase
t
3
2
1
0
1
2
3
Decrease
t
Dec-Feb
Dec-Apr
Feb-Apr

2of2

Table 4, Appendix 3. To identify trends in changes, the values have been organized graphically in Figure 7. The graph shows the magnitude of the t-statistics for the December vs February and February vs April/May comparisons and the overall differences between the December and April/May means. The t-statistics plotted on the positive side of the y-axis indicate an increase in mean values (February means greater then December means, April means greater than February or December means). Those plotted on the negative y-axis indicate a decrease in mean values.

What is immediately apparent from Figure 7 is that the changes in mean values are highly inconsistent, not only for the various parameters measured, but also for the same parameters from the snow profiles at the same site. A number of statistically significant differences between the December, February and April/May means do occur (the number of significant differences being greatest at site 1, followed by sites 2, 3 and 4), but they rarely identify a trend in which the mean values for any given parameter have decreased or increased at all three sampling locations over the same period. In fact, in many cases, the changes are contradictory. Examples include changes in pH(1) and (2), K and Na at all four sites and Ca, Mg, TDP and particulate matter at sites 2, 3 and 4. Of these samples, several contradictory changes are significant: site 1, pH(1) and (2) (Feb/Apr), Na (Dec/Apr); site 2, pH(2) (Dec/Apr); site 3, pH(2) (Dec/Feb and Dec/Apr), Ca (Dec/Feb) and site 4, Na (Dec/Feb).

In spite of the variations observed, a few consistent patterns can be identified, but they are usually restricted to the behaviour of one chemical constituent within one site only and for only one or two sampling-date comparisons. This does not allow many general statements to be made concerning the behaviour of a given parameter during the winter or to compare this behaviour between sites.

Those patterns which can be identified indicate that at site 1, Ca and Mg both increased in concentration between December and February and decreased between February and April. In two out of the three comparisons, both Ca and Mg concentrations were significantly greater in the February, compared to the December snowpack. The following decrease in Ca concentration was not significant, but in two comparisons, Mg concentrations were significantly less in the April snowpacks than they had been in February. Calcium concentrations were significantly higher (for all comparisons) in the snowpack in April, compared to December, suggesting an overall increase in Ca in the snowpack over the winter. Phosphorus concentrations decreased throughout the winter at site 1 and, by April, the TDP concentration of the snowpack was significantly less than it had been in the December snow cover. Particulate matter showed a general increase, but the difference was not a significant one.

At site 2, pH(2) and Na concentrations increased between February and April, the differences being significant at two sampling locations for pH and one for Na. As at site 1, phosphorus concentrations also decreased throughout the winter at site 2. In only one example, however, were the differences significant. Particulate matter concentrations were significantly higher in the February snowpack than in December, but the pattern was inconsistent for the remainder of the winter at this site.

pH(1) and (2) decreased at site 3 between December and February. The difference was significant for pH(2), which also indicated overall lower mean snowpack pH in April compared to December. Sodium concentrations were significantly higher in the April snowpack compared to February and led to overall, significantly higher Na concentrations at the end of the winter. Phosphorus decreased slightly from December to February, but the difference was not significant. Particulate matter increased from December to February and in April, particulate matter concentration was higher in the snowpack than it had been in December.

At site 4, pH(1) was lower in the February, than in the December snowpack (one significant difference). Mean Mg concentrations decreased slightly over the same period and were lower at the end of the winter than they had been in December, but the differences were not significant. Sodium concentrations were significantly greater in the profiles sampled in the April snowpack than in December and particulate matter also increased between December and April, but the differences were not significant.

The above changes indicate that mean TDP concentrations decreased over the winter at sites 1, 2 and 3, that mean Na concentrations increased at sites 2, 3 and 4 and that mean particulate matter concentrations increased at all the sites. Given the inconsistencies in the other changes, it is not possible to arrive at general conclusions for the other parameters.

The inconsistencies in the observed patterns probably arise because of the within-site variability in vegetation cover and micro-relief. This leads to varying snow accumulation patterns and densities and thus varying water equivalents within the sites (section 4.2). The vegetation canopy may also be altering the chemistry of the snow passing through it and the canopy and underlying vegetation are sources of litter in the snowpack. Thus, the distribution of vegetation in the sampling sites could, to a large extent, affect the snowpack chemistry within the site. This would make the identification of changes in snowpack chemistry during the winter difficult.

The same difficulty in identifying changes in nutrient concentrations arises with identifying changes in nutrient contents. It is, however, possible to identify more consistent changes, based on absolute amounts, than it is using nutrient concentrations. According to the values in Table 8, Ca increased throughout the winter at sites 1 and 3 (this was also seen in Ca concentrations at site 1). At site 2, increases in Ca were common to all three sampling locations between December and February and Ca content was higher at the end of the winter at all three locations than it was in December. At sites 1 and 2, Mg contents increased from December to February and decreased between February and April, but were still higher in the spring snowpack than they had been in December. The increase between December and February was also evident at site 3. Potassium contents at site 3 were also higher in the February and April snowpacks than in December. Sodium showed consistent increases throughout the winter at sites 3 and 4 and contents were higher in the spring snowpack at sites 1 and 2 than they had been in December. Phosphorus contents were lower in the spring snowpack at site 1 but higher at sites 2 and 4 than in December. Particulate matter was higher in the spring snowpacks at all four sites, but increases were only continuous through the winter at site 1. Hydrogen ion content was, likewise, greater in all four spring snowpacks, but again, increases were consistent only at site 1 through the winter.

Many of the changes in concentrations were Negligible , being less than 0.01 mg/l, yet, as seen in Table 8, they correspond to measureable changes in absolute amounts. For example, mean Ca concentration in the December snowpack at site 2 was 0.033 mg/l. The mean concentration in April was 0.031 mg/l. These values correspond to mean Ca contents of 0.05 kg/ha in December and 0.12 kg/ha in April. Similar examples can be seen for K and Na, also at site 2, Mg and K at site 3 and K at site 4.

From the concentration values it would appear that, in such instances, concentrations are being maintained through an input of nutrients which is proportional to the increasing water equivalents. Decreases in concentrations between December, February and April are very minor, where they do occur, compared to the increases. Increases in concentrations and increased water equivalents result in large increases in absolute amounts. This is most pronounced at sites 3 and 4.

Table 12: The chemistry of the surface snow samples collected on 21.02.81

Site	pH(1)	pH(2)	Ca	Mg	K	Na	TDP	pm
				mg/l			ug/l	mg/l
1	4.47±0.26	5.04±0.13	0.042±0.035	0.008±0.005	0.070±0.070	0.090±0.006	3.18±1.36	43.8±22.2
2	4.83±0.09	5.16±0.18	0.032±0.011	0.006±0.006	0.034±0.011	0.103±0.017	2.60±0.74	56.0±18.6
3	4.26±0.22	5.04±0.18	0.032±0.018	0.008±0.005	0.070±0.074	0.136±0.097	3.43±2.87	66.0±21.0
4	4.22±0.08	4.78±0.20	0.048±0.030	0.006±0.006	0.046±0.032	0.134±0.066	4.45±3.66	50.0±12.1

n=5

The combined means in Table 10 may be used to identify general changes over the winter at each site. Comparison of the changes in concentrations and the changes in amounts reveals many discrepencies (ie. site 1: H, Ca, Mg, K, Na; site 2: H, Ca, K, Na, TDP; site 3: TDP and particulate matter and site 4: H, Ca, Mg, K, TDP).

The trend, almost without exception, is for the amount of nutrients contained in the snowpack to increase over the winter. This suggests a storage of nutrients as the winter progresses. The only exceptions are Mg and K, which decrease between February and April at site 1 and H, which decreases slightly between February and April at site 3. Phosphorus contents at site 1 do not change over the winter. Increases in mean concentrations do not, however, necessarily correspond to these increases in absolute amounts in the snowpack, although there is an agreement at site 3 for the four cations and H (which decreases both in amount and concentration between February and April).

4.3.6 Fresh Snow Chemistry

Samples were collected from the snow surface at each of the four study sites on 21.02.81, following a minor snow fall. The mean concentrations are presented in Table 12. The complete data set is presented in Table 1, Appendix 1. Mean pH(1) values ranged from 4.2 at site 4 to 4.8 at site 2 and mean pH(2) values from 4.8 at site 4 to 5.2 at site 2. Cation and TDP concentrations were very low. Calcium ranged from 0.03 to 0.05 mg/l, Mg concentrations were 0.01 mg/l. Potassium ranged from 0.03 to 0.07 mg/l, Na from 0.09 to 0.14 mg/l and TDP from 2.60 to 4.45 ug/l. Particulate matter concentrations ranged from 43.8 mg/l at site 1 to 66.0 mg/l at site 3. These values are comparable to the overall mean snowpack concentrations in Table 7.

Analyses of variance (Table 5, Appendix 3) indicate that, with the exception of pH, significant differences in the chemistry of the surface snow samples between the four study sites are not apparent. The t-statistics (Table 6, Appendix 3) indicate that mean pH(1) values were significantly lower at sites 1, 3 and 4 compared to site 2 and at site 4 compared to site 1. Mean pH(2) was significantly lower at site 4 than at the other three sites. The only other significant difference was between TDP concentrations at sites 2 and 3.

4.3.7 A Comparison of the Snowpack Chemistries Measured at the Control and Experimental Profiles

Vertical distributions of the chemical parameters in the control and experimental spring snow profiles are comparable, having the same range of values, with the exception of the lower profile sections and the snowpack base samples (Figures 6a to 6p). At sites 1, 2 and 3, the same general pattern of comparisons between the base sample values occur; pH is lower and K, TDP and particulate matter concentrations are higher in the base samples in direct contact with the ground and/or vegetation surface. Differences between Ca, Mg and Na are not as marked.

At site 1, the pH(2) of the base samples from the control profiles (Figs. 6a, b and C) range from 4.5 to 4.7, compared to the experimental profiles (Fig. 6d), where values range from 4.8 to 4.9. Magnesium concentrations do not change (0.01 mg/l) and Ca (0.06 compared to 0.12 mg/l) and Na (0.01 compared to 0.25 mg/l) show only minor differences. At two sampling locations, K concentrations are considerably higher in the control profile samples (stake location 4, 0.12 vs 0.01 mg/l and location 2, 0.55 vs 0.02 mg/l). At location 1, the values are comparable (0.09 and 0.04 mg/l). Phosphorus concentrations are similar, ranging from 4.4 to 4.5 and 4.8 to 9.2 ug/l for the experimental and control profiles, respectively. At stake location 4, particulate matter concentrations are higher in the control profile base samples (416 vs 22 mg/l), but are less at stake location 1 (48 vs 128 mg/l).

At site 2, pH values are lower near the base of two of the control snow profiles (Figs. 6f and g) than at the corresponding experimental profiles (Fig 6e). Values range from 4.5 and 4.6 to 4.7 and 4.8. Particulate matter concentrations are larger in the base samples from all three control profiles, with an extreme difference between profiles 11 and 12 (1550 vs 28 mg/l). In addition to the very large difference in particulate matter, Ca, Mg, K and TDP concentrations are also higher at the base of profile 11. With the exception of Ca concentrations in profiles 7 and 8, the differences between the other profiles are not large.

The main differences at site 3 are in the phosphorus concentrations which range from 12.8 to 16.1 ug/l in the base samples of the experimental profiles (Fig. 6l) compared to 52.7 to 198 ug/l in the control profiles (Figs. 6i, j and k). At two sampling locations, 4 and 5, K also shows considerable differences in the range of values; 0.10 to 0.15 mg/l in the experimental profiles samples compared to 1.03 to 1.62 mg/l in the control profile samples. The K concentrations in the base samples at location 1 are higher than at the other two profile locations but the control and experimental profile base snow samples are comparable (2.26 and 2.77 mg/l).

The differences in cation concentrations are much more pronounced at site 4 than at sites 1, 2 or 3 with the exception of Na which shows little difference. Differences in particulate matter concentrations are not large and pH is higher in the control profile base samples. pH(2) ranges from 5.4 to 6.2 in the control profile samples (Figs. 6m, n and o) compared to 4.9 to 5.1 in the experimental profile samples (Fig. 6p). Calcium concentrations range from 1.16 to 1.55 vs 0.07 to 2.06 mg/l, Mg from 0.72 to 1.50 vs 0.01 mg/l and K from 0.02 to 2.06 vs 0.01 and 0.02 mg/l for the control and experimental profile samples, respectively. Differences in phosphorus concentrations are comparable to those at site 3; 21.6 to 50.9 ug/l compared to 4.71 to 9.41 ug/l.

Although the majority of values for mean cation, phosphorus and particulate matter concentrations are slightly higher in the samples removed from the control snow profiles (Table 7), the differences are rarely significant. The only significant differences are between pH and Na concentrations at sites 1, 2 and 4 (Table 7, Appendix 3). None of the differences at site 3 were found to be significant. The significance of many of the differences is probably reduced by the large standard deviations of the means, particularly for the control profile mean values.

The degree of variation in concentrations through the snowpack is seen in the (often large) standard deviations of the mean concentrations. Certainly the variations throughout the entire profile contribute to these large standard deviations, but, in many cases, the higher concentrations in the samples removed from the base of the snowpack greatly affect their magnitude. The two sets of statistics presented in Table 8, Appendix 3, are the means and standard deviations of the eight parameters measured, calculated using the entire data set and recalculated omitting the base sample values.

In many cases, the mean concentrations do not change appreciably, as the accompanying t-statistics illustrate, and none of the differences are statistically significant (although in many examples this is due to the large standard deviations). There are, however, two prevalent patterns in these comparisons; mean values calculated excluding the base sample value are slightly lower than means calculated using the complete data set and the standard deviations decrease when the base sample values are omitted. This suggests that the concentrations in the base samples are large enough to noticeably affect the mean concentration of a given parameter in the snowpack; in this case to increase the overall concentration.

A more comprehensive comparison between the means for both the spring control and experimental profiles is presented

Table 14: A comparison of the bulk chemical composition of the control and experimental spring snowpacks

Site	Profile	x̄ pH1^{1}	s.d.^{1}	x̄ pH1^{2}	s.d.^{2}	Profile	x̄ pH1^{3}	s.d.^{3}
1	9	4.26	0.28	4.26	0.29	10	4.18	0.31
	7	4.11	0.17	4.12	0.17	8	4.53	0.36
	11	4.60	0.19	4.63	0.17	12	4.48	0.28
2	7	4.65	0.45	4.69	0.47	8	4.80	0.28
	9	4.38	0.37	4.43	0.35	10	4.14	0.32
	11	4.19	0.32	4.19	0.34	12	4.21	0.20
3	7	4.60	0.41	4.47	0.15	8	-	-
	9	4.48	0.15	4.49	0.16	10	4.56	0.25
	11	4.40	0.29	4.35	0.22	12	4.34	0.20
4	7	4.86	0.38	4.76	0.18	8	4.82	0.34
	9	4.37	0.36	4.31	0.25	10	4.46	0.26
	11	4.68	0.43	4.52	0.21	12	4.29	0.16

Site	Profile	x̄ Ca^{1}	s.d.^{1}	x̄ Ca^{2}	s.d.^{2}	Profile	x̄ Ca^{3}	s.d.^{3}
		mg/l	mg/l	mg/l	mg/l		mg/l	mg/l
1	9	0.069	0.032	0.068	0.033	10	-	--
	7	0.048	0.027	0.043	0.018	8	0.053	0.021
	11	0.075	0.060	0.071	0.062	12	0.066	0.023
2	7	0.021	0.045	0.005	0.012	8		
	9	0.021	0.056	0.003	0.007	10	0.045	0.089
	11	0.050	0.065	0.040	0.068	12	0.009	0.016
3	7	0.503	0.755	0.339	0.611	8	0.437	0.622
	9	0.120	0.220	0.110	0.220	10	0.078	0.086
	11	0.057	0.108	0.029	0.019	12	0.078	0.086
4	7	0.616	1.28	0.512	1.31	8	0.258	0.557
	9	-	-	0.020	0.018	10	0.011	0.017
	11	0.123	0.328	0.029	0.034	12	0.025	0.020

Site	Profile	x̄ pH2^{1}	s.d.^{1}	x̄ pH2^{2}	s.d.^{2}	Profile	x̄ pH2^{3}	s.d.^{3}
1	9	5.09	0.30	5.11	0.31	10	5.00	0.22
	7	4.83	0.20	4.85	0.19	8	4.81	0.20
	11	4.72	0.19	4.74	0.18	12	4.75	0.19
2	7	4.97	0.14	4.97	0.15	8	4.88	0.29
	9	4.77	0.22	4.80	0.22	10	4.75	0.26
	11	4.76	0.20	4.82	0.19	12	5.02	0.44
3	7	4.82	0.38	4.71	0.17	8	-	-
	9	4.77	0.18	4.77	0.18	10	4.83	0.18
	11	4.83	0.36	4.77	0.28	12	4.75	0.20
4	7	4.02	0.45	4.80	0.20	8	4.93	0.20
	9	4.80	0.26	4.75	0.20	10	4.69	0.22
	11	5.00	0.55	4.92	0.29	12	4.64	0.18

Site	Profile	x̄ Mg^{1}	s.d.^{1}	x̄ Mg^{2}	s.d.^{2}	Profile	x̄ Mg^{3}	s.d.^{3}
		mg/l	mg/l	mg/l	mg/l		mg/l	mg/l
1	9	0.007	0.005	0.007	0.005	10	0.006	0.005
	7	0.006	0.006	0.005	0.005	8	0.008	0.005
	11	0.005	0.005	0.004	0.005	12	0.006	0.005
2	7	0.006	0.011	0.003	0.005	8	0.007	0.011
	9	0.006	0.013	0.002	0.004	10	0.010	0.011
	11	0.042	0.083	0.008	0.013	12	0.003	0.005
3	7	0.122	0.240	0.043	0.023	8	0.089	0.152
	9	0.012	0.012	0.008	0.004	10	0.009	0.006
	11	0.014	0.022	0.009	0.005	12	0.012	0.009
4	7	0.143	0.429	0.020	0.037	8	0.006	0.005
	9	-	-	0.003	0.005	10	0.003	0.005
	11	0.064	0.207	0.007	0.007	12	0.005	0.007

Site	Profile	x K^{1}	s.d.^{1}	x K^{2}	s.d.^{2}	Profile	x K^{3}	s.d.^{3}
		mg/l	mg/l	mg/l	mg/l		mg/l	mg/l
1	9	0.009	0.023	0.004	0.005	10	0.004	0.011
	7	0.097	0.194	0.062	0.150	8	0.075	0.174
	11	0.022	0.031	0.014	0.011	12	0.010	0.010
2	7	0.053	0.081	0.041	0.080	8	0.011	0.022
	9	0.016	0.034	0.006	0.008	10	0.020	0.043
	11	0.040	0.062	0.027	0.056	12	0.004	0.005
3	7	0.462	0.869	0.174	0.092	8	0.424	0.703
	9	0.136	0.272	0.062	0.046	10	0.125	0.097
	11	0.189	0.401	0.086	0.066	12	0.129	0.137
4	7	0.302	0.677	0.142	0.408	8	0.014	0.014
	9	-	-	0.031	0.024	10	0.061	0.137
	11	0.039	0.066	0.025	0.045	12	0.019	0.010

Site	Profile	x TDP^{1}	s.d.^{1}	x TDP^{2}	s.d.^{2}	Profile	x TDP^{3}	s.d.^{3}
		ug/l	ug/l	ug/l	ug/l		ug/l	ug/l
1	9	3.99	2.82	3.45	1.94	10	3.59	1.10
	7	3.97	1.49	3.90	1.53	8	-	-
	11	2.63	2.29	2.03	1.01	12	4.41	2.35
2	7	5.06	2.27	4.33	0.99	8	4.11	1.12
	9	3.49	0.94	3.45	0.98	10	3.74	1.12
	1	4.68	3.53	3.36	0.55	12	4.13	1.90
3	7	12.0	15.6	6.96	3.44	8	-	-
	9	14.7	22.9	8.86	9.13	10	23.7	28.9
	11	33.5	50.9	20.3	17.8	12	13.3	10.2
4	7	6.36	13.5	2.31	0.92	8	2.86	1.09
	9	4.58	5.46	3.17	1.99	10	4.66	2.67
	11	7.93	14.5	4.02	5.43	12	4.19	1.73

	11	4.88	0.43	4.52	0.21	12	4.29	0.16

Site	Profile	$\bar{x}$ pH2^1	s.d.^{1}	$\bar{x}$ pH2^2	s.d.^{2}	Profile	$\bar{x}$ pH2^3	s.d.^{3}
1	9	5.09	0.30	5.11	0.31	10	5.00	0.22
	7	4.83	0.20	4.85	0.19	8	4.81	0.20
	11	4.72	0.19	4.74	0.18	12	4.75	0.19
2	7	4.97	0.14	4.97	0.15	8	4.88	0.29
	9	4.77	0.22	4.80	0.22	10	4.75	0.26
	11	4.76	0.20	4.82	0.19	12	5.02	0.44
3	7	4.82	0.38	4.71	0.17	8	-	-
	9	4.77	0.18	4.77	0.18	10	4.83	0.18
	11	4.83	0.36	4.77	0.28	12	4.75	0.20
4	7	4.62	0.45	4.80	0.20	8	4.93	0.28
	9	4.80	0.26	4.75	0.20	10	4.69	0.22
	11	5.00	0.55	4.92	0.29	12	4.64	0.18

	11	0.123	0.328	0.029	0.034	12	0.025	0.020

Site	Profile	$\bar{x}$ Mg^1	s.d.^{1}	$\bar{x}$ Mg^2	s.d.^{2}	Profile	$\bar{x}$ Mg^3	s.d.^{3}
		mg/l	mg/l	mg/l	mg/l		mg/l	mg/l
1	9	0.007	0.005	0.007	0.005	10	0.006	0.005
	7	0.006	0.006	0.005	0.005	8	0.008	0.005
	11	0.005	0.005	0.004	0.005	12	0.006	0.005
2	7	0.006	0.011	0.003	0.005	8	0.007	0.011
	9	0.006	0.013	0.002	0.004	10	0.010	0.011
	11	0.042	0.083	0.008	0.013	12	0.003	0.005
3	7	0.122	0.240	0.043	0.023	8	0.089	0.152
	9	0.012	0.012	0.008	0.004	10	0.009	0.006
	11	0.014	0.022	0.009	0.005	12	0.012	0.009
4	7	0.143	0.429	0.020	0.037	8	0.006	0.005
	9	-	-	0.003	0.005	10	0.003	0.005
	11	0.064	0.207	0.007	0.007	12	0.005	0.007

Site	Profile	x K^1	s.d.^{1}	x K^2	s.d.^{2}	Profile	x K^3	s.d.^{3}
		mg/l	mg/l	mg/l	mg/l		mg/l	mg/l
1	9	0.009	0.023	0.004	0.005	10	0.004	0.011
	7	0.097	0.194	0.062	0.150	8	0.075	0.174
	11	0.022	0.031	0.014	0.011	12	0.010	0.010
2	7	0.053	0.081	0.041	0.080	8	0.011	0.022
	9	0.016	0.034	0.006	0.008	10	0.020	0.043
	11	0.040	0.062	0.027	0.056	12	0.004	0.005
3	7	0.462	0.869	0.174	0.092	8	0.424	0.703
	9	0.136	0.272	0.062	0.046	10	0.125	0.097
	11	0.189	0.401	0.086	0.066	12	0.129	0.137
4	7	0.302	0.677	0.142	0.408	8	0.014	0.014
	9	-	-	0.031	0.024	10	0.061	0.137
	11	0.039	0.066	0.025	0.045	12	0.019	0.010

Site	Profile	x TDP^1	s.d.^{1}	x TDP^2	s.d.^{2}	Profile	x TDP^3	s.d.^{3}
		ug/I	ug/l	ug/l	ug/l		ug/l	ug/l
1	9	3.99	2.82	3.45	1.94	10	3.59	1.10
	7	3.97	1.49	3.90	1.53	8	-	-
	11	2.63	2.29	2.03	1.01	12	4.41	2.25
2	7	5.06	2.27	4.33	0.99	8	4.11	1.12
	9	3.49	0.94	3.45	0.98	10	3.74	1.12
	1	4.68	3.53	3.36	0.55	12	4.13	1.90
3	7	12.0	15.6	6.96	3.44	8	-	-
	9	14.7	22.9	8.86	9.13	10	23.7	28.9
	11	33.5	50.9	20.3	17.8	12	13.3	10.2
4	7	6.36	13.5	2.31	0.92	8	2.86	1.09
	9	4.58	5.46	3.17	1.99	10	4.66	2.67
	11	7.93	14.5	4.02	5.43	12	4.19	1.73

Site	Profile	x Na^1	s.d.^{1}	x Na^2	s.d.^{2}	Profile	x Na^3	s.d.^{3}
		mg/l	mg/l	mg/l	mg/l		mg/l	mg/l
1	9	0.164	0.049	0.157	0.044	10	0.124	0.032
	7	0.190	0.076	0.188	0.078	8	0.137	0.029
	11	0.134	0.045	0.132	0.046	12	0.126	0.039
2	7	0.152	0.036	0.138	0.019	8	0.127	0.021
	9	0.121	0.043	0.111	0.032	10	0.159	0.105
	11	0.123	0.032	0.120	0.033	12	0.110	0.037
3	7	0.206	0.034	0.203	0.035	8	0.269	0.034
	9	0.179	0.074	0.167	0.063	10	0.164	0.049
	11	0.167	0.065	0.164	0.067	12	0.174	0.057
4	7	0.182	0.097	0.173	0.095	8	0.179	0.076
	9	-	-	0.242	0.078	10	0.175	0.047
	11	0.179	0.091	0.168	0.087	12	0.183	0.040

Site	Profile	x pm^1	s.d.^{1}	x pm^2	s.d.^{2}	Profile	x pm^3	s.d.^{3}
		mg/l	mg/l	mg/l	mg/l		md/l	mg/l
1	9	57.0	106	31.4	39.1	10	63.1	62.3
	7	37.1	11.7	34.7	7.85	8	-	-
	11	106	164	61.3	17.1	12	61.7	27.9
2	7	83.4	14.6	79.9	11.6	8	74.9	22.0
	9	61.1	75.7	40.0	30.6	10	48.6	36.5
	11	248	575	31.0	24.3	12	20.9	12.5
3	7	72.3	23.9	72.7	25.8	8	-	-
	9	95.5	196	41.8	30.5	10	33.2	22.1
	11	156	234	97.1	52.9	12	-	-
4	7	56.5	46.1	43.2	14.6	8	36.3	23.6
	9	28.4	26.9	26.7	17.6	10	26.0	15.4
	11	60.1	42.3	56.1	41.9	12	57.1	32.6

in Table 13. The means of the control profiles, including and excluding the base samples, are compared with one another and with the means of the complete data set for the experimental profiles.

Of the four sites, only site 4 shows pronounced changes for the majority of parameters in the control profiles when the base samples are not included. Both pH(1) and (2) decreased as did Ca, K and TDP concentrations. Large decreases in the means and standard deviations of Mg, K and TDP also occurred when the values for site 3 were recalculated. Potassium is the only parameter for which the means and standard deviations decreased at all four sites. The values for Na did not change. Where changes in pH occurred, the values decreased at sites 3 and 4 and increased at sites 1 and 2. With the exception of K and particulate matter, the base sample values do not appear to influence the mean concentration of the nutrients in the snowpack at site 1, although the mean particulate matter content decreased when the base sample values were excluded. Some larger differences occurred at sites 2 and 3, but the decreases were most consistent at site 4 for the majority of the parameters.

The means and standard deviations for the experimental profiles are lower than both sets of values calculated for the control profiles. The plastic sheet removed the interface of the snowpack and ground cover and impeded the migration of nutrients into the base of the snowpack. With the exception of K concentrations at site 1 and Mg at sites 2, 3 and 4, even recalculating the statistics for the control profiles by omitting the base samples did not lead to values which were low enough to be comparable with the mean values of the experimental profiles

The mean chemical concentrations in the control and experimental snowpack base samples (collected after the onset of melt in mid-May) are presented in Table 14. The complete data sets are presented in Table 2, Appendix 2. The comparisons show

Table 14: Chemistry of the snow samples collected from the base of the control and experimental profiles in mid-May

Site	pH(1)	pH(2)	Ca	Mg	K	Na	TDP
				mg/l			ug/l
control 1	4.52±0.17	4.30±0.09	0.056±0.073	0.011±0.007	0.150±0.070	0.161±0.061	17.9±4.36
experimental	4.63±0.17	4.39±0.11	0.024±0.025	0.009±0.007	0.135±0.178	0.164±0.065	6.52±2.76
control 2	4.42±0.13	4.49±0.14	0.224±0.308	0.069±0.082	0.245±0.366	0.138±0.039	11.3±5.36
experimental	4.37±0.15	4.47±0.18	0.063±0.088	0.015±0.021	0.084±0.066	0.119±0.047	6.28±3.82
control 3	5.33±0.27	4.92±0.28	0.537±0.358	0.120±0.091	1.460±1.080	0.168±0.052	63.5±46.5
experimental	4.81±0.23	4.62±0.27	0.108±0.115	0.044±0.057	0.456±0.425	0.170±0.063	16.9±9.22
control 4	6.08±0.45	5.99±0.54	2.00 ± 1.67	1.47 ±1.15	0.489±0.261	0.242±0.101	14.0±7.15
experimental	5.74±0.61	5.50±0.71	1.15 ± 1.23	0.785±0.819	0.168±0.105	0.172±0.174	8.17±3.68

that mean pH, Ca, Mg, K, Na and TDP concentrations are higher in the control snow samples. The exceptions are pH(1) and (2) at site 1 and Na concentrations at sites 1 and 3. Differences are minor at site 1 and most pronounced at site 3.

The differences between the control and experimental sample mean concentrations were tested using the t-statistic (Table 15). pH, Ca, Mg, K and TDP concentrations were found to be significantly higher in the control samples at site 3. The mean TDP concentrations are significantly higher in the control samples at all four sites. Other significant differences include pH(2), site 1, Mg, site 2 and pH(2), K and Na, site 4.

Between-site comparisons are given in Tables 9 and 10, Appendix 3. Analyses of variance (Table 9) show that, with the exception of Na, the mean values for both the control and experimental samples are significantly different between the four sites. The t-statistics (Table 10) identify the significant between-site differences. The smallest number of significant differences are between sites 1 and 2. Differences involving either sites 3 or 4 are largely significant, especially between the sample means of the control samples. The most consistent significant differences are between sites 3 and 4, where mean pH, Ca, Mg, K and Na concentrations are significantly higher and mean TDP concentrations significantly lower at site 4 for both the control and experimental samples. Differences between sites 1 and 4 and sites 2 and 4 are also, largely, significant, with the exception of phosphorus and Na concentrations in the experimental samples of both between-site comparisons. Differences in mean K concentrations between sites 1 and 4 for the experimental samples and sites 2 and 4 for the control samples are also not significant. With the exception of Na (where the differences are not significant), the mean values at site 3, for both the experimental and control samples, are significantly higher than at site 1. The experimental and control mean TDP concentrations are significantly higher at site 3 than at sites 1, 2 or 4, whereas differences between sites 1 and 4 and sites 2 and 4 are not significant and only the control mean TDP concentration at site 1 is significantly higher than at site 2.

In Table 16, the sites have been ranked in order of decreasing mean pH, cation and TDP concentrations for both data sets. All parameters (with the exception of TDP from the control samples at sites 1 and 4) show greatest mean values at sites 3 or 4 and lowest at sites 1 or 2. Where the highest values occur at site 4, these concentrations are significantly greater than at the other sites. This also applies, with the exception of Na, when highest concentrations occur at site 3. In very few instances, are mean concentrations significantly greater at site 1 than at site 2 or vice versa. Exceptions are the experimental and control pH(1) and pH(2) values, mean Na and TDP concentrations for the control samples and mean Na concentration for the experimental samples.

The preceding comparisons have illustrated that within this small area, defined as the May Lake catchment, there is a great deal of spatial variability in snowpack chemistry. This is not only apparent between the four sites, but also within each site and appears to be related to the vegetation structure of the area. The difficulty in identifying temporal changes in the snowpack chemistry is probably due to the within-site variations. The ground cover appears to have some influence on the snowpack chemistry. This effect is most pronounced at sites 3 and 4. The data also indicates that the snowpacks at sites 3 and 4 accumulated more nutrients than at either sites 1 or 2.

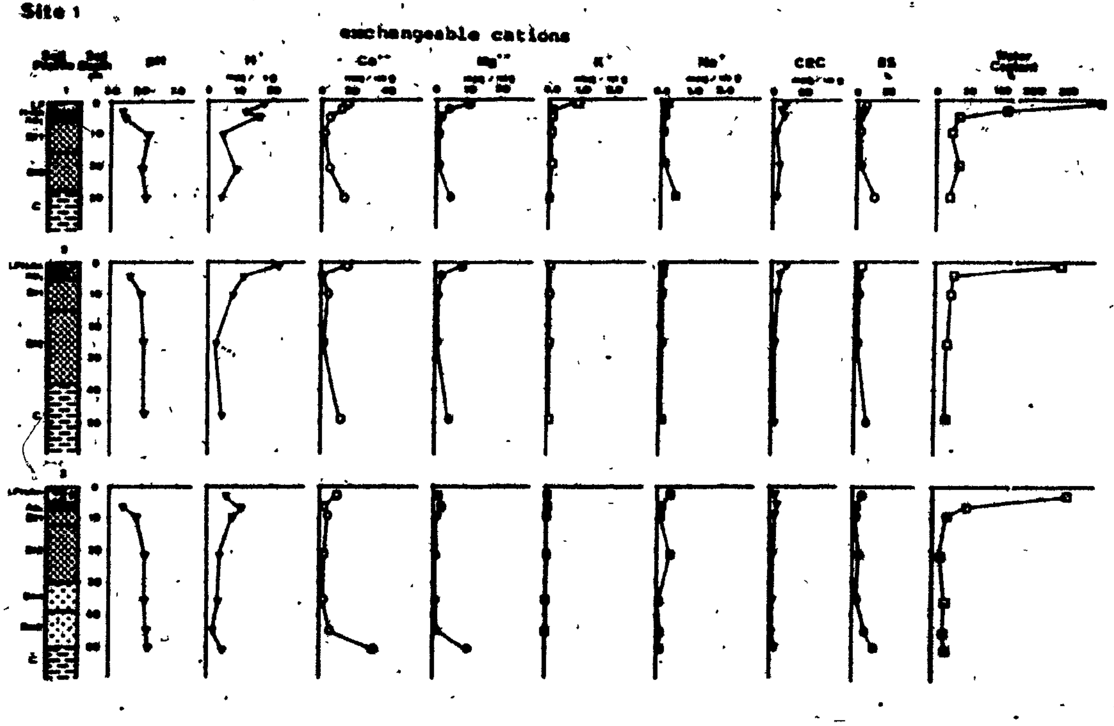
4.4 Soil Properties and Organic Horizon Chemistry

4.4.1 A Description of the Soils at the Four Study Sites

The soil morphology, measured at the three profiles at each site in September, 1980, is presented in Table 1, Appendix 2. The soil horizonation and chemistry is presented in Figure 8. The following soil descriptions are based on these observa-

Figure 8: Soil horizonation and chemical properties

Site 1



Site 2

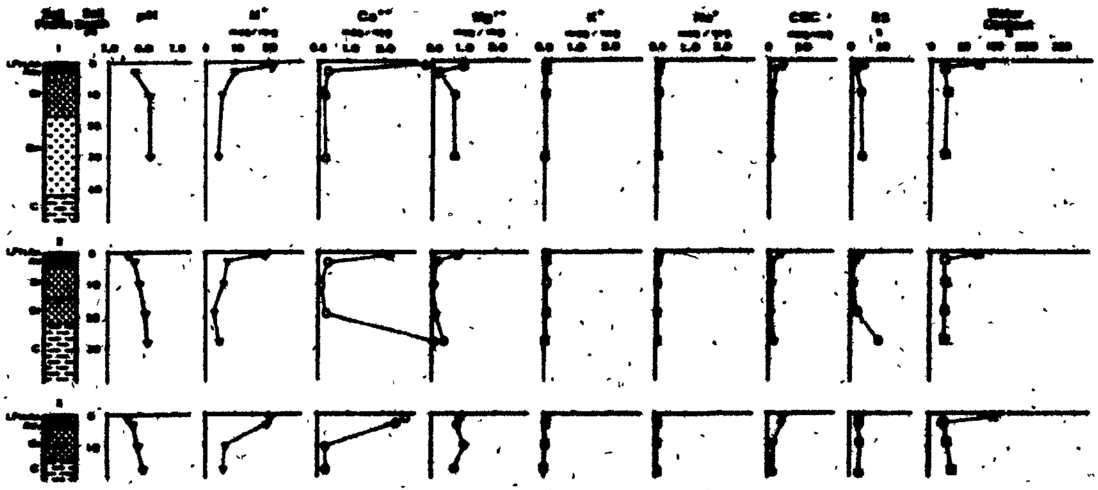


Figure 8 cont

Site 3

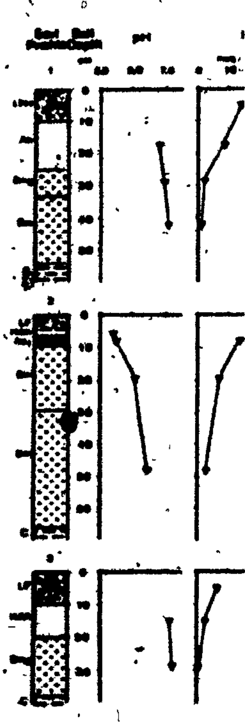
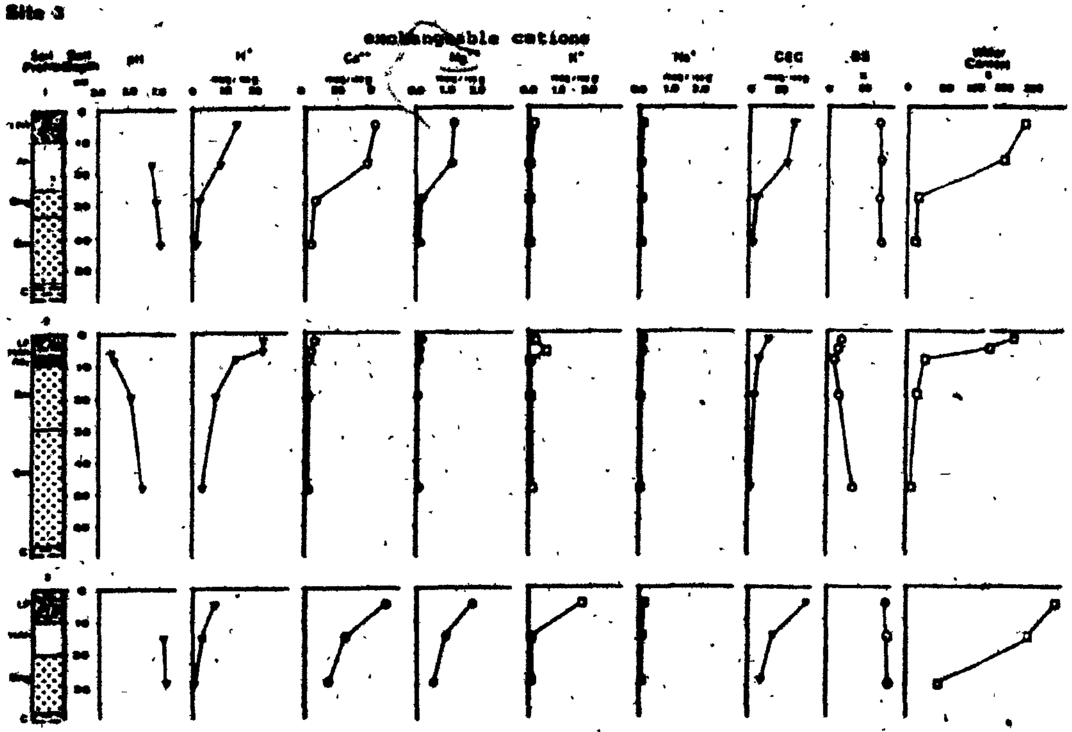


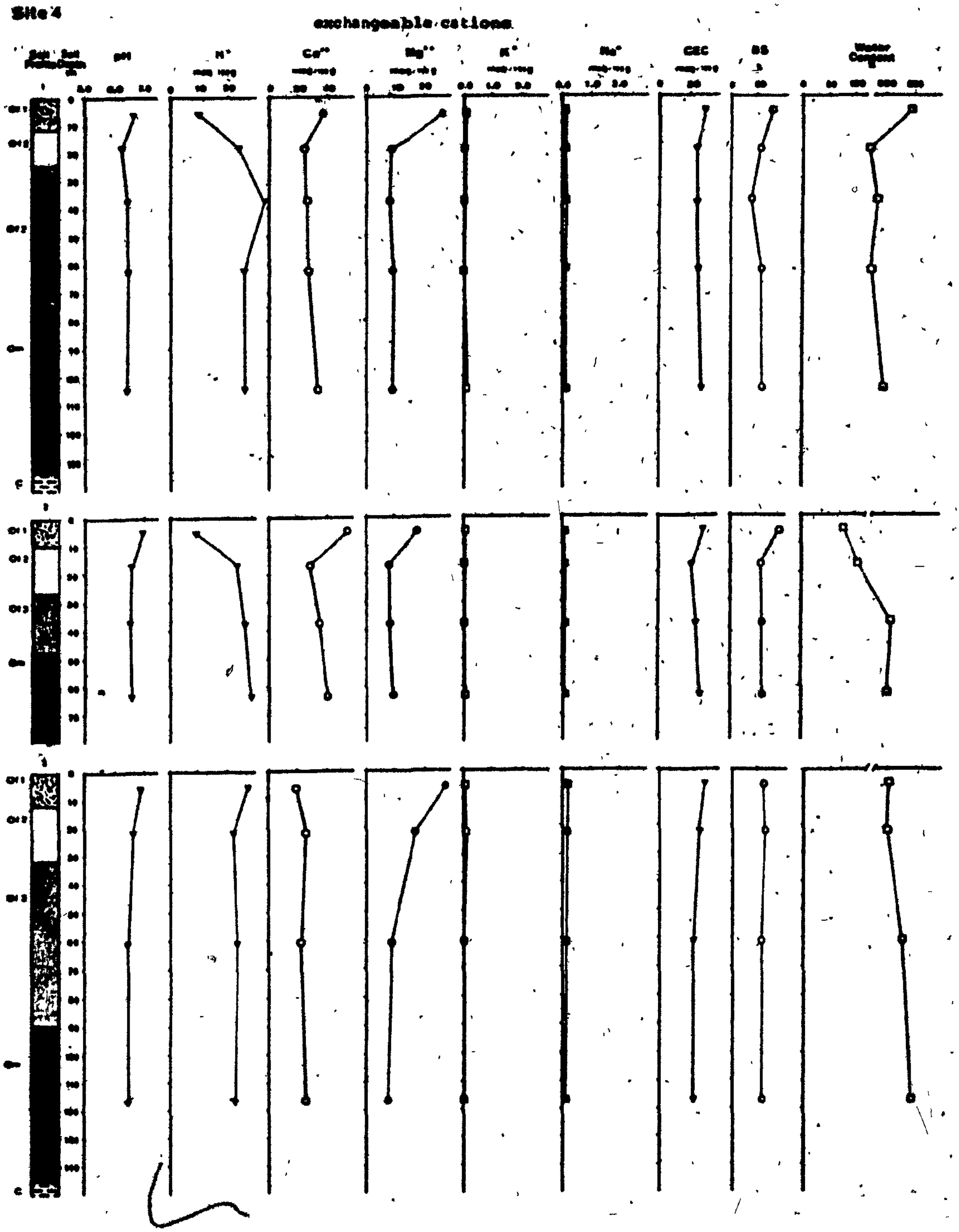
Figure 8 cont.

Site 3



2of2

Figure 8 cont.



tions.

i) The spruce lichen woodland and lichen-heath tundra:

These soils are classified as Eluviated Dystric Brunisols (Canada Soil Survey Committee, 1974) which are probably the equivalent to the Mini Humo-Ferric Podzols described by Nicholson (1973) for some of the soils in this region. The surface organic soil horizons (LFH/Ah) are thin (<5 cm) and pass down into a very thin (1-3 cm) Ae horizon, beneath which are reddish-brown Bm and Bf horizons. The soils are shallow; the C horizons or bedrock being reached at < 58 cm.

The soils are acidic throughout; pH values ranged from 3.7 to 4.7 in the surface organic horizons to 4.9 to 5.3 in the mineral subsoil. Cation exchange capacity is relatively high in the organic horizons (20-25 meq/100 g soil). Base saturation values are low (3 to 17 percent) although there is an increase in the subsoil horizons where there is more Mg. At the time of sampling (05.-20.09.80), the gravimetric water content was high (300-400 percent) in the surface horizons and about 25 percent in the subsoil horizons, similar to values reported by Moore (1980).

ii) Feathermoss forest

The feathermoss forest site is underlain, at two of the pits (1 and 3), by a Gleyed Melanic Brunisol (Canada Soil Survey Committee, 1974). These soils have a thicker accumulation of surface organic material than the soils at the woodland or lichen-heath tundra. The LFH horizons are 10 cm thick and overlie a 10-15 cm thick Ah. This passes directly into a gleyed Bm horizon 8 to 18 cm thick. At pit 1, this horizon passed into a second Bm horizon that did not show signs of gleying. Nicholson (1973) also describes gleyed B horizons directly beneath saturated Ah horizons in the forest settings. The C horizon was encountered at depths of 38 to 54 cm.

The soils are neutral; pH values range from 6.5 to 7.5 and increase with depth. Cation exchange capacity ranges from 80 to 100 meq/100 g soil. These soils have higher cation contents, particularly Ca and Mg, than the Dystric Brunisols and base saturation ranges from 80 to 90 percent.

The soil at pit 2, site 3 is classified with the soils at sites 1 and 2 as an Eluviated Dystric Brunisol. This pit was excavated on a lower slope where the feathermoss forest grades into lichen woodland. The soil has a thin (5 cm) LF horizon over a very thin (1-3 cm) Ae horizon. The underlying Bm horizon is not gleyed, as in profiles 1 and 3, nor is there a strongly red-coloured B horizon, as at sites 1 and 2.

The organic horizons are acidic (3.8 to 3.9) and pH increases in the B horizons (5.1 to 5.8). Cation exchange capacity compares to that of the soils at sites 1 and 2; 20 to 25 meq/100 g soil in the organic and 5 to 15 meq/100 g soil in the inorganic horizons, but base saturation is higher, ranging from 14 to 42 percent. The gravimetric water content of the three soils at site 3 was 250 to 350 percent in the organic horizons and 10 to 30 percent in the subsoil horizons.

iii) Sedge-moss fen

The organic soil or peat in the sedge-moss fen is classified as a Fibrisol because of the low degree of decomposition in the upper half of the core samples. A mesic bottom tier places it in the category of a Mesic Fibrisol (Canada Soil Survey Committee, 1974). The upper Of of all three cores contained large amounts of recognizable, poorly decomposed organic material. The rubbed fibre content ranged from approximately 85 percent in the upper to 50 percent in the lower Of tiers. The Om layer in the bottom tier had a rubbed fibre content of approxi-

Table 17: Chemistry of the surface soil horizons, fall 1980 and spring 1981

	Site	pH	H	Ca	Mg	Na	P	CEC	%BS	%Water Content
			exchangeable cations meq/100 g soil				ug/100 g soil	meq/100 g soil		
						Fall				
woodland	1	3.76±0.13	16.3±1.28	1.68±1.14	0.90±0.45	0.11±0.03	3.83±4.07	19.0±2.88	13.9±6.59	321 ±48.7
tundra	2	4.39±0.13	12.6±1.86	1.89±0.47	0.78±0.24	0.06±0.02	3.43±3.85	15.3±2.26	17.7±3.46	85.4±20.2
forest	3	4.73±0.03	17.7±2.61	14.7±8.62	4.60±4.28	0.17±0.09	7.29±2.80	33.5±8.03	44.1±21.2	286 ±36.3
fen	4	6.14±0.37	10.0±5.19	37.5±5.11	21.5±3.31	0.18±0.06	4.46±3.99	69.6±6.52	86.4±7.45	826 ±112
						Spring				
control	1	3.81±0.15	38.3±6.34	3.38±1.57	1.09±0.38	0.23±0.09	1.71±0.48	43.8±7.66	12.5±3.36	327 ±53.4
experimental		3.62±0.13	33.8±13.0	2.57±1.61	1.02±0.29	0.22±0.08	2.55±0.87	41.7±10.2	10.7±3.26	288 ±70.4
control	2	4.16±0.15	36.8±11.3	5.62±1.88	0.97±0.48	0.28±0.11	1.94±0.57	42.7±10.1	17.1±4.97	151 ±98.7
experimental		4.17±0.17	34.2±15.7	3.76±1.63	1.96±2.43	0.30±0.13	1.78±0.51	40.6±15.7	16.7±10.5	224 ±176
control	3	5.13±0.79	30.7±16.5	41.4±20.1	6.00±3.83	1.27±0.12	8.54±3.81	80.2±13.8	61.0±20.7	314 ±70.8
experimental		5.02±1.08	39.7±18.3	34.6±20.7	7.89± 6.98	1.38±0.19	1.83±1.54	84.2±13.4	50.8±26.0	405 ±107
control	4	6.10±0.34	9.1±7.95	49.7±12.9	33.8±5.35	1.26±0.08	2.87±1.38	94.1±11.7	91.0±9.00	766 ±129
experimental		6.21±0.35	8.4±9.02	55.1±17.7	33.6±4.92	1.24±0.04	9.13±10.7	93.4±30.1	89.6±9.98	721 ±115

mately 25 percent. Some woody material was still recognizable in this layer, although it had a thick, mucky texture and was almost black in colour. The peat deposit is not deep (<140 cm) and is underlain by marl. A hydric layer was present in two of the cores which extended from approximately 80 cm.

The pH ranges from 6.2 to 6.8 in the uppermost fibric layer to 5.8 to 6.2 in the middle and bottom tiers. Cation exchange capacity is highest in the upper fibric layer and decreases slightly with depth, the overall range being from 56 to 76 meq/100 g soil. Base saturation ranges from 64 to 87 percent in the surface tier and from 43 to 66 percent in the middle and lower tiers. Hydrogen ion content is comparable to that in the organic horizons of the soils at sites 1 and 2 (9 to 34 meq/100 g soil). The Ca and Mg contents are much higher; 19 to 47 and 8 to 28 meq/100 g soil, respectively. Magnesium concentrations are highest in the least decomposed surface layer. As at the other study sites, K and Na are present in only minimal concentrations. This peaty material has a very high water holding capacity and had a water content, at the time of sampling, of 500 to 1000 percent.

4.4.2 The Chemistry of the Fall and Spring Organic Horizon Samples

A complete summary of the organic horizon chemical analyses is given in Tables 2 and 3, Appendix 2. The means and standard deviations are presented in Table 17. The three data groups include i) the fall ii) spring control and iii) spring experimental (beneath plastic) samples of the organic horizons to a depth of 10 cm.

Between-site comparisons of the three data groups are presented in Table 11, Appendix 3. In Table 18, the study sites are arranged in order of decreasing values for mean pH, cation and available phosphorus concentrations, CEC, base saturation and percent water content. The general between-site relation-

Table 18: Study sites ranked according to highest mean value for each chemical parameter measured in the surface soil samples

general relationship	differences significant at at least α=0.05	general relationship	differences significant at at least α=0.05
pH		**H**	
a 4>3>2>1	4>3, 2, 1; 3, 2>1	a 3>1>2>4	3>2, 4; 1>2, 4
b 4>3>2>1	all	b 1>2>3>4	1, 2, 3>4; 1>3
c 4>3>2>1	all	c 3>2>1>4	1, 2, 3>4
Ca		**Mg**	
a 4>3>2>1	4>3, 2, 1; 3>2, 1	a 4>3>1>2	4>3, 2, 1; 3>2, 1
b 4>3>2>1	4>2, 1; 3>2, 1; 2 1	b 4>3>1>2	4>3, 2, 1; 3>2, 1
c 4>3>2>1	4>3, 2, 1; 3>2, 1	c 4>3>1>2	4>3, 2, 1; 3>2, 1
K		**Na**	
a 3>4>1>2	1>2	a 4>3>1>2	4>1, 2; 3>1, 2; 1>2
b 3>4>1>2	3>4, 1, 2; 4, 1>2	b 2>3>4>1	none
c 3>4>1>2	3>4, 1, 2; 4>1, 2	c 3>2>4>1	3 1, 4
P		**CEC**	
a 3>4 1>2	3>4, 1, 2	a 4>3>1>2	all
b 3>4 2>1	3>4, 2, 1; 4>2, 1	b 4>3>1>2	4>3, 1, 2; 3>1, 2
c 4>1 3>2	4>1, 3, 2; 1>2	c 4>3>1>2	4>1, 2; 3>1, 2
%BS		**%WC**	
a 4>3>2>1	4>3, 2, 1; 3>2, 1	a 4>1>3>2	4>1, 2, 3; 1, 3>2
b 4>3>2>1	all	b 4>1>3>2	4>1, 2, 3; 1, 3>2
c 4>3>2>1	4>3, 2, 1; 3>2, 1	c 4>3>1>2	4>1, 2, 3; 3>1, 2

a: Fall samples
b: Spring control samples
c: Spring experimental samples

ships are described on the left. On the right, the significant differences (based on the one-tailed test) are identified. Significance is accepted at the 95 percent level. The between-site relationships remain constant in the fall and spring sampling periods and between the control and experimental spring data sets for the following parameters: pH, Ca, Mg, K, CEC and base saturation. For these parameters, mean values are highest for the samples from sites 3 or 4 and lowest for samples from sites 1 or 2. The pattern is less well defined for H, Na and available phosphorus (in the control samples).

The majority of differences are statistically significant at at least the 95 percent level. Many comparisons show significant differences between all of the sites. Differences which are frequently not significant occur between site 1 and 2 and sites 2 and 3. Where highest mean values occur at site 4, they are significantly higher than at the other three study sites. This applies to pH, Ca, Mg, Na, CEC, base saturation and water content in both the fall and spring samples (control and experimental). Where highest mean values occur at site 3, they are not always significantly higher, although this does apply for K concentrations in spring, Na concentrations in the experimental spring samples and available P in the fall and control spring samples.

Differences remain, in general, significant from the fall to the spring and the same significant differences apply to both the control and experimental samples. Where changes in significance do occur, they involve comparisons between sites 1 and 2 or sites 2 and 3.

The t-statistics for the within-site comparisons between 1) the control and experimental samples and 2) the spring and fall samples are given in Table 19. A pattern can not be defined, which identifies either higher or lower mean pH, cation or P concentrations, CEC, base saturation or percent water content in

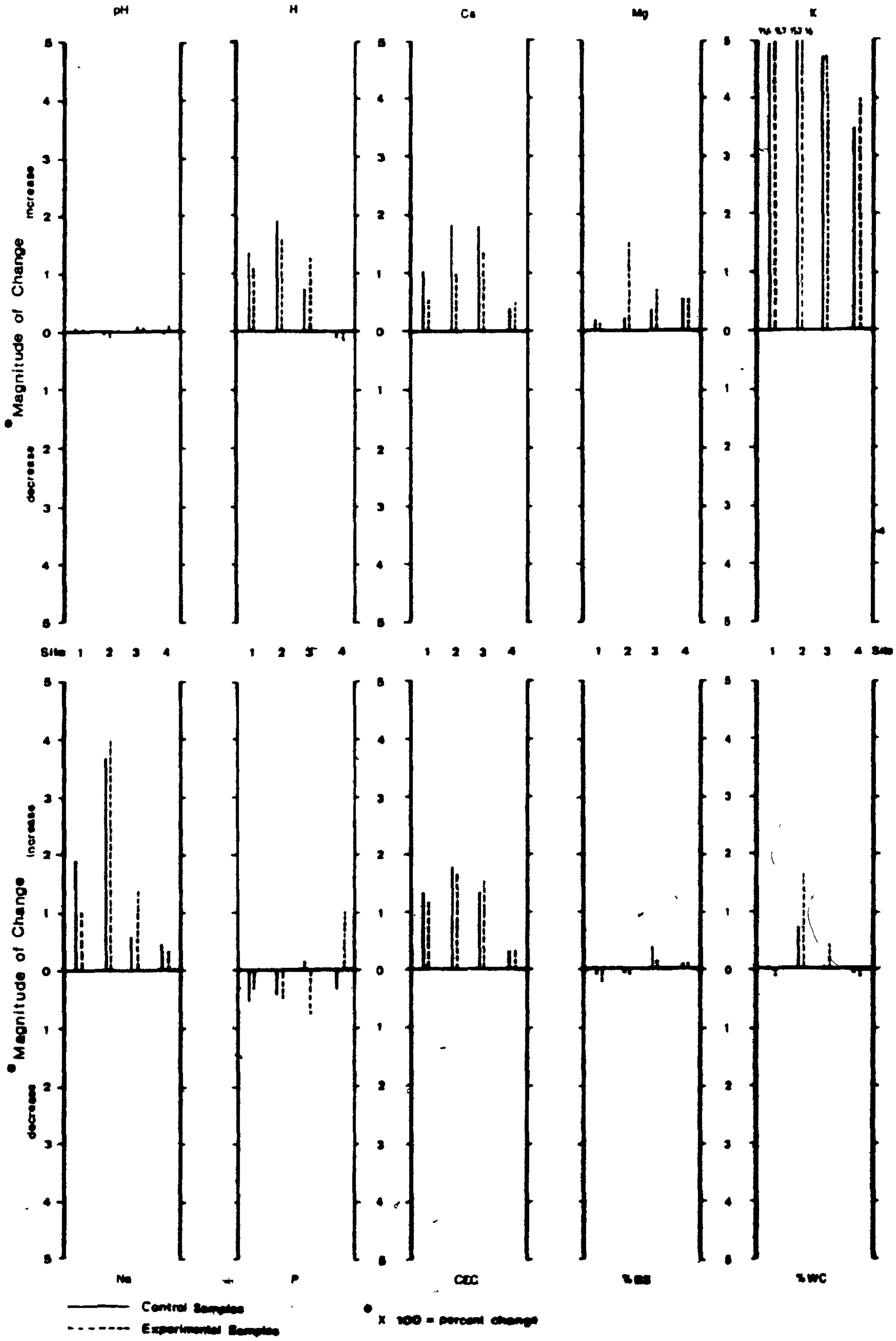
Table 19: A statistical comparison of the surface soil horizon chemistry between i) the control and experimental samples and iia) the fall and spring control samples and iib) the fall and spring experimental samples, within the same site.

Site	pH	H	Ca	Mg	K	Na	P	CEC	%BS	%Water Content
i)	t	t	t	t	t	t	t	t	t	t
1	−2.94:	−0.29	−1.63	−0.46	−0.81	−0.26	+2.64·	−0.46	−1.23	−1.37
2	+0.14	−0.43	+2.03	+1.26	+0.09	+0.37	−0.64	−0.34	−0.10	+1.14
3	−0.26	+1.16	−0.73	+1.42	=0.00	+1.55	−5.16⁝	+0.68	−0.97	−2.24·
4	+0.71	−0.18	+0.75	−0.34	+1.01	−0.68	+1.74	−0.07	−0.97	−0.81
ii)										
1 a	+0.77	+10.8⁝	+2.77:	+1.02	+9.31⁝	+4.00⁝	−1.63	+9.88⁝	−0.60	+0.26
1 b	−2.41·	+8.57⁝	+1.26	+0.71	+5.64⁝	+4.07⁝	−0.97	+5.80⁝	−1.32	−1.17
2 a	−3.66:	+6.68⁝	+5.48⁝	+0.89	+6.45⁝	+6.22⁝	−1.21	+11.8⁝	−0.30	+2.06·
2 b	−3.25:	+4.32⁝	+3.28:	+1.53	+6.07⁝	+5.78⁝	−1.34	+4.79⁝	−0.27	+2.47·
3 a	+1.25	+2.46·	+3.83:	+0.77	+7.09⁝	+2.11·	+0.84	+8.12⁝	+1.36	+1.11
3 b	+0.73	+3.76:	+2.76:	+1.27	+7.18⁝	+3.16:	−0.45	+8.66⁝	+0.50	+3.33:
4 a	−0.25	−0.30	+2.78:	+5.12⁝	+5.20⁝	+2.63:	−1.23	+5.49⁝	+1.22	−1.11
4 b	+0.43	−0.49	+2.87⁝	+4.86⁝	+4.06⁝	+2.44·	+1.17	+2.32·	+0.77	−2.07·

± mean values at site 2, 3 and 4 > or < at site 1; at sites 3 and 4 > or < at site 2; at site 4 > or < at site 3.

Level of significance
⁝ 0.001
: 0.01 one-tailed test
· 0.05

Figure 9 Changes in the nutrient status of the surface soil horizons between fall and spring



either the control or experimental samples. With the exception of pH and available P at site 1 and available P and water content at site 3, there are no significant differences between the spring and experimental samples.

The changes in concentrations between the fall and spring samples are presented graphically in Figure 9. What is immediately apparent is that the majority of changes are increases in concentrations. Changes, which are significant at at least the 95 percent level, include pH, H, Ca (sites 1, 2 and 3), Mg (site 2) K, Na, CEC and percent water content (sites 2, 3 and 4).

Changes in pH are small in magnitude, although the slight decreases at site 2 (4.4 to 4.2) are enough to be significant, as is the decrease in the experimental samples at site 1 (3.8 to 3.6). If it were not for the large standard deviations of the mean pH values at site 3, these differences (4.7 compared to 5.1) would also, probably, be significant, since they show the largest degree of change. Changes at site 4 were minor and not significant.

Hydrogen ion concentrations increased significantly at sites 1, 2 and 3. Increases were from 16 to 38 meq/100 g soil at site 1, 13 to 37 meq/100 g soil at site 2 and 18 to 31 meq/100 g soil at site 3 (despite the increase in pH at this site). Changes in H ion concentrations at site 4 were minor and not significant.

Calcium, K and Na concentrations increased significantly at all four sites. The increase in mean Mg concentration was significant only at site 4. In absolute terms, the most important increases occurred in mean Ca and Mg (site 4) concentrations. Calcium increased by 2, 3.5, 26 and 12 meq/100 g soil at sites 1, 2, 3 and 4, respectively. Magnesium increased by 12 meq/100 g soil at site 4. However, the greatest percentage increases occurred in K concentrations at all four sites. At site 1, the increase of 0.80 meq/100 g soil (from 0.07 to 0.87 meq/100 g soil) was an increase of 1100 percent. At site 2, the increase was 1600 percent and 350 percent at sites 3 and 4. Increases in Na concentrations, although also small in absolute values, are significant and at site 2 are large in terms of percentage increase (375 percent from 0.06 to 0.28 meq/100 g soil).

Given the significant increases in the basic cations and H, it is only logical that the CEC of the organic horizons should also increase. The increase was significant at all four sites. The magnitude of the increase is comparable between sites 1, 2 and 3, but is much less at site 4. Although the base cation concentrations increased in all cases, the base saturation shows only very small changes and even decreases slightly at sites 1 and 2. The changes are not significant. The same changes are due to the large increases in H ion concentration at sites 1, 2 and 3, which minimize the effect of the increases in basic cation concentrations at these sites.

Percent water content increases are significant at sites 2 and 3 (control samples) and the decrease at site 4 is also significant. Perhaps the most important change is at site 2. During the fall, the water content of the surface soil horizons was less than 100 percent by weight. In the spring, this material was saturated. Interestingly, the changes in the values of the majority of parameters is also most pronounced at site 2. H, K and Na all show decidedly greater increases here than at the other sites. Changes in Ca concentrations are also large and CEC show changes of the greatest magnitude at site 2. pH values at site 2 decrease in both the control and experimental samples, both of which have significantly lower pH values than those measured in the fall.

4.5 Over-Winter Mass Losses in Plant Tissues

Mean percent mass losses shown by the tissue samples over

Table 20: Percent mass lost from plant tissue samples during the winter at the four study sites

Site 1

Tissue	Birch	Labrador tea	Spruce
% mass loss $\bar{x}$, σ	33.9±3.73	14.4±2.01	18.6±1.73

Site 2

Tissue	Birch	Labrador tea	Blueberry
% mass loss $\bar{x}$, σ	20.6±2.75	9.04±1.46	20.1±1.78

Site 3

Tissue	Birch	Labrador tea	Spruce
% mass loss $\bar{x}$, σ	40.3±4.86	16.2±1.77	20.3±3.92

Site 4

Tissue	Birch	Tamarack
% mass loss $\bar{x}$, σ	31.0±4.85	30.7±6.70

Table 21: Between-site comparisons of percent mass losses shown by the different plant tissues

	Birch					
Between-Site Comparisons	1vs2 t	1vs3 t	1vs4 t	2vs3 t	2vs4 t	3vs4 t
	$^{-}$12.72⁝	$^{+}$4.67⁝	$^{-}$2.05⁝	$^{+}$15.68⁝	$^{+}$7.97⁝	$^{+}$5.87⁝

	Labrador tea			Black spruce
Between-site Comparisons	1vs2 t	1vs3 t	2vs3 t	3vs4 t
	$^{-}$9.32⁝	$^{+}$2.93⁝	$^{+}$13.45⁝	$^{+}$1,77

Table 22: Comparisons of percent mass losses between the different plant tissues within the same site

	Site 1		
Tissue Comparisons	Birch vs L. tea t	Birch vs Spruce t	L. tea vs Spruce t
	20.46⁝	16.56⁝	6.90⁝

	Site 2		
Tissue Comparisons	Birch vs L. tea t	Birch vs B.berry t	L.tea vs B.berry t
	16.09⁝	0.67	20.71⁝

	Site 3		
Tissue Comparisons	Birch vs L. tea t	Birch vs Spruce t	L. tea vs Spruce t
	20.77⁝	14.32⁝	4.24⁝

	Site 4
Tissue Comparisons	Birch vs Tamarack t
	0.16

± values at sites 2, 3 and 4 > or < at site 1; values at sites 3 and 4 > or < at site 2; values at site 4 > or < at sit 3.

Levels of Significance
⁝ 0.001
: 0.01
· 0.05

the winter are presented in Table 20. The complete data set is given in Table 4, Appendix 2. Results of the t-test, comparing the percent mass losses between species, are given Table 21. Statistically significant differences (at at least the 95 percent level) in mass losses are apparent between the three tissue types at site 1. Birch tissue showed the greatest loss (one-third of its original mass), which is significantly greater than either that shown by Labrador tea or by spruce tissues. Spruce tissue experienced slightly higher percent mass loss than Labrador tea, which, in terms of absolute values, does not appear to be greatly different (18.6 vs 14.4 percent for spruce and Labrador tea, respectively) but is significant.

At site 2, birch and blueberry tissues showed almost identical mass losses, 20.6 and 20.1 percent, respectively. Both of these losses are significantly higher than that shown by Labrador tea. At site 3, differences in mass losses between all three tissue types are significant. Birch tissue showed the greatest mass loss followed by spruce and Labrador tea. At site 4, birch and tamarack showed almost identical mass losses (31.0 and 30.7 percent, respectively).

The differences in mass losses for the same tissue type between each site have been compared statistically (Table 22) and, for each tissue type, the study sites have been ranked from greatest to least amount of mass loss (Table 23). For those study sites which have common tissue types, site 3 shows the greatest mass loss for the three tissue types, birch, Labrador tea and spruce. For birch and Labrador tea, site 1 showed greater losses than site two. Birch also showed greater mass losses at site 1 compared to site 4 and at site 4 compared to site 2. All of these comparisons show statistically significant differences. Within each site, birch tissue showed greater losses than spruce and Labrador tea showed the least mass loss.

Table 23: Study sites ranked in order of decreasing percent mass loss

Birch	L. tea	B. spruce
3 > 1 > 4 > 2	3 > 1 > 2	3 > 1

The visual appearance of the retrieved tissue samples also suggested that decomposition had occurred. Although the spruce and tamarack needles and the Labrador tea tissues were intact, the birch and Labrador tea samples had undergone physical changes which, other than some bleaching of the spruce needles, did not appear to have affected the other tissue types. They had changed colour to a large degree, had compacted and clumped together in the litter bags and some of the leaves were covered with mould.

In order to avoid the effects on decomposition which could have occurred in the event of large time differences between sample retrieval, the tissue samples were retrieved on the same day, June 8, but before the snowpack had completely disappeared from site 3, whereas at sites 2 and 4, the snow cover had melted more than one week previously. At site 1, the snow cover had almost completely melted.

The use of the 1mm mesh size is common in many litter decomposition studies and is considered to be small enough to prevent any major losses of litter, although tamarack needles fall through easily. Therefore, the 0.5 mm mesh size was used for this tissue type. The different mesh size could possibly render comparisons between the data unreliable. It is possible that some litter did actually fall through the mesh and that, therefore, the weight losses are not real. However, the very small standard deviations of the means of the 20 samples (Table 20) suggest that these weight losses are real and that each sample lost approximately the same percent of mass. Had the litter fallen through the litter bags, the standard deviations would most likely have been much higher.

Mesh bags can exclude macro-faunal decomposers, but Lucarotti (1976) has shown that the macro-faunal population of the lichen woodland soils around Schefferville is low, so that the use of the mesh bags in this environment should not exclude any important decomposers. However, the same data are not necessarily applicable to the forest, fen or tundra sites, where macro-faunal population counts were not made. Thus, this assumption may not apply to the entire study area.

Table 24: A comparison of May Lake snow chemistry with snow chemistries from other regions

Location	Date	pH	Ca mg/l		Mg mg/l		K mg/l		Na mg/l	P ug/l		Source
Schefferville, P.Q.:												
May Lake Catchment												
lichen woodland	15.12.80	4.98	0.03		0.01		0.05		0.14	9.31		
	22.02.81	4.84	0.08		0.02		0.04		0.17	5.66		
	30.04.81	4.88	0.06		0.01		0.04		0.16	3.53		
lichen-heath tundra	12.12.80	4.87	0.03		0.01		0.04		0.14	7.24		
	24.02.81	4.61	0.05		0.02		0.03		0.09	6.98		
	04.05.81	4.84	0.03		0.02		0.04		0.13	4.41		
feathermoss forest	11.12.80	5.06	0.08		0.03		0.16		0.10	31.5		present study
	23.02.81	4.61	0.10		0.05		0.25		0.11	14.8		
	09.05.81	4.81	0.23		0.05		0.26		0.18	20.1		
sedge-moss fen	16.02.80	4.91	0.11		0.10		0.14		0.13	12.1		
	22.02.81	5.03	0.09		0.03		0.13		0.15	15.8		
	03.05.81	4.93	0.25		0.07		0.12		0.20	6.29		
lichen woodland	21.02.81	5.04	0.04		0.01		0.07		0.09	3.18		
lichen-heath tundra	21.02.81	5.16	0.03		0.01		0.03		0.10	2.60		present study
feathermoss forest	21.02.81	5.04	0.03		0.01		0.07		0.14	5.43		
sedge moss fen	21.02.81	4.78	0.05		0.01		0.05		0.13	4.45		
Schefferville, P.Q.										PO_4-P	Tot P	
lichen woodland	Apr 76	5.73	0.33		0.10		0.10		0.95	7.0	8.0	Moore (1980)
Resolute, NWT										Sol P	TDP	
Char Lake Catchment	May/Jun 71	nd	2.09		0.50		0.10		0.96	13	18	Schindler et al. (1972)
Southern Norway												
Storefjell	Jan 74	4.91	0.33		0.03		–		0.77	6		
Fryesdal & Valabjørg	Jan 74	4.57	0.47		0.14		0.14		1.40	3		Johannessen and Henriksen (197
Blindern	Jan 74	3.98	0.87		0.15		0.87		1.32	2		
Todval, S. Norway												
Upper Catchment	04.04.77	4.38	0.07		0.05		0.08		-	-		
	16.04.77	4.47	0.09		0.06		0.08		-	-		
	26.04.77	4.40	0.05		0.04		0.01		0.45	-		and
	06.05.77	4.57	0.05		0.02		0.01		0.36	-		Skartveit Gjessing (1979)
Lower Catchment	04.04.77	4.55	0.06		0.03		0.07		0.33	-		
	16.04.77	4.57	0.07		0.03		0.05		0.36	-		
	26.04.77	4.66	0.07		0.02		0.01		0.31	-		
	06.05.77	4.85	0.04		0.02		0.02		0.90	-		
Rocky Mountains			Fresh snow	Snow pack	Fresh snow	Snow pack	Fresh snow	Snow pack				
S.E. Wyoming												
open	May 77	-	0.15	0.25	0.07	0.04	0.10	0.04	-			
pine forest	May 77	-	0.33	0.37	0.08	0.09	0.12	0.25	-			Fahey (1979)
mixed forest	May 77	-	0.61	0.66	0.13	0.14	0.30	0.54	-			
spruce/fir forest	May 77		0.62	0.60	0.14	0.11	0.48	0.65	-			
N. central Minnesota										Sol P	Tot P	
open	winter 75	-	0.33		0.07		0.04		0.12	6	63	
black spruce forest	winter 75	-	0.37		0.01		0.03		0.13	8	78	Verry and Timmons (1979)
aspen-hazel forest	winter 75	-	0.73		0.13		0.14		0.12	9	70	
S. central Ontario												
open	Mar 80	5.09	2.57		0.16		0.59		0.30			
wooded	Mar 80	5.08	3.02		0.22		0.57		0.45			Pierson and Taylor (1980)
total catchment	Mar 80	5.09	2.79		0.19		0.58		0.36			

CHAPTER 5

Discussion of Results

5.1 A Comparison of the May Lake Catchment Snow Chemistry with the Snow Chemistry from Other Study Areas

During all sampling seasons, nutrient concentrations in the May Lake catchment snowpacks were extremely low. The combined mean pH, cation, TDP and particulate matter concentrations for the December, February and spring snowpacks and the mean values for the February surface samples are summarized in Table 24 and compared with snowpack and fresh snow chemistry measured earlier at Schefferville and with other locations in northern and southern Canada, northern United States and northern Europe. The differences and similarities in these values are related to regional variations in climatic patterns, continental or coastal locations, long-range transport of pollutants, vegetation (both overlying and underlying) and soils. The range of differences, which is seen in comparing the snowpack concentrations from different vegetation zones within the same study area, is often as large as the differences between snowpack or fresh snow chemistry from different regions of the world.

Comparison of the May Lake data with values reported by Moore (1980) shows that the mean cation concentrations in the May Lake catchment snowpacks were lower than those values measured in a woodland snowpack near Schefferville in 1976. Differences between these two data sets could be due to local influences or because of differing synoptic conditions. If the bulk of Schefferville's winter precipitation has come from the Hudson Bay/Labrador coast region, the cation content would be higher. If the storms come from the south, the pH would likely be lower.

Although the concentrations in the fresh snow samples are clearly lower than values measured from other regions, the snowpacks show a range of values which agree with higher and lower concentrations elsewhere. The highest concentrations occur in the spring snowpack in the feathermoss forest and the fen and are comparable to values from other studies conducted in the spring. Phosphorus concentrations in both the snowpack and fresh snow samples agree well with findings from other areas.

The pH values from the May Lake study areas are noticeably lower than the 5.7 measured in 1976 in the lichen woodland (Moore, 1980) or compared to mean pH values of spring snowpacks reported by Drake and Moore (1980) ranging from 5.2 to 5.6. The May Lake values, which range from 4.8 to 5.1 in the spring snowpacks, are comparable to findings of Pierson and Taylor (1980) for snowpacks in south - central Ontario or to the values measured in the Storefjell snowpacks in southern Norway (Johannessen and Henriksen, 1978). The snowpacks are much less acidic than those sampled in Todval, Norway, which had pH values of 4.4 to 4.9, increasing as the melt progressed.

Although the Todval, Norway snowpacks are more acidic than those at Schefferville, there is close agreement between the cation and phosphorus concentrations measured in the woodland and tundra snowpacks. This similarity is particularly interesting since, of those areas presented, the vegetation structure of Todval resembles that of the study area most closely. The area is dominated by a heath vegetation cover with scattered pine and birch in the upper catchment and spruce forest in the lower catchment (Skartveit and Gjessing, 1979). Snow chemistry in Todval is, however, influenced by the long-range transport of pollutants from more southerly areas in Europe, as are the study areas from Johannessen and Henriksen (1978). This is, apparently, not a factor in the Schefferville area during the winter, although local SO_2 emmissions from the townsite, in addition to mining operations and burning at the town dump, probably affects the snow chemistry in the immediate, surrounding area, particularly the snow pH (Drake and Moore, 1980).

The May Lake catchment snowpack data can also be compared to the other studies, independent of absolute concentrations, in terms of spatial and temporal changes in snow chemistry, such as the differing concentrations between forested and non-forested areas and the changes in snowpack concentrations during the winter. The data from Fahey (1979), Verry and Timmins (1979) and Pierson and Taylor (1980), available for different vegetation covers, show differences in concentrations between open and forested regions, the open areas having generally lower concentrations. This was true for both the fresh snow and the snowpack samples. Fahey (1979) suggested that because Ca, Mg and K concentrations in fresh snow collected from beneath the tree canopy were all higher than from open areas, the enrichment was due to canopy leaching or washing of particulate matter from leaf surfaces rather than being due to augmentation of nutrients in the snow after it reaches the ground. This enrichment was also higher in the denser forest stands. Fresh snow, collected in precipitation collectors by Pierson and Taylor (1980), also showed higher concentrations in a densely forested area which they attributed to the effects of the overlying vegetation. Samples from a clearing, circled by birch, showed lower concentrations than at the forested area and also lower than in in the open area. It was suggested that this small clearing was protected from the effects of aeolian contributions which influenced the content of the fresh snow samples in the open.

In general, the snowpack concentrations in the May Lake catchment show the same pattern when comparing data for the same sampling dates. The feathermoss forest, which is the most densely vegetated site, had the highest snowpack nutrient concentrations. The lichen woodland and the 'open' lichen-heath tundra both had lower concentrations. The fen roughly corresponds to the clearing described by Pierson and Taylor (1980) in that it too is ringed by trees. However, this site showed the second highest snowpack concentrations of the four sites. This could be due to contributions from underlying vegetation, an effect which will be discussed in section 5.3.

The concentration of the surface snow samples collected in February showed no differences in cation or TDP concentrations between the four study sites. However, the snowpack concentrations did show differences (which were often significant). Although data are not available for fresh snow samples throughout the winter, to substantiate the following assumption, it would appear that nutrients are being supplied to the May Lake catchment snowpacks following snowfall, unlike the explanation suggested by Fahey (1979). This will be be discussed in detail in section 5.3.

Wright and Dovland (1978), Johannessen and Henriksen (1978) and Skartveit and Gjessing (1979) suggested that ionic species are lost from the snowpack during the winter. This is based on studies showing higher cumulative ion concentrations in snow collected in precipitation collectors compared to snowpacks which were sampled on corresponding dates. By sampling at different levels in the snowpack, Jeffries and Snyder (1981) also found that, over the winter, migration and loss of nutrients occurred prior to spring melt. Johannessen and Henriksen (1978) reported sizeable nutrient losses from the snowpack at the onset of the melt. This is to be expected since the elements would become concentrated in the meltwater and removed from the snowpack.

The chemistry of the May Lake catchment snowpacks also appeared to be undergoing changes through the winter. The distribution patterns of the chemical constituents changed in concordance with the findings of Jeffries and Snyder (1981) in that migration through the snowpack appeared to be occurring. Potassium, Mg and, to a lesser extent, P concentrations showed a tendency to decrease in the upper and middle snowpack sections in the woodland, lichen-heath tundra and fen sites. In the February and spring snowpacks, K was no longer present in measureable concentrations in these snowpack levels. This did not occur in the snowpack in the feathermoss forest, where input from the vegetation cover would have the greatest influence.

5.2 The Relationship of Snowpack Structure to Snowpack Nutrient Distribution Patterns

Ice and slush layers in the snowpack result from periodic, short-lived melt episodes which often occur at the snow surface. The snowpacks sampled at all study sites in the May Lake catchment contained a number of ice layers of varying thicknesses (see section 4.2.2). The meltwater, which percolates through the snowpack, transports dissolved elements with it. These become deposited at lower depths in the pack or, during melt, are most probably washed out of the pack (Johannessen and Henriksen, 1978). If the melt water collects and freezes at a certain depth, it may be expected that the dissolved ions will also collect and concentrate, having been 'frozen out' in front of the freezing plane (a process similar to the one which leads to a concentrated layer of cations just below a lake-ice cover). This possible mechanism of redistribution and concentration of nutrients in the snowpack was not measured directly, but the sampling interval of 10 cm was small enough that, as seen in Figures 5a to 5l, coincidences of ice layers and increases in nutrient concentrations are apparent.

The distribution of nutrients in the snowpack can be related to particulate matter content. This is discussed further in section 5.3. However, the distribution of particulate matter may itself be partly related to ice layers since particulate matter can also be carried through the snowpack in the meltwater and, where seepage is blocked by an already existing ice layer, collect at this point. To what extent nutrients could have been lost from the snowpack through 'washing out' is not known, but depletion patterns shown by K, Mg and P would suggest that a sizeable proportion may have been lost in this manner from the snowpacks. A warm period in February resulted in some melting of the snowpack, which would make this a plausible mechanism, and the very presence of ice and slush layers in the snowpack is evidence that numerous minor melt episodes occurred. Jeffries and Snyder (1981) reported sizeable nutrient losses from the snowpacks in their study areas following the February melt period which also affected the central Ontario region.

Some illustrative examples can be drawn from the data which suggest that ice layers have affected, to some extent, the nutrient distributions in the snowpacks. Two examples at site 1, profiles 1 and 3, show slight increases in ion concentrations at the snowpack base, where an ice layer is present. Depletions above this level suggest that, at some time prior to sampling, cations may have been transported with meltwater from layers above but could not leave the snowpack because of the basal ice layers and collected above the ice. At site 4, profiles 4 (100-110 cm) and 7 (90-100 cm), Figure 5j, profile 5 (20-30 cm), Figure 5k and profiles 3 (40-50 cm) and 11 (90-100 cm), Figure 5l, marked increases in cation concentrations can be seen in the sampling intervals immediately above the ice layers, below which depletions are apparent. This effect is most pronounced in profiles 4, 8 and 11 and for Mg and K.

The snow profiles at site 3 have fewer major ice layers than were found at the other sites and the nutrient distribution patterns are more erratic at this site than at sites 1, 2 or 4. Depletions are also not as marked. Factors such as particulate matter content may be responsible for this, but the thin, less frequent ice layers at this site suggest that washing out or redistribution of nutrients in the snowpack was not as pronounced as it was at site 4. The effects of radiation melting could be reduced at this site because of the closed forest canopy. This prevents much of the direct sunlight from reaching the snowpack surface and therefore from having as great an effect on surface melting as occurs at an open site. However, some nutrient increases appear to be related to ice layers at this site, most notably at profile 2 (40-50 cm) (Fig. 5h) where concentrations above this level are noticeably lower and also in profile 7 (40-50 cm) (Fig. 5g). In these examples, particulate matter does not show an increase at these levels and therefore does not appear to have had an effect on the higher concentrations. There do not appear to be any pronounced coincidences of ice layers and increased nutrient concentrations in the site 2 snowpacks, with the exception of profile 11 (20-40 cm) (Fig. 5f) where concentrations are higher between two ice layers, one at 18 cm and a major one between 30 and 38 cm.

5.3 The Effect of Particulate Matter on Snowpack Nutrient Concentrations

The very low chemical concentrations in the fresh snow samples at all sites collected in February, compared to the chemical concentrations in the samples of older snow removed from other depths in the snowpack, particularly from those intervals where a corresponding, higher concentration of particulate matter occurs, suggests that the nutrients are not carried with the falling snow but enter the snowpack through the localized contributions of litter fall and dry deposition.

At Schefferville, a snow cover begins to develop before litter fall is complete and litter, particularly birch, Labrador tea and tamarack, becomes incorporated into the lower snow profile. This was most apparent at the woodland and feathermoss forest sites. Snow, which collects in the tree canopies, eventually falls to the snow surface, carrying with it pieces of bark, needles and the epiphytic lichens from the spruce trees. This was very noticeable in the forest site, where the profile horizonation was often poorly discernible due to the large amounts of snow which had cascaded from the overlying canopy, interrupting the normal horizonation in the snow profile and also adding chunks of ice which were carried down with the cascade. In this way, litter material is further added to the snowpack.

Dust, which is removed from unprotected surfaces, is transported and deposited on the snow surfaces in areas of snow deposition. This becomes less important later in the winter once a continuous snow cover, even on the ridge areas, is established. The pink layer in some of the lower profile sections at sites 1, 3 and 4 was most likely a layer of iron-ore dust, although chemical analysis for iron content is not available to support this assumption. The same layer was not found in the snowpack at site 2, an area of snow removal and redistribution, particularly in early winter. In these ways, particulate matter, composed of dust and litter, becomes incorporated into the snowpack.

Concentration peaks, which occurred in the snowpack, frequently corresponded to increases in particulate matter. The examples of this were outlined in section 4.3.1. Not all higher cation and phosphorus concentrations corresponded to larger amounts of particulate matter. However, occurrences are numerous enough to suggest that particulate matter could be a contributor to the nutrient content of the snowpack. This applies, in varying degrees of importance, to all four sampling sites. Certainly, the nature of the litter and the amount vary from site to site and at various depths.

As was shown in section 4.3.1, Table 6, there is a strong correlation between particulate matter and Ca, Mg and K in the December profiles at the forest and fen sites. This was not evident in either the woodland or tundra site profiles. These correlations at site 3 were found to correspond to the examples of profiles where the cation and particulate matter distribution patterns paralleled each other. This suggests that particulate matter is contributing to the nutrient content of the snowpack at this site. In addition, one February profile (profile 4, Fig. 6i) also showed a high correlation between K and particulate matter and the distribution patterns of these two parameters were very similar. The same was also true of particulate matter and all four cations and TDP in the May profile, 9 (Fig. 6j).

The reasons for the high correlation coefficients between the cations and particulate matter in December at site 4 is not as apparent from the graphs as it is at site 3. Particulate matter appears to be more evenly distributed through the profiles at site 4 and is present in lower concentrations with the exception of the bottom 10 cm. The large increases in the cation concentrations in the base samples do, however, parallel large increases in particulate matter. These values could be influencing the correlation coefficients between these parameters.

The high correlations did not continue through the winter. One reason for this could be the redistribution of the nutrients and/or particulate matter through meltwater transport. It would, in any event, appear that migration has occurred, as previously shown in section 4.3.2. This would have removed the nutrients from their early winter positions in the snowpack, corresponding to high particulate matter concentrations, thus leading to the lower correlation coefficients between these parameters in February and May.

Certain parameters, particularly K, showed marked increases in the base samples of the snowpack. In many of these samples, the particulate matter content also increased. At this level, the particulate matter is largely litter, which becomes incorporated into the snowpack base from the forest floor or from the low shrubs which are partially or fully covered before litter fall is complete. At site 2, where some of the profiles were excavated over bare ground, it was found that some soil and stones where incorporated into the first few centimeters of the snowpack, probably due to freezing or frost bubbles.

The nature of the ground cover, the organic matter horizons and the litter at the four sites are all different. But, whereas there are some similarities between the woodland, tundra and forest sites, the fen is very different in all respects. The results in Figure 8, section 4.4.1, showed that, in the autumn, the organic soil at site 4 was basic, particularly in comparison to sites 1, 2 and 3, and that the base cation concentrations in the upper organic mat, composed primarily of sphagnum moss and sedges, was higher than at the other three sites, whereas H ion concentration was lowest (Table 17, section 4.4.2). Calcium and Mg were present in much higher concentrations in the fen soil than in the woodland, tundra or forest soils and K and Na concentrations were greater in the woodland and tundra soils. Available P contents were found to be similar at all four sites. The organic horizons of the Brunisols at sites 1, 2 and 3 were acidic (4.7 to 3.8), being most acidic at site 1. There appears to be an effective buffering system in the feathermoss forest Brunisols which counters the large H ion concentration in the soil, leading to higher soil pH than in the woodland or tundra soils. Although the concentrations of all parameters, with the exception of available P, increased in the spring samples, the same fundamental relationship of between-site nutrient status was maintained.

In terms of comparative concentrations, it should not be surprising that, given the higher concentrations in the surface material at site 4, the concentrations of the same elements were found to be highest in the base samples from the snowpack at this site. Similarly, concentrations are higher in the organic horizons at site 3 than at sites 1 or 2 and increases in the concentrations of the cations and phosphorus in the snowpack base samples were also greater during December, February and April. Potassium appears to be the most mobile of the four cations, being easily leached from the underlying vegetation cover. Although K is present in the smallest concentrations in the soil surface horizons at all four sites, it shows the most appreciable increases in the base samples of all the snowpacks. At the woodland site, it is the only element which showed an increase. At site 2, the tundra, K did increase in the spring, although no increases occurred in December or February. Calcium and Mg, which are present in much higher concentrations, showed only minimal increases in the base snow samples from the profiles in the forest and did not increase at this level at all at sites 1 or 2. The only appreciable increases in Ca, Mg and Na occurred at the fen, although K concentration increases were still much greater.

The migration of elements from the soil or ground cover into the base of the snowpack can affect the overall snowpack chemistry. The degree of this effect depends on the type of ground cover. The data presented in section 4.3.7 indicated that contact with the ground surface definitely increases the concentration of nutrients in the snow at the base of the snowpack and that this effect is most pronounced following the onset of the melt.

Recalculating the mean snowpack concentrations, omitting the base sample values (Table 8, Appendix 3 and Table 13, section 4.3.7), illustrated the extent to which direct contact with the ground surface can affect the mean snowpack concentrations. Although the differences between the two sets of means were not significant, they did show that the base sample values do increase the mean concentrations and the standard errors. The influence of the ground cover on the snowpack chemistry was found to be most pronounced at the fen site and least at the woodland site. The effect was particularly pronounced in the spring. In addition, the differences between the control and experimental profile mean concentrations were also largest for the fen and least for the woodland site. This suggests that the mobilization of nutrients from the organic horizons or vegetation mat, and their migration across the snow/vegetation/soil interface, was least pronounced at the woodland site and most important at the fen.

It was found that, after the melt began, nutrient concentrations were significantly higher in the control samples removed from the base of the snowpacks in the fen and feathermoss forest (Tables 14 and 15, section 4.3.7). The differences in the nutrient concentrations between the control and experimental samples from the woodland and lichen-heath were not significant, suggesting that mobilization of nutrients from the soil surface (site 2) or the lichen mat (site 1) is minimal, even in the presence of water at the base of the spring snowpacks. The larger increases in the nutrient concentrations of the snow samples from the forest and fen reflect the higher nutrient status of the organic material at these two sites. It would thus appear that the interaction between the snowpack and the underlying vegetation is most effective in those study sites where moss forms the underlying vegetation cover.

The low nutrient concentrations in the base snow samples from the lichen-heath tundra suggest that the lack of a continuous ground cover and the low nutrient content of the soil organic horizons at this site are factors in the limited mobilization of nutrients from the soil surface or the vegetation mat. However, the effect is more pronounced at this site than at the woodland. Here the lichen mat provides an effective barrier to the exchange of nutrients across this interface. The snowpack is separated from the organic surfaces beneath the mat and the lichen mat itself does not appear to be interacting with the snowpack.

The greater interaction between the snowpack and the ground cover at sites 3 and 4 could be due to several factors. Data presented in section 4.2.2, Figures 5a to 51, showed that the temperatures at the base of the snowpack were comparable between sites 1, 3 and 4 (at or near 0°C), whereas those at site 2 were consistently lower (-2.0°C). Just prior to snowmelt, the basal snowpack temperatures were 0.3°C (site 2), 0.5°C (site 4), 0.7°C (site 3) and 0.9°C (site 1). Shallow snow depths and the lack of an insulating vegetation cover were cited as reasons for the lower temperatures at site 2. In addition to its insulating properties, the moss mat has a high water holding capacity and can absorb many times its weight in meltwater from the snowpack. In the woodlands, water collects at the base of the lichen mat in the decomposing layer. At site 2, the lack of a continuous vegetation cover and the fact that in the spring the ground just below the surface is frozen, results in the immediate runoff of the meltwater. Water is not held at the base of the snowpack by a highly absorbant mat, whereas at sites 3 and 4, it is available for such processes as mobilization of nutrients through leaching from the vegetation cover. At site 1, water is available at the base of the lichen mat, but the organic material and the mat itself have a much lower nutrient status than the moss cover and organic horizons at sites 3 and 4. In comparison to the moss surfaces, the lichen mat can release very few nutrients, although the temperature at the snowpack base at site 1 was slightly higher than at sites 3 or 4 and although water was available. It appears that this ability is being controlled, to a large extent, by the limited nutrient status of the system.

5.4 Over-Winter Mass Losses from Plant Tissues

The percent of mass lost by tissue samples during the winter was presented in section 4.5. These losses suggest that the tissues underwent physical and/or chemical decomposition during the winter. The percent mass loss differed between the species. Birch and blueberry tissues experienced practically the same amount of mass loss at the tundra site (20.6±2.8 percent and 20.1±1.8 percent, respectively). Similarly, birch and tamarack tissues showed almost identical mass losses at the fen (31.0±4.9 percent and 30.7±6.7 percent, respectively). At the tundra site, birch and blueberry mass losses were twice that of Labrador tea (9.0±1.5 percent) and at the woodland site, the mass lost from birch tissues (33.9±3.7 percent) was slightly more than twice that from Labrador tea (14.5±2.0 percent) and slightly less than twice that from spruce (18.6±1.7 percent). At the forest site, birch (40.3±4.9 percent) lost approximately two and one-half times as much mass as Labrador tea (16.2±1.8 percent) and twice as much as spruce tissues (20.3±3.9 percent). All of these differences are statistically significant, including that between the spruce and Labrador tea tissues at site 4. Moore (in press, a) reported mass losses of 29 percent for birch and 20 percent for spruce tissues over one winter in a lichen woodland, values which are comparable to those of the woodland site in this study.

Birch and blueberry leaves are much more delicate than either Labrador tea or spruce needles and are therefore more susceptible to mechanical disintigration. In addition, they present a larger surface area across which nutrient leaching or exchange processes can occur. This accounts for the greater mass losses shown by the birch and blueberry tissues. Tamarack needles are likewise more delicate than the spruce and would also be more susceptible to mechanical decomposition but they do not offer as large a surface area as birch and blueberry for chemical interactions.

Mass losses varied significantly between the four sites. A comparison of birch tissue mass losses between the sites shows that losses were greatest in the forest (40.3 percent), followed by the woodland (33.9 percent), the fen (31.0 percent) and least at the tundra (20.6 percent). Comparisons between Labrador tea mass losses (not measured at site 4) showed the same between-site relationship, as did the spruce tissue samples at sites 3 and 1. These differences were all significant at at least the 95 percent level.

Results from litter decomposition studies in a lichen woodland near Schefferville indicate that the greatest amount of mass loss from tissues occurs in the fall prior to the formation of a continuous snow cover (Moore, in press, b). Over-winter mass losses from birch, black spruce and lichen tissues ranged from 13 to 29 percent (birch >spruce >lichen); 80, 51 and 46 percent of the total losses occurred between early September and early November for birch, spruce and lichen tissues, respectively. Moore (in press, b) suggests that litter susceptibility to increased occurrences of freeze-thaw cycles during the fall may be a factor in the greater amount of decomposition occurring at this time. The remaining mass losses (20 percent for birch, 49 percent for spruce and 54 percent for lichen) occurred evenly throughout the winter under a deep snow cover.

The majority of nutrient losses from the tissues also occurred between September and November. This was most pronounced for the birch samples (90 percent of the total K loss). Potassium was most easily removed from the tissues (80 percent loss over the winter from the birch). Spruce and lichen tissues also showed significant K losses following the establishment of a snowpack. Calcium and Mg were also removed from the tissues but spruce tended to retain much Ca and lichen Mg. Major P losses occurred from the birch and spruce tissues but not from the lichen. Bartsch (per. comm.) measured over-winter K losses from sphagnum tissues of 60 to 80 percent and from birch leaves of 65 to 85 percent in three bog sites near Schefferville. Calcium and Mg were retained by the sphagnum tissues.

Although there is no direct evidence of nutrient losses from the tissues in the present study, the mass losses are comparable to those measured by Moore (in press, a and b) and the results of the studies from the Schefferville region indicate that over-winter mass losses from plant tissues are, in part, due to nutrient removal. The pronounced leaching of K is particularly interesting, since it is this ion which has shown the largest increases in the base snow samples and in concentrations in the snow profile, corresponding to high particulate matter contents.

If, as suggested by Moore (in press, a), freeze-thaw activity is an important aspect of decomposition during the fall, then the fact that the soil and tissues would probably freeze earlier at the exposed lichen-heath tundra should reduce the effectiveness of the freeze-thaw cycles on this material. This would lead to the lower mass losses of the tissues at this site. Losses from birch tissues were less at the fen that at the woodland or forest sites. The moss surface, being saturated with water, would probably freeze before a snow cover developed, thus having a similar effect on the possible freeze-thaw/mass loss relationship as at site 2, should this be a factor in fall tissue decomposition.

Although most of the mass and nutrient losses from birch tissues occurred during the fall, 50 percent of the mass loss shown by spruce needles took place gradually beneath the snow cover (Moore, in press, b). If early freezing of the tissues at the tundra site does cause mass losses to be less than those measured in the tissues from the forest and woodland sites, then the development of a deep, insulating snow cover may also be important in providing an environment for over-winter decomposition. Snowpack basal temperatures and a water supply may be additional factors leading to the differences in mass losses between the four sites.

Although snowpack basal temperatures at site 1 were slightly higher than at the other sites, including site 3, the nature of the lichen mat is such that meltwater percolates through the mat and collects beneath it. The litter is deposited on the mat surface and does not have a direct, continuous supply of available water. If leaching is occurring in over-winter decomposition, it may be less at this site than at site 3 because of the lack of water at the snowpack base. Basal snowpack temperatures at site 3 were very close to those at site 1, but the water holding capacity of the moss ground cover is greater than that of the lichen mat. In fact, melt water was found at the base of the snowpacks in the forest and the moss cover was saturated at this time. In contrast, the lichen mat was dry and neither meltwater nor a slush layer was present. The combination of available water and temperatures at or above freezing was possibly enough to encourage greater decomposition of the tissues beneath the snowpack at the forest site. The mass loss from birch tissues was less at site 4 than at sites 3 or 1 (although the percent mass loss at site 1 was only 2.8 percent greater than at site 4, the difference was significant). Water was certainly available at site 4 for decomposition processes, but temperatures at the snowpack base were lower than thoes at site 3, particularly in spring, and this could have limited the amount of mass lost by the tissues at this site.

Mass losses shown by birch and Labrador tea tissues at the tundra site were one-half of what was measured at the forest site. Earlier freezing of the tissues in the fall could be one reason for this difference, but the shallow snow depths and the resultant, lower temperatures at the snowpack base could also have inhibited the continuation of decomposition over the winter.

The main difficulty with this study is that it is not possible to separate that portion of the mass losses which occurred during the fall from that which occurred beneath the snowpack. However, if the snow cover is influencing the amount of decomposition which occurs and if spring conditions, when there is a large supply of melt water at the snowpack base, are also important, then an environment, favourable to litter decomposition, is maintained longer at site 3 than at the other sites. Snow cover disappeared earliest from site 2, followed by sites 4, 1 and finally site 3. The tissue mass losses were least at site 2, followed by sites 4 and 1 and greatest at site 3. It appears that decomposition, as evidenced by mass loss, is greatest at the sites where the snow cover remained the longest. If this is true, then an environment, favourable to over-winter decomposition, is maintained longest in the feathermoss forest.

5.5 The Influence of the Snow Cover on the Nutrient Regime of the Soils at the Four Study Sites

The data presented in section 4.4.2 showed that the base cation and H ion concentrations and the CEC of the surface horizons increased significantly at all four sites from the fall to the spring, immediately following the disappearance of the snowpack. However, the between-site relationship of the soil nutrient status did not change; base saturation remained highest in the fen (86 to 91 percent, fall to spring), followed by the feathermoss forest (44.9 to 61.0 percent), the lichen-heath tundra (17.7 to 17.1 percent) and the lichen woodland (13.9 to 12.5 percent).

Although large in magnitude (particularly K), the absolute increases in base cation concentrations were not large enough to significantly increase the nutrient status of the soils at the woodland and tundra sites. The 17 percent increase in the base saturation at the forest site can be attributed to the large, significant increase in Ca concentration from 14.7 to 41.1 meq/100 g soil. This increase in base saturation was, however, not significant.

The increases in the base cation concentrations were counteracted by the large increases in H ion concentrations (with the exception of site 4, where the H ion content did not change). Only the soil at the forest site was able to buffer the increase (13 meq H /100 g soil) and soil pH increased from 4.7 to 5.1. However, due to the large standard error of the sample replicates, the increase was not significant. The decrease in pH at site 2 from 4.4 to 4.2 (an increase of 24.2 meq H /100 g soil) was significant. Other investigators have found that a H ion flush occurs at the onset of melt from many snowpacks in different study areas (Jeffries et al., 1979; Johannessen and Henriksen, 1978; Skartveit and Gjessing, 1979). It is possible that the increase in the H ion content of the surface horizons is in part due to contributions from the overlying snowpack. Should this be the case, then the mobilization of the exchangeable cations in the soils at sites 3 and 4 was particularly important in buffering the effect of a potentially large H ion flush to the soil.

The presence of a continuous vegetation cover and/or organic horizons (which, at site 2, is very thin and often intermittent) appears to be important in buffering the effect of the increased H ion content of the soils through the release of available cations, particularly Ca and Mg, to the system. Not only is the presence of an organic horizon important, but also its nutrient status and thus the capacity to provide available cations. At sites 1 and 2, the nutrient status of the organic horizons is low and, as evidenced by the base saturation values and low pH, the ability to effectively buffer an increase in H ions through the release of cations is also, consequently, low.

Although K concentrations remained very low in the soils (0.03 to 0.30 meq/100 g soil in the fall and 0.50 to 1.70 meq/100 g soil in the spring at sites 1 and 3, respectively), K showed the greatest magnitude of increase of the four cations, as was illustrated in Figure 9, section 4.4.2. This cation has shown the most marked behaviour throughout the study. Potassium appeared to be particularly susceptible to removal from particulate matter in the snowpack and to depletion through 'washing-out' processes from the snowpack. Potassium showed the greatest increases in the base snow samples throughout the winter, an increase which was most pronounced in the samples removed during the melt. The data indicated that these increases were due to the leaching of K as well as the other cations from the underlying surfaces. Leachate measurements from lichen woodland soils have shown that K and Ca are most susceptible to losses (Moore, 1980). Moore (in press, a) has also found that this cation is most readily removed from decomposing litter during the winter.

A combination of the following factors could be responsible for the increased nutrient content of the soil surface horizons:

i) nutrients contained in the snowpack are released during the melt;

ii) nutrients are leached from the particulate matter contained in the snowpack once melt begins;

iii) litter decomposition occurring beneath the snowcover and

iv) the decomposition of the soil organic matter beneath the snow cover.

The areal values for the nutrient content of the surface horizons have been estimated from the nutrient concentrations and from values from Moore (1974) for the organic carbon content (in kg/ha) for the surface soil horizons in a lichen woodland, feathermoss forest, lichen-heath tundra and a peatland and a

Table 25: An estimate of the amount of nutrients contained in the surface soil horizons and expressed on an areal basis in kg/ha

Site	*Organic Matter in the surface horizons	H	Ca	Mg	K	Na	P
				kg/ha			
				Fall			
1	3.7	6.0	12.4	4.0	1.0	0.9	1.4
2	7.8	9.8	29.5	7.8	0.9	1.1	2.7
3	7.0	12.4	206	38.6	8.2	2.7	5.1
4	5.2	52.0	3900	1342	50.7	21.5	23.2
				Spring			
1	3.7	14.2	25.0	4.8	12.6	2.0	0.6
2	7.8	28.7	84.6	9.1	15.2	5.0	1.5
3	7.0	21.5	580	50.4	46.4	4.4	6.0
4	5.2	47.3	5168	2109	225	31.1	14.9
				Difference			
1		8.2	12.6	0.8	11.6	1.1	-0.8
2		18.9	55.1	1.8	14.2	3.9	-1.2
3		9.1	374	11.8	38.2	1.7	0.9
4		-4.7	1268	767	174	9.6	-8.3

*values based on the organic carbon contents in woodland, forest, tundra and bog soils from Moore (1974) and a conversion factor of 2 for organic matter (Howard, 1966)

Table 26: An estimate of the contribution of the snowpack to the increase in the nutrient content of the surface soil horizons

H	Ca	Mg	K	Na		H	Ca	Mg	K	Na
		kg/ha						kg/ha		
		Site 1						Site 2		
8.2	12.6	0.80	11.6	1.10	change in the nutrient content of the surface horizons	18.9	55.1	1.8	14.2	3.9
0.7	0.39	0.02	0.04	0.16	amounts contained in the spring snowpack	0.06	0.12	0.06	0.14	0.55
-	1.0	0.2	1.0	-	*estimates of amounts contributed from snowpack litter during melt	-	1.6	0.4	1.5	-
	1.39	0.22	1.04		total nutrients	-	1.72	0.46	1.64	-
	11	25	9		snowpack contribution as a percent of the increase in the soil		3	26	11	
		Site 3						Site 4		
9.1	374	11.8	38.2	1.7	change in the nutrient content of the surface horizons	-4.7	1268	767	174	96
0.07	0.94	0.05	1.12	0.8	amounts contained in the spring snowpack	0.06	1.17	0.33	0.57	0.95
-	1.5	0.4	1.5	-	estimates of amounts contributed from snowpack litter during melt	-	0.7	0.8	0.7	-
-	2.44	0.45	2.62	-	total nutrients	-	1.17	1.13	1.27	-
	1	4	7		snowpack contribution as a percent of the increase in the soil		0.01	0.2	1	

* based on values for Ca, Mg and K as a percent weight of plant tissues (Moore, in press, a) and particulate matter contents of the spring snowpack

conversion factor of 2.0 (Howard, 1966) to estimate organic matter content. The contents for fall and spring are presented in Table 25. In Table 26, the increases in the nutrient content of the surface horizons are compared with the amount of nutrients contained in the spring snowpack, including an estimate of the potential contributions from the particulate matter contained in the snowpack (based on the assumption that most of the particulate matter is litter).

It is apparent from these estimates that the nutrients accumulated in the snowpack over the winter can not account for the magnitude of increases in the exchangeable nutrient content of the underlying soil. In the woodland, the amounts contained in the snowpack accounted for 9, 11 and 25 percent increases in K, Ca and Mg, respectively. At the tundra site, the percentages were 11, 3 and 36 percent for the same cations. These percentages were even smaller at the forest site; 7, 1 and 4 percent for K, Ca and Mg, respectively. At the fen, the amounts contained in the snowpack were so small, compared to the increases in the surface layers of the peat, that their estimated contributions were less than one percent. These increases must therefore be due to the decomposition of the litter layer and organic matter beneath the snow cover over the winter. The mass losses shown by the various plant tissues at all four sites indicate that decomposition was occurring. This is further substantiated by the findings of Moore (in press, a and b) and Bartsch (per.comm.), showing that nutrient release from plant tissues, particularly K, occurs between the fall and spring. The large increases in the nutrient concentration of the snowpack base samples further confirms these findings and it does appear that nutrients are being leached from the underlying ground cover, litter and/or organic horizons.

Although the snowpack accumulates nutrients from atmospheric throughfall and litter inputs over the winter, the accumulation represents only a minor contribution to the increased nutrient contents measured in the soils at the four study sites. The snowpack contributions are of greater importance at the woodland and tundra sites where the additions from the thin, organic layers and vegetation mat are small, but they have no impact on the nutrient status of the soils at the forest and fen where the nutrients are released through the decomposition of the thick, litter and organic layers at these two sites. Thus, it would appear that the importance of the snow cover to the nutrient regime of these subarctic soils is that it provides an environment at the snow/vegetation/soil interface, which is conducive to over-winter decomposition in an otherwise harsh environment. The nutrients accumulate at the base of the snowpack and do not appear to be removed from the soil during the melt period.

CHAPTER 6

Summary and Conclusions

1) Snow cover accumulation

The observed differences in snow cover accumulation and snowpack structure were found to be directly related to the variations in the roughness zone parameters of topography and vegetation in the May Lake catchment. The snowpack was shallowest at the exposed tundra site and deepest in the woodland and fen. During December and February, the snowpack water equivalents and densities were similar at the woodland, forest and fen. Water equivalents were consistently lower and densities higher at the tundra site. By peak snow year, the differences between sites 1, 3 and 4 had increased considerably so that snow water equivalent was greatest for the woodland snowpack followed by the fen, forest and least for the tundra.

2) The subnivean environment

The differences in snowpack accumulation and structure resulted in between-site variation in the subnivean environments, as evidenced by the temperature regime of the snowpacks and, particularly, the very consistent basal temperatures. The snowpack basal temperatures at site 2 were consistently lower than the values measured at the other three sites. These temperatures appeared to be controlled not only by snowpack density and depth, but also by the presence and thickness of ice layers in the snowpack, features which also varied between the four sites.

3) Spatial variations in snowpack chemistry

Snowpack chemistry was found to vary considerably, both within and between the four sites. The spatial variability has been shown to be closely related to the vegetation structure of the site. The most densely forested site, the feathermoss forest, contained large amounts of particulate matter (largely litter) throughout the snowpack. Concentration increases at certain levels in the snowpack were often associated with high particulate matter concentrations at the same levels, an effect which was very pronounced at the forest site and also in the woodland, but which was not strongly expressed in the tundra or fen. The nature of the underlying vegetation mat appeared to have a significant effect on the mean snowpack concentration. The snow/vegetation/soil interface was active over the winter. The mobilization and migration of chemical constituents from the underlying vegetation to the snowpack base was important in influencing the mean snowpack nutrient concentrations. This was found to be particularly true in the forest and fen, where the underlying vegetation cover is a moss mat and where the nutrient status of the soils, and the surface horizons in particular, are considerably higher than at either the tundra or woodland sites.

4) Temporal variations in snowpack chemistry

Temporal changes also reflected the varying vegetation structure of the sites. Potassium, Mg and, to a lesser extent, P became depleted from the upper and middle profile sections in mid- and late winter at the woodland, tundra and fen sites. This did not occur at the forest site, where throughfall effects from the forest canopy or inputs from litter would be the most pronounced through the winter.

Temporal changes in mean snowpack concentrations were difficult to identify because of the within-site variations caused by variable water equivalents and very localized inputs from the litter and underlying ground cover. However, the mean nutrient contents, in kg/ha, showed that the snow cover accumulated nutrients throughout the winter but, once again, the amounts were related to vegetation type and ground cover. The total nutrient accumulation in the spring snowpacks was greatest at the fen, where the underlying moss mat appeared to have the most pronounced influence on mean nutrient concentrations, and in the forest, where the moss groundcover and litter inputs are important. The woodland snowpack contained less than half of the total nutrients accumulated in the snowpack at sites 3 and 4 and the tundra snowpack contained roughly one-quarter of this amount.

5) Litter decomposition

The percent mass losses, shown by the plant tissues, indicated that decomposition was occurring over the winter. The amount of mass which was lost varied between the different tissues sampled (birch > spruce > Labrador tea) and also between the four sites for the same tissue types. Mass losses were greatest at the forest site, where a combination of a deep snow cover, snowpack basal temperatures near 0°C and available water, particularly in the spring, may have enhanced the decomposition process beneath the snowpack. In addition, a continuous snow cover remained the longest at this site. This is in contrast to site 2, where the percent mass loss, shown by the plant tissues, was the least of the four sites and where the snowpack was the shallowest, where snowpack basal temperatures were the lowest and where the snowcover disappeared the earliest.

6) Seasonal changes in the soil nutrient status

Although the exchangeable nutrient content of the soil surface horizons was greater in the spring than in the fall at all four study sites, the base saturation of the tundra and woodland soils did not change (due to the large increases in H ion concentrations in the soils) and thus the nutrient status of these soils did not increase. The increases were most effective in the surface horizons at the forest and fen sites, where the nutrient status of these soils was already high compared to the very low nutrient concentrations in the tundra and lichen woodland soils.

7) Conclusions

Topography and vegetation influence the development of both the physical and chemical properties of the snowcover in this area. The snowpack does not accumulate enough nutrients from either atmospheric or vegetation inputs to make any sizeable contribution in direct inputs to the nutrient status of the soils in the respective topographic/vegetation units. It does, however, provide an environment where over-winter litter and organic matter decomposition can occur and where nutrients are accumulated at the snow/vegetation/soil interface. The following factors are thus identified as being important in determining the extent to which the snow cover influences the nutrient regime of the soils in this area:

i) the topography and vegetation structure of a site, in that they control snow cover accumulation and hence the development of a deep, insulating snowpack, beneath which over-winter decomposition and nutrient release can occur and

ii) the presence and nature of a continuous vegetation mat or LFH horizon which can influence both the thermal and water regime of the snow/vegetation/soil interface and hence decomposition processes at the interface. This organic material also leads to the development of a thick organic horizon, from which nutrients can be mobilized in over-winter decomposition beneath the snowpack.

BIBLIOGRAPHY

Adams, W.P. and N. Roulet, 1982: Illustration of the roles of snow in the evolution of the winter cover of a lake. Arctic, vol. 33, 100-116.

Adams, W.P., W.R. Cowan, B.F. Findlay, J.S. Gardner and R.J. Rogerson, 1966: Snowfall and snowcover at Knob Lake, central Labrador-Ungava. McGill Sub-Arctic Research Papers, No. 22, pp 114-140.

Allington, K.R., 1961: The bogs of central Labrador-Ungava: an examination of their physical characteristics. Geogr. Annaler, Vol. 43, pp 401-417.

Armstrong, F.A.J. and D.W. Schindler, 1971: Preliminary chemical characterization of waters in the Experimental Lakes area, northwestern Ontario. Jour. Fish. Res. Bd. Can., Vol. 28, pp 171

Barica, J. and F.A.J. Armstrong, 1971L Contribution by snow to the nutrient budget of some small northwestern Ontario Lakes. Limnol. Oceanogr., Vol. 16, pp 891-899.

Barr, D.R. and R.K. Wright, 1981: Selected climatological data, 1955-1980, for the Schefferville (A) station in Environmental Studies in the Central Quebec-Labrador Penninsula. T.R. Moore (ed.). McGill Subarctic Research Paper, No. 32, pp 13-36.

Bartsch, I., personal communication. Department of Geography, McGill University, Montreal.

Bleak, A.T., 1970: Disappearance of plant material under a snow cover. Ecology, Vol. 51, pp 915-917.

Bliss, L.C., O.W. Heal and J.J. Moore (eds.), 1981: Tundra Ecosystems: a comparative Analysis. International Biological Programme 25. Cambridge University Press, New York, 813 pp.

Brown, R.J.E., 1970: Permafrost in Canada. Canadian Building Series, No. 4, Toronto, 234 pp.

Canadian Soil Survey Committee, 1974: The System of Soil Classification for Canada. Can. Dept. Agric., Ottawa, Ontario, 164 pp.

Canada Department of Energy, Mines and Resources, 1974: The National Atlas of Canada, 4th ed., rev. MacMillan of Canada, Toronto, 254 pp.

Chapman, H.D., 1965a: Cation Exchange Capacity in Methods of Soil Analysis, C.A. Black (ed.). Am. Soc. Agron., Mono., No. 9, pp 891-901.

Chapman, H.D., 1965b: Total Exchangeable Bases in Methods of Soil Analysis, C.A. Black (ed). Am. Soc. Agron., Mono., No. 9, pp 902-904.

Cowles, S., 1982: Preliminary results investigating the effect of lichen ground cover on the growth of black spruce. Naturaliste Canadian, Vol. 109, pp 573-581.

Drake, J.J. and T.R. Moore, 1980: Snow pH and dust loading at Schefferville, Quebec. The Canadian Geographer, Vol. 24, pp 286-291.

Dubreuil, M.A. and T.R. Moore, 1982: Laboratory study of post-fire nutrient redistribution in subarctic, spruce lichen woodlands. Can. Jour. Bot., Vol. 60, pp 2511-2517.

Elgmork, K., A. Hagen and L. Langeland, 1975: Polluted snow in southern Norway during the winters 1968-1971. Environ. Pollut., Vol. 4, pp 41-52.

English, M.C., personal communication. Department of Geography, McGill University, Montreal, Quebec.

Fahey, T.J., 1979: Changes in nutrients of snow water during outflow from a Rocky Mountain coniferous forest. Oikos, Vol. 32, pp 422-428.

Fletcher, N.H., 1970: The Chemical Physics of Ice. Cambridge University Press, New York, 271 pp.

Gjessing, E.T., A. Henriksen, M. Johannessen and R.F. Wright, 1976: Effects of acid precipitation on freshwater chemistry in Impact of Acid Precipitation of Forest and Freshwater Ecosystems in Norway. F.H. Braekke (ed.). SNSF-project FR 6/76, 111 pp.

Granberg, H.B., 1972: Snow depth variations in a forest-tundra environment, Schefferville, P.Q., winter 1968-1969. Unpub. MSc. Thesis, McGill Univeristy, Montreal, 134 pp.

Granberg, H.B., 1973: Indirect mapping of snowcover for permafrost prediction at Schefferville, Quebec. Proc. Second Int. Conf. on Permafrost. Yakutsk, USSR, pp 113-120.

Granberg, H.B., 1975: Snow in different roughness zones at Schefferville: its character and hydrological significance. Proc. 32nd Eastern Snow Conf., Manchester, N.H., pp 108-123.

Granberg, H.B., 1979: Snow accumulation and roughness changes through winter at a forest tundra site near Schefferville, Quebec. Proc. Modelling of Snow Cover Runoff. S.S. Colbeck and M. Ray (eds). Hannover, N.H., pp 83-92.

Granberg, H.B., 1980: Snow sampling bias in the boreal forest. Proc. 37th Eastern Snow Conf., Peterborough, Ontario, preprint.

Gregory, S., 1978: Statistical Methods and the Geographer, 4th ed. Longman Group Ltd., London, 240 pp.

Haag, R.W., 1974: Nutrient limitations to plant production in two tundra communities. Can. Jour. Bot., Vol. 52, pp 103-116.

Haapla, H., P. Stepponen and E. Meskies, 1975: Effect of spring floods on water acidity in the Kuminkijoki area, Finland, Oikos, Vol. 26, pp 25-31.

Hammond, R. and P.S. McCullagh, 1978: Quantitative Techniques in Geography: an Introduction, 2nd ed. Clarendon Press, Oxford, 364 pp.

Hare, F.K., 1950: Climatic and zonal divisions of the boreal forest formation in eastern Canada. Geogr. Rev., Vol. 40, pp 615-635.

Hare, F.K. and J.E. Hay, 1971: Anomalies in the large-scale annual water balance over northern North America. Can. Geogr., Vol. 15, pp 79-94.

Henriksen, A. and R.F. Wright, 1977: Effects of acid precipitation on a small acid lake in southern Norway. Nordic Hydrology, Vol. 8, pp 1-10.

Holding, A.J., O.W. Heal, S.F.MacLean and P.W. Flanagan, 1974: Soil organisms and decomposition in Tundra. Tundra Biome Steering Committee, Stockholm, Sweden, 398 pp.

Howard, P.J., 1966: The carbon-organic matter factor in various soil types. Oikos, Vol. 15, pp 229-236.

Jeffries, D.S., C.M. Cox and P.J. Dillon, 1979: The depression of pH in lakes and streams in central Ontario during snowmelt. Jour. Fish. Res. Bd. Can., Vol. 36, pp 640-646.

Jeffries, D.S. and W.R. Snyder, 1981: Variations in the chemical composition of the snowpack and associated meltwaters in central Ontario. Proc. 38th Eastern Snow Conf., Syracuse, New York, pp 11-22.

Johannessen, M. and A. Henriksen, 1978: Chemistry of snow meltwater: changes in concentration during melting. Water Resources Research, Vol. 14, pp 615-619.

Knuston, E.O., S.K. Sood and J.D. Stockholm, 1976: Aerosol collection by snow and ice crystals. Atmos, Envir., Vol. 10, pp 395-402.

Lewis, J.E., personal communication, Department of Geography, McGill University, Montreal.

Lewis, W.M. and M.C. Grant, 1980: Relationships between snow cover and winter losses of dissolved substances from a mountain watershed. Arctic and Alpine Research, Vol. 12, pp 11-17.

Lucarotti, C.J., 1976: Post-fire changes in mycoflora species and meso-fauna populations in lichen woodland soils, Schefferville, Quebec. MSc Thesis, McGill University, Montreal, 94 pp.

McBrayer, J.F. and K. Cromack, Jr., 1980: Effect of snowpack on oak-litter breakdown and nutrient release in a Minnesota forest. Pedobiologia, Vol. 20, pp 47-54.

McGill Subarctic Research Station Snow Course Records. McGill Subarctic Research Station, Schefferville, Quebec.

Moore, T.R., in press, a: Litter decomposition in a sub-arctic spruce-lichen woodland, eastern Canada. Ecology.

Moore, T.R., in press, b: Winter-time litter decomposition in subarctic woodlands. Arctic and Alpine Research.

Moore, T.R., 1981: Controls on the decomposition of organic matter in subarctic spruce-lichen woodland soils. Soil Science, Vol. 131, pp 107-113.

Moore, T.R., 1980: The nutrient status of subarctic woodland soils. Arctic and Alpine Research, Vol. 12, pp 147-160.

Moore, T.R., 1978: Soil formation in northeastern Canada. Annals of the Assoc. of Amer. Geog., Vol. 68, pp 518-534.

Moore, T.R., 1974: Pedogenesis in a subarctic environment. Arctic and Alpine Research, Vol. 6, pp 281-291.

Nicholson, F.H., 1975: Snow depth mapping from aerial photographs for use in permafrost prediction. Proc. 32nd Eastern Snow Conf., Manchester, N.H., pp 124-136.

Nicholson, F.H. and H.B. Granberg, 1973: Permafrost and snow cover relationships near Schefferville in Permafrost: the North American Contribution to the International Conference, pp 151-158.

Nicholson, H.M., 1973: Pedological studies in a subarctic environment, Schefferville, Quebec. Unpub. MSc. Thesis, McGill University, Montreal, 248 pp.

Nicholson, H.M. and T.R. Moore, 1977: Pedogenesis in a subarctic, iron-rich environment, Schefferville, Quebec. Can. Jour. Soil Sci., Vol. 57, pp 35-45.

Olsen, S.R. and L.A. Dean, 1965: Phosphorus in Methods of Soil Analysis, C.A. Black, (ed). Am. Soc. Agron., Mono., No. 9, Madison, Wisconsin, pp 1035-1048.

Peech, M., 1965: Hydrogen Ion Activity in Methods of Soil Analysis. C.A. Black (ed). Am. Soc. Agron., Mono., No. 9, Madisno, Wisconsin, pp 914-925.

Pierson, D.C. and C.H. Taylor, 1980; The influence of snow on the nutrient input and movement of cations within a small watershed: methods and preliminary results. Proc. 37th Eastern Snow Conf., Peterborough, Ontario, preprint.

Perkin-Elmer, 1976: Analytical Methods for Atomic Absorption Spectrophotometry. Perkin-Elmer, Connecticut.

Prudhomme, T., personal communication. Systems Ecology Research Group, San Diego State University, San Diego, California.

Rencz, A., 1976: The level and distribution of biomass and nutrients in a subarctic lichen woodland. MSc. Thesis, McGill University, Montreal, 56 pp.

Rueslatten, H.G. and P, Jorgensen, 1978: Interaction between bedrock and precipitation at temperatures close to 0°C. Nordic Hydrology, Vol. 9, pp 1-6.

SAS Institute, 1979: SAS User's Guide. Statistical Analysis System, SAS Institute, Cary, N.C., pp 173-175.

Schindler, D.W. and J.E. Nighswander, 1970: Nutrient supply and primary production in Clear Lake, eastern Ontario. Jour. Fish. Resch. Bd. Can., Vol. 27, pp 2009.

Skartveit, A. and Y.T. Gjessing, 1979: Chemical budgets and chemical quality of snow and runoff during spring snowmelt. Nordic Hydrology, Vol. 10, pp 141-154.

Smith, D.L., 1972: The solution of limestone in an arctic environment. Instit. Brit. Geog., Vol. 4, pp 187-201.

Schindler, D.W., H.E. Welch, J. Kalff, J.G. Brunskill and N. Kritsch, 1974: Physical and chemical limnology of Char Lake, Cornwallis Island (74°N latitude). J. Fish Res. Bd. Can., Vol. 31, pp. 585-607.

Stark, N., 1973: Nutrient Cycling in a Jeffrey Pine Ecosystem. University of Montana Press, Missoula. 389 pp.

Strickland, J.D.H. and T.R. Parsons, 1968: A Practical Handbook of Seawater Analysis. Fisheries Research Board of Canada, Bulletin 167, pp 49-62.

Takahashi, T., 1963: Chemical composition of snow in relation to their crystal shapes. Jour. Met. Soc. Japan, Vol. 41, pp 327-336.

Tedrow, J.F.C., 1977: Soils of the Polar Landscapes. Rutgers University Press, New Brunswick, N.J., 638 pp.

Thom, B.J. and H.B. Granberg, 1970: Patterns of Snow accumulation in a forest-tundra environment, central Labrador-Ungava. Proc. 27th Eastern Snow Conf., Albany, N.Y., pp.76-86.

Thorn, C.E., 1976: Quantitative evaluation of nivation in the Colorado Front Range. Geol. Soc. Amer. Bull., Vol. 87, pp 1169-1178.

UNESCO, 1970: Ecology of Subarctic Regions. Proc. Helsinki Symp., UNESCO, Paris. 364 pp.

Verry, E.S. and D.R. Timmons, 1977: Precipitation nutrients in the open and under two forests in Minnesota. Can. Jour. For. Resch., Vol. 7, pp 112-119.

Werren, G.L., 1979: Winter stress in subarctic spruce associations: a Schefferville case study. Unpub. MSc. Thesis, McGill University, Montreal. 257 pp.

Williams, J.E., 1949: Chemical Weathering at low temperatures. Geog. Rev., Vol. 39, pp 129-135.

Wright, R.F. and H. Dovland, 1978: Regional surveys of the chemistry of the snowpack in Norway, late winter 1973, 1974, 1975, 1976 and 1977. Atmos. Envir., Vol. 12, pp 1755-1768.

APPENDIX 1

Results of Snow Chemical Analyses

Table 1: Fresh snow chemistry

Sample Number								
Site 1								
1	4.52	4.90	0.09	0.01	0.17	0.10	4.29	43
2	4.02	5.15	0.04	0.01	0.07	0.18	4.92	39
3	4.68	5.18	0.00	0.01	0.00	0.04	1.75	60
4	4.61	5.07	0.06	0.01	0.10	0.04	2.54	10
5	4.52	4.90	0.02	0.00	0.01	nd	2.38	67
x̄,σ	4.47 0.26	5.04 0.13	0.042 0.035	0.008 0.005	0.070 0.070	0.090 0.006	3.18 1.36	43.8 22.2
Site 2								
1	4.80	5.10	0.02	0.00	0.02	nd	3.65	50
2	4.69	5.02	0.02	0.00	0.03	0.10	2.06	43
3	4.88	5.46	0.04	0.01	0.05	0.08	1.75	72
4	4.89	5.06	0.04	0.01	0.04	0.11	2.70	79
5	4.93	5.18	0.04	0.01	0.03	0.12	2.86	36
x̄,σ	4.83 0.09	5.16 0.18	0.032 0.011	0.006 0.006	0.034 0.011	0.103 0.017	2.60 0.74	56.0 18.6
Site 3								
1	3.95	5.14	0.04	0.01	0.06	0.14	2.70	58
2	4.15	5.25	0.02	0.00	0.02	0.06	6.98	50
3	4.36	4.79	0.02	0.01	0.03	0.07	3.49	50
4	4.30	4.95	0.06	0.01	0.20	0.30	9.68	72
5	4.54	5.07	0.02	0.01	0.04	0.11	4.29	100
x̄,σ	4.26 0.22	5.04 0.18	0.032 0.018	0.008 0.005	0.070 0.074	0.136 0.097	3.43 2.87	66.0 21.0
Site 4								
1	4.30	4.68	0.02	0.00	0.03	0.09	3.18	48
2	4.10	4.60	0.08	0.01	0.07	0.10	6.19	58
3	4.20	4.96	0.02	0.00	0.00	0.07	1.43	54
4	4.25	4.64	0.04	0.01	0.05	0.21	10.0	30
5	4.24	5.04	0.08	0.01	0.08	0.20	1.43	60
x̄,σ	4.22 0.08	4.78 0.20	0.048 0.030	0.006 0.006	0.046 0.032	0.134 0.006	4.45 3.66	50.0 12.1

Table 2: Chemistry of the snowpack base samples

Sample Number	pH1	pH2	Ca	Mg	K	Na	TDP
				mg/l			ug/l
Site 1 Control Samples							
1	4.55	4.28	0.06	0.02	0.11	0.23	27.5
2	4.68	4.40	0.24	0.01	0.10	0.15	17.2
3	4.45	4.18	0.06	0.03	0.30	0.17	22.5
4	4.65	4.25	0.02	0.01	0.08	0.13	14.1
5	4.72	4.25	0.06	0.01	0.17	0.23	15.2
6	4.28	4.20	nd	0.01	0.23	0.26	19.1
7	4.30	4.29	0.04	0.01	0.14	0.11	18.4
8	4.35	4.28	0.00	0.00	0.09	0.12	13.5
9	4.52	4.38	0.00	0.01	0.16	0.13	17.8
10	4.72	4.48	0.02	0.00	0.12	0.08	14.1
x̄,o	4.52±0.17	4.30±0.09	.056±.073	.011±.007	.150±.070	.161±.061	17.9±4.36
Site 1 Experimental Samples							
1	4.58	4.28	0.04	0.02	0.10	0.22	1.56
2	4.72	4.25	0.06	0.01	0.08	0.16	6.41
3	4.74	4.38	0.04	0.01	0.11	0.29	6.03
4	4.69	4.40	0.00	0.00	0.05	0.16	8.28
5	4.69	4.37	0.02	0.01	0.10	0.21	3.38
6	4.52	4.40	0.06	0.02	0.13	0.19	10.4
7	4.82	4.52	0.02	0.01	0.63	0.10	6.91
8	4.68	4.58	0.00	0.00	0.03	0.11	6.77
9	4.20	4.25	0.00	0.00	0.02	0.08	6.77
10	4.64	4.42	0.00	0.01	0.10	0.12	8.68
x̄,o	4.63±0.17	4.39±0.11	.024±.025	.009±.007	.135±.178	.164±.065	6.52±2.76

Sample Number	pH1	pH2	Ca	Mg	K	Na	TDP
				mg/l			ug/l
Site 2 Control Samples							
1	4.53	4.68	0.78	0.25	1.11	0.17	23.1
2	4.42	4.52	0.02	0.01	0.03	0.09	6.88
3	4.20	4.28	0.02	0.01	0.03	0.20	9.29
4	4.45	4.34	0.14	0.04	0.04	0.10	nd
5	4.42	4.54	0.82	0.17	0.71	0.17	10.3
6	4.60	4.55	0.10	0.02	0.17	0.15	16.2
7	4.58	4.68	0.10	0.02	0.10	0.12	7.94
8	4.45	4.50	0.08	0.03	0.08	0.15	7.34
9	4.30	4.34	0.16	0.04	0.14	0.15	13.0
10	4.28	4.44	0.02	0.10	0.04	0.08	7.79
x̄,o	4.42±0.13	4.49±0.14	.224±.308	.069±.082	.245±.366	.138±.039	11.3±5.36
Site 2 Experimental Samples							
1	4.48	4.70	0.00	0.01	0.06	0.10	12.2
2	4.20	4.26	0.02	0.01	0.04	0.08	1.21
3	4.42	4.26	0.04	0.01	0.08	0.10	2.34
4	4.65	4.71	0.13	0.03	0.10	0.12	3.75
5	4.10	4.22	0.04	0.01	0.07	0.12	4.56
6	4.34	4.64	0.10	0.01	0.15	0.24	7.66
7	4.32	4.52	0.00	0.00	0.03	0.12	5.29
8	4.38	4.48	0.02	0.00	0.03	0.09	6.62
9	4.45	4.50	0.28	0.07	0.24	0.14	12.8
10	4.32	4.45	0.00	0.00	0.04	0.08	6.42
x̄,o	4.37±0.15	4.47±0.18	.063±.088	.015±.021	.084±.066	.119±.047	6.28±3.82

Table 2 cont.

Sample Number	pH1	pH2	Ca	Mg	K	Na	TDP
				mg/1			ug/1
Site 3 Control Samples							
1	5.25	4.92	1.10	0.30	2.24	0.20	46.2
2	5.22	4.42	0.02	0.01	0.14	0.19	24.4
3	5.32	4.88	0.88	0.19	1.82	0.17	13.5
4	5.65	5.14	0.42	0.11	3.73	0.11	20.0
5	5.50	4.58	0.78	0.15	1.41	0.12	90.0
6	5.50	5.22	0.50	0.09	1.01	0.20	42.5
7	5.12	4.95	0.20	0.02	0.59	0.12	81.5
8	5.65	5.28	0.78	0.20	1.99	0.27	139
9	4.75	4.75	0.10	0.04	0.21	0.12	40.0
10	5.38	5.08	0.58	0.09	1.41	0.18	138
$\bar{x}$,0	5.33±0.27	4.92±0.28	.537±.358	.120±.091	1.46±1.08	.168±.052	63.5±46.5
Site 3 Experimental Samples							
1	4.62	4.38	0.38	0.15	0.61	0.29	9.67
2	4.69	4.42	0.04	0.01	0.10	0.15	2.94
3	4.68	4.44	0.04	0.01	0.34	0.14	15.3
4	4.67	4.46	nd	0.14	1.55	0.29	15.8
5	4.62	4.36	0.06	0.01	0.24	0.11	15.6
6	5.08	4.98	nd	0.06	0.33	0.17	18.1
7	5.02	4.88	0.04	0.01	0.12	0.13	15.6
8	5.06	4.95	0.12	0.02	0.29	0.17	11.6
9	4.50	4.43	0.06	0.01	0.21	0.15	30.3
10	5.12	4.90	0.12	0.02	0.57	0.15	34.3
$\bar{x}$,0	4.81±0.23	4.62±0.27	.108±.115	.044±.057	.456±.425	.170±.063	16.9±9.22

Sample Number	pH1	pH2	Ca	Mg	K	Na	TDP
				mg/1			ug/1
Site 4 Control Samples							
1	5.14	4.85	0.62	0.52	0.96	0.43	19.7
2	5.58	5.35	0.89	0.62	0.38	0.19	10.3
3	6.20	6.38	2.32	2.06	0.61	0.19	23.0
4	6.26	6.32	5.54	3.82	0.91	0.42	11.8
5	6.35	6.10	nd	nd	0.34	0.23	8.13
6	6.06	5.98	0.54	0.34	0.51	0.25	28.1
7	5.78	5.68	0.56	0.46	0.30	0.17	10.4
8	6.48	6.45	1.84	1.47	0.27	0.16	12.4
9	6.56	6.38	3.46	2.40	0.39	0.16	10.2
10	6.42	6.42	2.20	1.52	0.22	0.22	5.94
$\bar{x}$,0	6.08±0.45	5.99±0.54	2.00±1.67	1.47±1.15	.489±.261	.242±.101	14.0±7.15
Site 4 Experimental Samples							
1	4.85	4.72	0.60	0.06	0.09	0.17	16.7
2	5.16	4.80	0.16	0.11	0.12	0.10	8.13
3	6.20	6.22	2.33	2.04	0.30	0.19	12.2
4	6.31	6.38	3.30	1.76	0.34	0.34	7.96
5	6.12	6.22	2.09	1.31	0.22	0.19	5.63
6	5.05	4.98	0.00	0.00	0.05	0.19	6.47
7	5.32	4.82	0.24	0.17	0.18	0.13	5.59
8	6.24	6.34	1.09	0.79	0.11	0.12	6.62
9	5.62	5.03	0.00	0.01	0.03	0.18	7.94
10	6.49	5.45	2.21	1.60	0.24	0.22	4.41
$\bar{x}$,0	5.74±0.61	5.50±0.71	1.15±1.23	.785±.819	.168±.105	.172±.174	8.17±3.68

APPENDIX 2

Soil Profile Morphology and Soil Chemical Analyses

Table 1: Soil Morphology

Site 1

Profile	Horizon	Depth cm	Munsell Colour (moist)	Texture	Structure	Consistency	Roots	Boundary
1.	Eluviated Dystric Brunisol; lichen woodland; well-drained; level							
	LF	0-3	5YR2.5/2	organic	fibrous	-	abundant fine and medium	clear
	H/Ah	3-4	5YR2.5/1	organic	Fibrous	-	abundant fine and medium	clear
	Aej	4-6	10YR6/3	g.s.l.	fine granular	friable	few fine	diffuse
	Bf1	6-15	2.5YR3/5	g.s.l.	single grain	friable	few fine	diffuse
	Bf2	15-27	5YR4/4	g.s.l.	fine granular	friable	none	clear
	C	27-	10YR5/4	stoney	unconsolidated material	-	none	-
2.	Eluviated Dystric Brunisol; lichen woodland; well-drained; level							
	L-H/Ah	0-3	5YR2.5/2	organic	fibrous	-	abundant fine and medium	diffuse
	Aej	3-5	10YR6/3	s.l.	single grain	friable	abundant fine and medium	discontinuous
	Bf1	5-15	5YR4/4	g.s.l.	fine granular	friable	none	diffuse
	Bf2	15-38	5YR3/4	g.si.l.	crumb	friable	none	clear
	C	38-58	10YR5/2.5	vg.s.l.	granular and platy	firm	none	-
3.	Eluviated Dystric Brunisol; lichen woodland; well-drained; level							
	L-H/Ah	0-5	5YR2.5/2	organic	fibrous	-	abundant fine and medium	diffuse
	Aej	5-7	10YR5/2	g.s.l.	single grain	friable	abundant fine and medium	discontinuous
	Bfj	7-12	5YR3/4	g.si.l.	single grain	friable	few fine	diffuse
	Bf	12-30	5YR4.5/3	g.s.l.	fine granular	friable	none	diffuse
	Bm1	30-39	5YR4/6	g.s.l.	granular to crumb	friable	none	diffuse
	Bm2	39-50	5YR3/4	g.s.l.	granular	friable	none	abrupt
	C	50-51	10YR3/3	v.g.	unconsolidated material	-	none	-

Table 1 cont.

Site 2

Profile	Horizon	Depth cm	Munsell Colour (moist)	Texture	Structure	Consistency	Roots	Boundary
1. Eluviated Dystric Brunisol: lichen-heath tundra; well-drained; level; discontinuous vegetation								
	L-H/Ah	0-2	5YR2.5/1	organic	fibrous	-	few fine and medium	discontinuous
	Aej	2-3	10YR5/2.5	g.s.	single grain	friable	few fine and medium	discontinuous
	Bf	3-17	5YR4.5/4	g.s.l.	crumb	friable	none	diffuse
	Bm	17-42	7.5YR4/4	g.l.	weak blocky	firm	none	clear
	C	42-44	-	stoney	unconsolidated material	-	none	-
2. Eluviated Dystric Brunisol: lichen-heath tundra; moderate to well-drained; slight depression; discontinuous vegetation								
	L-H/Ah	0-1	5YR2.5/1	organic	fibrous	-	few fine and medium	discontinuous
	Aej	1-4	10YR6/2	g.s.l.	single grain	friable	few fine and medium	discontinuous
	Bf1	4-14	5YR4.5/4	g.s.l.	crumb	friable	none	clear
	Bf2	14-22	5YR3.5/3	g.s.l.	crumb	friable	none	diffuse
	C	22-33	10YR5/4	vg.s.l.	crumb	-	none	-
3. Eluviated Dystric Brunisol: lichen-heath tundra; well-drained; level; discontinuous vegetation								
	L-H/Ah	0-2	5YR2.5/1	organic	fibrous	-	few fine and medium	discontinuous
	Aej	2-4	7.5YR6/3	g.s.l.	single grain	friable	few fine and medium	diffuse
	Bf	4-14	5YR4.5/4	g.s.l.	crumb	friable	none	clear
	C	14-20	10YR5/4	vg.s.l.	crumb	friable	none	-

Table 1 cont.

Site 3

Profile	Horizon	Depth cm	Munsell Colour (moist)	Texture	Structure	Consistency	Roots	Boundary
1. Gleyed Melanic Brunisol: feathermoss forest; moderately well-drained; slight depression								
	L-H	0-10	5YR2.5/1	organic	fibrous	-	abundant fine and medium	clear
	Ah	10-25	5YR2.5/1	organic l.	turfy	-	abundant fine and medium	clear
	Bmg	25-33	10YR3/4	si.l.	crumb	friable	few fine	diffuse
	Bm	33-54	7.5YR4.5/2	si.l.	weak blocky	friable to firm	none	diffuse
	C	54-	-	vg.	unconsolidated stoney material		none	-
2. Eluviated Dystric Brunisol: feathermoss forest; well-drained; 2° slope								
	LF	0-5	5YR2.5/1	organic	fibrous	-	abundant fine and medium	clear
	H/Ah	5-7	5YR2.5/1	organic l.	turfy	-	abundant fine and medium	clear
	Aej	7-10	10YR6/3	g.s.l.	single grain	friable	abundant fine and medium	diffuse
	Bm1	10-30	10YR3.5/3	si.l	crumb	friable	few fine	diffuse
	Bm2	30-67	10YR3.5/3	g.si.l	crumb	friable	none	-
3. Gleyed Melanic Brunisol: feathermoss forest; imperfectly drained; slight depression								
	LF	0-10	5YR2.5/1	organic	fibrous	-	abundant fine and medium	clear
	H/Ah	10-20	5YR2.5/1	organic l.	turfy	-	abundant fine and medium	clear
	Bmg	20-38	7.5YR3/2	g.si.l.	weak blocky	firm	few fine	-

Table 1 cont.

Site 4

Profile	Horizon	Depth cm	Munsell Colour (moist)	Texture	Structure	Consistency	Roots	Boundary
1. Mesic Fibrisol: sedge-moss fen; very poorly drained								
	Of1	0-12	10YR3/3	organic	very fibrous	-	-	clear
	Of2	12-25	10YR2/2	organic	fibrous	-	-	diffuse
	Of3	25-75	10YR2/1	organic	fibrous to peaty	-	-	clear
	Om	75-135	10YR3/1	organic	peaty	-	-	clear
	C	135-	-	cl.	-	firm	-	-
2. Mesic Fibrisol: sedge-moss fen; very poorly drained								
	Of1	0-10	10YR3/3	organic	very fibrous	-	-	clear
	Of2	10-27	10YR2.5/2	organic	fibrous	-	-	clear
	Of3	27-48	10YR3/1	organic	fibrous to peaty	-	-	diffuse
	Om	48-80	10YR2.5/1	organic	peaty	-	-	clear
	C	80-	-	cl.	-	firm	-	-
3. Mesic Fibrisol: sedge-moss fen; very poorly drained								
	Of1	0-13	10YR3/3	organic	very fibrous	-	-	clear
	Of2	13-32	10YR2.5/2	organic	fibrous	-	-	diffuse
	Of3	32-90	10YR2/1	organic	fibrous to peaty	-	-	diffuse
	Om	90-145	10YR2/1	organic	peaty	-	-	clear
	C	145-	-	cl.	-	firm	-	-

Table 2:. Results of the chemical analyses of the fall surface soil samples

Sample Number	pH	H	Ca	Mg	K	Na	P	CEC	% BS	% Water Content
		meq/100 g soil					ug/100g soil	meq/100g soil		
Site 1										
57	3.72	15.2	1.5	0.66	0.06	0.09	1.70	17.5	13.1	360
58	3.72	14.9	0.4	0.37	0.03	0.05	0.70	15.6	5.2	377
59	3.76	18.7	0.8	0.81	0.08	0.13	2.60	20.5	8.8	290
60	3.75	17.3	0.7	0.65	0.08	0.12	2.10	18.8	8.0	316
61	3.91	15.2	2.5	0.95	0.06	0.09	4.36	18.8	19.1	273
62	4.01	15.5	1.1	0.57	0.02	0.09	1.25	17.2	9.9	223
63	3.62	16.5	1.2	0.83	0.06	0.12	1.50	18.7	11.8	381
64	3.60	17.2	1.6	1.38	0.07	0.12	1.40	20.3	15.3	362
65	3.68	15.2	3.1	1.01	0.07	0.09	14.5	19.4	21.6	313
66	3.84	17.2	3.9	1.88	0.12	0.15	3.72	23.2	25.9	322
Site 2										
67	4.18	16.7	2.4	0.86	nd	0.10	1.90	20.0	16.5	128
68	4.48	13.5	1.5	0.55	0.03	0.06	1.96	15.6	13.5	71.2
69	4.56	12.0	2.3	1.26	0.03	0.05	1.10	15.6	23.1	68.1
70	4.42	12.0	2.1	0.79	0.03	0.05	1.66	14.9	19.5	75.9
71	4.48	11.2	1.0	0.53	0.04	0.05	14.0	12.8	12.5	69.0
72	4.30	14.9	2.5	0.93	0.04	0.06	2.60	18.4	19.0	86.8
73	4.45	11.2	1.6	0.53	0.02	0.04	0.80	13.3	15.8	80.0
74	4.30	11.2	1.8	0.91	0.04	0.05	4.06	14.0	20.0	92.3
75	4.22	11.5	2.1	0.88	0.04	0.06	3.70	14.5	21.4	112.
76	4.54	12.0	1.6	0.57	nd	0.67	2.50	14.2	15.5	70.6
Site 3										
77	4.08	20.5	8.1	0.40	nd	0.11	12.0	29.1	29.6	318
78	4.01	20.7	4.2	1.69	0.04	0.09	6.36	26.7	22.5	332
79	4.96	15.2	22.2	7.07	0.22	0.13	4.50	44.8	66.1	298
80	4.60	19.0	nd	1.64	0.08	0.12	6.40	nd	nd	281
81	4.84	16.0	7.6	1.66	nd	0.38	8.26	nd	nd	292
82	4.86	14.0	16.0	2.38	0.85	0.09	11.5	33.3	58.0	285
83	5.92	14.2	31.8	13.9	nd	0.18	6.16	nd	nd	221
84	4.70	20.2	9.0	2.10	nd	0.16	8.86	nd	nd	262
85	3.90	18.0	17.0	7.59	nd	0.27	4.76	nd	nd	329
86	5.39	18.8	16.1	7.58	nd	0.12	4.10	nd	nd	243
Site 4										
87	6.29	8.44	36.9	25.0	nd	0.15	2.10	70.5	88.0	923
88	5.34	20.9	29.9	18.2	0.07	0.23	3.36	70.5	70.4	962
89	5.94	12.9	32.7	17.4	0.06	0.11	0.80	63.2	79.6	911
90	5.74	14.4	nd	17.4	0.07	0.16	1.86	nd	nd	952
91	6.44	5.00	42.5	25.6	0.10	0.16	6.56	73.4	93.2	646
92	6.25	8.90	34.3	25.4	0.09	0.13	7.66	68.8	87.1	718
93	6.55	10.4	41.7	23.3	0.13	0.23	3.70	75.8	86.3	862
94	6.25	10.9	44.5	21.8	1.66	0.22	14.0	79.1	86.2	810
95	6.19	4.00	33.9	19.1	0.05	0.29	1.75	57.3	93.0	753
96	6.42	4.50	41.1	22.2	0.05	0.13	2.76	68.0	93.4	726

Table 3: Results of the chemical analyses of the spring surface soil samples

Site 1

Sample Number	pH	H	Ca	Mg	K	Na	P	CEC	% BS	% Water Content
				meq/100 g soil			ug/100 g soil	meq/100 g soil		
• 1.1.1	3.32	45.0	1.8	0.86	0.45	0.37	2.76	48.5	7.2	210
• 1.1.2	3.67	30.0	1.4	0.68	0.60	0.21	1.55	32.7	8.3	294
c 1.1.3	3.78	30.0	2.1	1.06	0.61	0.16	1.13	33.4	10.1	296
c 1.1.4	3.68	37.0	2.6	0.78	0.59	0.13	1.40	41.0	9.8	314
• 1.2.1	3.60	40.0	1.4	1.15	0.78	0.18	2.66	43.5	8.1	385
• 1.2.2	3.50	30.0	2.5	1.32	0.63	0.21	2.46	34.7	13.4	377
c 1.2.3	3.62	47.0	2.8	1.58	1.02	0.34	2.26	52.7	10.9	379
c 1.2.4	3.92	40.0	3.0	0.58	0.89	0.23	nd	44.7	10.5	376
• 1.3.1	3.68	45.0	4.9	1.35	1.13	0.15	3.36	52.5	14.3	311
• 1.3.2	3.68	37.0	nd	1.22	1.14	0.20	3.66	nd	nd	254
c 1.3.3	3.99	42.0	6.2	1.61	1.37	0.22	2.30	51.4	18.3	295
c 1.3.4	3.88	42.0	3.3	1.41	0.96	0.23	1.20	47.9	13.3	336
• 1.4.1	3.73	25.0	1.2	0.61	0.47	0.17	1.05	27.5	8.9	348
• 1.4.2	3.78	32.0	nd	0.68	0.07	0.23	1.70	nd	nd	278
c 1.4.3	3.80	45.0	2.9	1.03	1.06	0.35	1.85	50.3	10.6	416
c 1.4.4	3.58	30.0	3.1	1.33	0.62	0.14	2.26	35.2	14.7	nd
• 1.5.1	3.64	45.0	nd	1.01	0.96	0.13	2.80	nd	nd	255
• 1.5.2	3.58	45.0	4.8	1.29	1.26	0.35	3.46	52.7	14.6	167
c 1.5.3	3.98	40.0	6.2	0.93	1.07	0.35	1.75	48.6	17.6	262
c 1.5.4	nd	30.0	1.6	0.61	0.54	0.17	1.25	32.9	8.9	269

• experimental samples
c control samples

Site 2

Sample Number	pH	H	Ca	Mg	K	Na	P	CEC	% BS	% Water Content
				meq/100 g soil			ug/100 g soil	meq/100 g soil		
• 2.1.1	4.23	22	1.8	0.32	0.32	0.53	1.85	24.8	11.3	58.7
• 2.1.2	4.12	30	6.4	1.67	0.50	0.22	1.95	38.8	8.8	132
c 2.1.3	4.32	37	5.5	0.81	0.35	0.12	1.95	43.8	15.5	96.4
c 2.1.4	4.18	23	4.9	0.11	0.48	0.40	nd	28.9	20.4	133
• 2.2.1	4.42	52	3.8	0.71	0.36	0.33	1.40	57.2	9.1	103
• 2.2.2	4.20	42	3.5	8.75	0.45	0.20	1.35	54.9	23.5	85.9
c 2.2.3	4.32	25	6.2	1.13	0.55	0.30	1.70	33.2	24.6	70.5
c 2.2.4	4.22	45	3.7	0.71	0.03	0.11	1.95	49.6	9.2	128
• 2.3.1	4.12	52	nd	1.78	0.82	0.27	2.96	nd	nd	131
• 2.3.2	4.21	42	1.0	1.73	0.82	0.	1.60	45.9	8.5	106
c 2.3.3	4.30	25	2.0	0.51	0.36	0.36	1.76	28.2	11.5	89.4
c 2.3.4	4.00	45	6.6	1.60	0.79	0.38	3.36	54.4	17.2	174
• 2.4.1	3.92	45	4.5	1.26	0.08	0.38	2.20	51.2	12.2	338
• 2.4.2	3.88	45	4.4	1.41	0.85	0.15	1.76	51.8	13.2	482
c 2.4.3	3.98	55	nd	0.73	0.58	0.23	1.60	nd	nd	193
c 2.4.4	3.91	45	5.5	1.60	0.84	0.24	1.90	53.2	15.4	410
• 2.5.1	4.33	7	3.3	0.90	0.35	0.11	1.25	11.7	39.8	549
• 2.5.2	4.28	22	5.0	1.03	0.54	0.39	1.50	29.0	24.0	250
c 2.5.3	4.10	37	5.6	1.29	0.50	0.37	1.36	44.8	17.3	125
c 2.5.4	4.22	37	8.8	1.23	0.47	0.32	1.90	47.8	22.6	91.1

• experimental samples
c control samples

Table 3 cont.

Sample 3

Sample Number	pH	H	Ca	Mg	K	Na	P ug/100 g soil	CEC meq/100 g soil	% BS	% Water Content
				meq/100 g soil						
e 3.1.1	6.31	22	58	19.1	1.77	0.83	6.36	101.7	78.1	474
e 3.1.2	6.00	25	63	20.5	1.71	0.27	7.86	110.5	77.3	420
c 3.1.3	5.68	23	42	14.6	1.76	0.33	7.56	81.7	71.8	355
c 3.1.4	5.08	32	37	6.50	1.67	0.21	6.86	77.4	58.6	238
e 3.2.1	3.90	60	8.5	2.58	1.49	0.37	6.90	72.9	17.8	327
e 3.2.2	3.78	60	7.5	4.92	1.68	0.29	7.56	74.4	19.3	178
c 3.2.3	3.95	62	15	3.17	1.42	0.52	3.70	82.1	24.5	265
c 3.2.4	3.99	55	14	10.6	1.51	0.29	7.60	81.4	32.4	208
e 3.3.1	6.12	25	47	13.1	1.79	0.33	9.80	87.2	71.4	486
e 3.3.2	6.42	10	53	4.08	1.77	0.21	7.26	69.1	85.4	494
c 3.3.3	5.81	10	70	3.17	1.77	0.20	7.56	85.1	88.3	312
c 3.3.4	5.81	17	44	5.83	1.69	0.15	9.00	68.7	75.2	398
e 3.4.1	4.23	50	18	3.17	1.68	0.34	6.96	73.2	31.7	389
e 3.4.2	4.64	42	32	2.92	1.85	0.60	5.26	79.4	47.1	322
c 3.4.3	5.02	37	58	6.00	1.97	0.37	17.4	103.3	64.2	403
c 3.4.4	5.68	20	49	3.33	1.87	0.11	12.4	74.3	73.1 2	397
e 3.5.1	3.95	62	18	3.25	1.42	0.34	4.06	85.0	27.1	545
e 3.5.2	4.88	42	39	5.25	1.85	0.24	6.30	88.3	52.5	413
c 3.5.3	4.45	30	20	3.00	1.79	0.17	7.46	55.0	45.4	284
c 3.5.4	5.82	22	65	3.83	1.51	0.30	5.90	92.6	76.3	279

e experimental samples
c control samples

Site 4

Sample Number	pH	H	Ca	Mg	K	Na	P ug/100 g soil	CEC meq/100 g soil	% BS	% Water Content
				meq/100 g soil						
e 4.1.1	5.79	20	43	39.7	1.02	0.21	2.06	85.7	76.7	568
e 4.1.2	6.08	10	30	27.3	1.26	0.24	4.76	39.1	74.4	731
c 4.1.3	5.62	15	37	39.7	1.38	0.23	nd	93.3	83.9	953
c 4.1.4	6.12	17	57	38.3	1.24	0.24	nd	113.8	85.0	635
e 4.2.1	6.22	2.0	49	29.2	0.67	0.23	1.85	81.1	97.5	726
e 4.2.2	6.29	5.0	43	31.9	1.28	0.22	2.06	80.4	93.8	864
c 4.2.3	5.70	20	40	35.4	1.37	0.30	19.5	97.1	79.4	678
c 4.2.4	5.62	20	29	33.4	1.45	0.22	31.6	84.1	76.2	704
e 4.3.1	6.47	0.0	50	39.8	1.05	0.24	2.0	91.1	100	813
e 4.3.2	6.28	0.0	nd	nd	nd	nd	nd	nd	nd	864
c 4.3.3	6.42	0.0	43	39.2	1.30	0.30	4.36	83.8	100	678
c 4.3.4	6.38	5.0	46	24.5	1.46	0.23	5.80	77.2	100	704
e 4.4.1	6.32	20	90	34.7	1.58	0.21	5.70	146.5	86.3	540
e 4.4.2	6.60	5.0	65	36.7	1.61	0.25	2.56	108.6	95.4	714
c 4.4.3	6.02	5.0	58	35.0	1.26	0.20	2.96	99.5	94.9	669
c 4.4.4	6.39	5.0	60	25.3	1.42	0.18	2.10	91.9	94.6	891
e 4.5.1	5.50	22	69	29.7	0.71	0.43	2.40	121.8	82.0	618
e 4.5.2	6.59	0.0	57	27.8	0.81	0.35	2.46	86.0	100	776
c 4.5.3	6.44	2.0	72	36.0	0.78	0.27	3.00	111.1	98.2	989
c 4.5.4	6.32	2.0	55	31.4	0.88	0.25	3.70	89.5	97.8	754

e experimental samples
c control samples

Table 4: Percent mass losses from plant tissues

Site 1	Birch	Labrador tea	Black spruce	Site 2	Birch	Labrador tea	Blueberry
Sample Number	% mass loss	% mass loss	% mass loss	Sample Number	% mass loss	% mass loss	% mass loss
1	25.9	12.9	20.4	1	20.7	8.67	19.9
2	28.7	13.6	18.1	2	22.6	8.17	21.0
3	24.9	18.7	19.4	3	18.8	7.51	21.6
4	33.9	15.1	16.2	4	19.5	9.94	20.0
5	37.5	16.4	18.9	5	19.3	8.62	22.1
6	36.2	14.9	19.9	6	-	8.53	17.2
7	33.3	12.9	18.2	7	21.4	6.59	20.3
8	35.2	15.8	22.6	8	20.4	-	18.2
9	38.1	-	-	9	19.6	9.06	17.2
10	34.8	24.3	28.0	10	17.2	8.06	21.2
11	33.1	12.6	18.1	11	21.7	7.87	17.9
12	35.4	16.6	18.1	12	16.1	8.73	18.1
13	35.7	18.2	19.2	13	23.4	10.9	22.7
14	39.1	13.7	17.7	14	26.2	8.70	22.2
15	33.1	12.0	19.9	15	23.8	12.2	21.3
16	36.7	13.7	20.6	16	21.8	12.1	20.5
17	31.3	14.1	14.7	17	19.5	9.50	20.3
18	36.2	13.2	17.3	18	15.1	-	-
19	34.3	14.0	17.4	19	20.9	8.71	17.1
20	33.8	11.0	18.6	20	23.6	8.93	16.5
$\bar{x},\sigma$	33.9±3.73	14.4±2.01	18.6±1.73	$\bar{x},\sigma$	20.6±2.75	9.04±1.46	20.1±1.78

Site 3	Birch	Labrador tea	Black spruce	Site 4	Birch	Tamarack
Sample Number	% mass loss	% mass loss	% mass loss	Sample Number	% mass loss	% mass loss
1	37.5	15.8	18.4	1	39.4	31.2
2	37.1	16.9	18.7	2	-	29.4
3	39.0	13.0	20.0	3	32.2	23.5
4	43.8	15.4	17.5	4	28.8	28.8
5	38.3	19.1	19.2	5	34.2	35.3
6	54.0	19.4	17.8	6	32.6	29.6
7	41.5	16.4	20.5	7	31.5	23.7
8	43.2	18.0	20.1	8	31.6	27.5
9	35.1	15.3	35.3	9	36.5	52.0
10	36.3	16.6	20.0	10	42.1	30.2
11	43.7	16.2	19.3	11	27.6	30.7
12	40.0	17.0	18.5	12	32.2	31.2
13	38.8	18.1	20.3	13	-	29.1
14	44.7	13.2	17.0	14	22.9	26.9
15	38.3	-	22.8	15	27.8	43.2
16	45.1	15.2	20.7	16	26.7	31.5
17	33.0	15.9	21.3	17	25.2	27.7
18	33.7	16.2	19.9	18	28.6	24.4
19	43.7	14.1	17.6	19	30.3	24.9
20	38.2	-	-	20	27.9	32.7
$\bar{x},\sigma$	40.3±4.86	16.2±1.77	20.3±3.92	$\bar{x},\sigma$	31.0±4.85	30.7±6.70

APPENDIX 3

Statistical Analyses

Table 1: Correlation of the chemical parameters in the snowpack

Site 1 Stake 1 Profile 1 (Fig. 6a)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

                 H1        H2        CA        MG         K        NA         P        PM

H1          1.00000   0.89832   0.49758   0.47528  -0.31592  -0.35751   0.25643  -0.07361
             0.0000    0.0060    0.2096    0.2340    0.4459    0.3846    0.5399    0.8625
                  8         7         8         8         8         8         8         8

H2          0.89832   1.00000   0.32645   0.44701  -0.36827  -0.55670   0.31769  -0.03454
             0.0060    0.0000    0.4749    0.3146    0.4163    0.1943    0.4875    0.9414
                  7         7         7         7         7         7         7         7

CA          0.49758   0.32645   1.00000   0.71156   0.42696   0.58887   0.15139   0.53377
             0.2096    0.4749    0.0000    0.0478    0.2914    0.1246    0.7204    0.1730
                  8         7         8         8         8         8         8         8

MG          0.47528   0.44701   0.71156   1.00000   0.10580   0.32644   0.78243   0.81209
             0.2340    0.3146    0.0478    0.0000    0.8031    0.4300    0.0217    0.0143
                  8         7         8         8         8         8         8         8

K          -0.31592  -0.36827   0.42696   0.10580   1.00000   0.64236  -0.31989   0.43369
             0.4459    0.4163    0.2914    0.8031    0.0000    0.0859    0.4399    0.2830
                  8         7         8         8         8         8         8         8

NA         -0.35751  -0.55670   0.58887   0.32644   0.64236   1.00000  -0.01337   0.59086
             0.3846    0.1943    0.1246    0.4300    0.0859    0.0000    0.9749    0.1230
                  8         7         8         8         8         8         8         8

P           0.25643   0.31769   0.15139   0.78243  -0.31989  -0.01337   1.00000   0.61060
             0.5399    0.4875    0.7204    0.0217    0.4399    0.9749    0.0000    0.1079
                  8         7         8         8         8         8         8         8

PM         -0.07361  -0.03454   0.53377   0.81209   0.43369   0.59086   0.61060   1.00000
             0.8625    0.9414    0.1730    0.0143    0.2830    0.1230    0.1079    0.0000
                  8         7         8         8         8         8         8         8
```

Table 1 cont.

Site 1 Stake 2 Profile 2 (Fig. 6b)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

                  H1        H2        CA        MG         K        NA         P        PH

H1           1.00000   0.82841   0.65121   0.08814   0.36736   0.29917  -0.00907   0.01821
              0.0000    0.0416    0.1131    0.8356    0.3707    0.4716    0.9830    0.9659
                   8         6         7         8         8         8         8         8

H2           0.82841   1.00000   0.54368  -0.11700   0.02992   0.06287  -0.13946   0.37715
              0.0416    0.0000    0.3436    0.8253    0.9551    0.9058    0.7922    0.4611
                   6         6         5         6         6         6         6         6

CA           0.65121   0.54368   1.00000   0.00000   0.54918  -0.13572   0.41566   0.42904
              0.1131    0.3436    0.0000    1.0000    0.2017    0.7717    0.3537    0.3368
                   7         5         7         7         7         7         7         7

MG           0.08814  -0.11700   0.00000   1.00000   0.35675  -0.20976   0.46621   0.09309
              0.8356    0.8253    1.0000    0.0000    0.3857    0.6181    0.2443    0.8265
                   8         6         7         8         8         8         8         8

K            0.36736   0.02992   0.54918   0.35675   1.00000  -0.22449   0.00292   0.68344
              0.3707    0.9551    0.2017    0.3857    0.0000    0.5930    0.9945    0.0617
                   8         6         7         8         8         8         8         8

NA           0.29917   0.06287  -0.13572  -0.20976  -0.22449   1.00000  -0.34649  -0.80493
              0.4716    0.9058    0.7717    0.6181    0.5930    0.0000    0.4005    0.0159
                   8         6         7         8         8         8         8         8

P           -0.00907  -0.13946   0.41566   0.46621   0.00292  -0.34649   1.00000   0.12455
              0.9830    0.7922    0.3537    0.2443    0.9945    0.4005    0.0000    0.7689
                   8         6         7         8         8         8         8         8

PH           0.01821   0.37715   0.42904   0.09309   0.68344  -0.80493   0.12455   1.00000
              0.9659    0.4611    0.3368    0.8265    0.0617    0.0159    0.7689    0.0000
                   8         6         7         8         8         8         8         8
```

Table 1 cont.

Site 1 Stake 4 Profile 3 (Fig. 6c)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

                  H1        H2        CA        MG         K        NA         P        PM

H1           1.00000   0.69784   0.13208   0.53916  -0.14342  -0.04705  -0.30323   0.24204
              0.0000    0.0813    0.7777    0.2117    0.7590    0.9202    0.5591    0.6010
                   7         7         7         7         7         7         6         7

H2           0.69784   1.00000  -0.33138   0.22001  -0.60271  -0.37065  -0.54492   0.02408
              0.0813    0.0000    0.4678    0.6355    0.1520    0.4131    0.2635    0.9591
                   7         7         7         7         7         7         6         7

CA           0.13208  -0.33138   1.00000   0.73030   0.82150   0.88153   0.46038   0.10066
              0.7777    0.4678    0.0000    0.0624    0.0234    0.0087    0.3582    0.8300
                   7         7         7         7         7         7         6         7

MG           0.53916   0.22001   0.73030   1.00000   0.31957   0.61968   0.34104   0.38379
              0.2117    0.6355    0.0624    0.0000    0.4848    0.1377    0.5083    0.3954
                   7         7         7         7         7         7         6         7

K           -0.14342  -0.60271   0.82150   0.31957   1.00000   0.84955   0.15515   0.21310
              0.7590    0.1520    0.0234    0.4848    0.0000    0.0155    0.7691    0.6464
                   7         7         7         7         7         7         6         7

NA          -0.04705  -0.37065   0.88153   0.61968   0.84955   1.00000   0.26985   0.20852
              0.9202    0.4131    0.0087    0.1377    0.0155    0.0000    0.6050    0.6537
                   7         7         7         7         7         7         6         7

P           -0.30323  -0.54492   0.46038   0.34104   0.15515   0.26985   1.00000  -0.69637
              0.5591    0.2635    0.3582    0.5083    0.7691    0.6050    0.0000    0.1243
                   6         6         6         6         6         6         6         6

PM           0.24204   0.02408   0.10066   0.38379   0.21310   0.20852  -0.69637   1.00000
              0.6010    0.9591    0.8300    0.3954    0.6464    0.6537    0.1243    0.0000
                   7         7         7         7         7         7         6         7
```

Table 1 cont.

Site 1 Stake I Profile 4 (Fig. 6a)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / N = 11

                  H1        H2        CA        MG         K        NA         P

H1           1.00000   0.50808  -0.21863  -0.04961  -0.12533  -0.02724   0.08684
              0.0000    0.1106    0.5184    0.8848    0.7135    0.9366    0.7996

H2           0.50808   1.00000   0.62472   0.69791  -0.11633   0.77139   0.08994
              0.1106    0.0000    0.0399    0.0169    0.7334    0.0054    0.7926

CA          -0.21863   0.62472   1.00000   0.88652  -0.05435   0.76044  -0.02128
              0.5184    0.0399    0.0000    0.0003    0.8739    0.0066    0.9505

MG          -0.04961   0.69791   0.88652   1.00000   0.21529   0.84964  -0.06764
              0.8848    0.0169    0.0003    0.0000    0.5249    0.0009    0.8434

K           -0.12533  -0.11633  -0.05435   0.21529   1.00000   0.26989  -0.41087
              0.7135    0.7334    0.8739    0.5249    0.0000    0.4222    0.2094

NA          -0.02724   0.77139   0.76044   0.84964   0.26989   1.00000  -0.12895
              0.9366    0.0054    0.0066    0.0009    0.4222    0.0000    0.7055

P            0.08684   0.08994  -0.02128  -0.06764  -0.41087  -0.12895   1.00000
              0.7996    0.7926    0.9505    0.8434    0.2094    0.7055    0.0000
```

Table 1 cont.

Site 1 Stake 2 Profile 5 (Fig. 6b)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS
                     H1        H2        CA        MG         K        NA         P

      H1        1.00000   0.61717   0.08605  -0.10977  -0.40210  -0.39004  -0.37914
                 0.0000    0.0246    0.7903    0.7342    0.1951    0.2101    0.2502
                     13        13        12        12        12        12        11

      H2        0.61717   1.00000   0.03383  -0.19403  -0.42264  -0.50828  -0.61377
                 0.0246    0.0000    0.9169    0.5457    0.1711    0.0915    0.0446
                     13        13        12        12        12        12        11

      CA        0.08605   0.03383   1.00000   0.64431   0.45838   0.43290   0.48284
                 0.7903    0.9169    0.0000    0.0237    0.1339    0.1598    0.1575
                     12        12        12        12        12        12        10

      MG       -0.10977  -0.19403   0.64431   1.00000   0.63844   0.56185   0.19155
                 0.7342    0.5457    0.0237    0.0000    0.0255    0.0573    0.5960
                     12        12        12        12        12        12        10

      K        -0.40210  -0.42264   0.45838   0.63844   1.00000   0.97317   0.55692
                 0.1951    0.1711    0.1339    0.0255    0.0000    0.0001    0.0945
                     12        12        12        12        12        12        10

      NA       -0.39004  -0.50828   0.43290   0.56185   0.97317   1.00000   0.67933
                 0.2101    0.0915    0.1598    0.0573    0.0001    0.0000    0.0307
                     12        12        12        12        12        12        10

      P        -0.37914  -0.61377   0.48284   0.19155   0.55592   0.67933   1.00000
                 0.2502    0.0446    0.1575    0.5960    0.0945    0.0307    0.0000
                     11        11        10        10        10        10        11
```

Table 1 cont.

Site 1 Stake 4 Profile 6 (Fig. 6c)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

                   H1        H2        CA        MG         K        NA         P        PM

H1            1.00000   0.66946   0.48164  -0.21411  -0.17844  -0.29285  -0.05246   0.05786
               0.0000    0.0243    0.1129    0.5040    0.5790    0.3556    0.8783    0.8658
                   12        11        12        12        12        12        11        11

H2            0.66946   1.00000   0.73563  -0.32587  -0.18010  -0.13163   0.20299   0.09698
               0.0243    0.0000    0.0099    0.3281    0.5962    0.6997    0.5494    0.7767
                   11        11        11        11        11        11        11        11

CA            0.48164   0.73563   1.00000  -0.01785   0.21625  -0.29725   0.46183  -0.07605
               0.1129    0.0099    0.0000    0.9561    0.4996    0.3481    0.1527    0.8241
                   12        11        12        12        12        12        11        11

MG           -0.21411  -0.32587  -0.01785   1.00000   0.91738  -0.16028   0.45787   0.15157
               0.5040    0.3281    0.9561    0.0000    0.0001    0.6188    0.1567    0.6564
                   12        11        12        12        12        12        11        11

K            -0.17844  -0.18010   0.21625   0.91738   1.00000  -0.15119   0.72173   0.06893
               0.5790    0.5962    0.4996    0.0001    0.0000    0.6390    0.0122    0.8404
                   12        11        12        12        12        12        11        11

NA           -0.29285  -0.13163  -0.29725  -0.16028  -0.15119   1.00000  -0.14533   0.40910
               0.3556    0.6997    0.3481    0.6188    0.6390    0.0000    0.6698    0.2115
                   12        11        12        12        12        12        11        11

P            -0.05246   0.20299   0.46183   0.45787   0.72173  -0.14533   1.00000  -0.18474
               0.8783    0.5494    0.1527    0.1567    0.0122    0.6698    0.0000    0.5866
                   11        11        11        11        11        11        11        11

PM            0.05786   0.09698  -0.07605   0.15157   0.06893   0.40910  -0.18474   1.00000
               0.8658    0.7767    0.8241    0.6564    0.8404    0.2115    0.5866    0.0000
                   11        11        11        11        11        11        11        11
```

Table 1 cont.

Site 1 Stake 1 Profile 9 (Fig. 6a)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

                    H1        H2        CA        MG         K        NA         P        PM

H1             1.00000   0.32116  -0.09914   0.11534  -0.17490  -0.42195  -0.16508  -0.14499
                0.0000    0.2431    0.7252    0.6823    0.5330    0.1172    0.5899    0.6061
                    15        15        15        15        15        15        13        15

H2             0.32116   1.00000  -0.02999   0.49481   0.31583   0.24061   0.39105   0.40959
                0.2431    0.0000    0.9155    0.0608    0.2515    0.3877    0.1864    0.1295
                    15        15        15        15        15        15        13        15

CA            -0.09914  -0.02999   1.00000   0.18233   0.10708   0.33854  -0.00612   0.04010
                0.7252    0.9155    0.0000    0.5155    0.7041    0.2171    0.9842    0.8872
                    15        15        15        15        15        15        13        15

MG             0.11534   0.49481   0.18233   1.00000   0.18687   0.33167   0.20470   0.25480
                0.6823    0.0608    0.5155    0.0000    0.5048    0.2272    0.5023    0.3594
                    15        15        15        15        15        15        13        15

K             -0.17490   0.31583   0.10708   0.18687   1.00000   0.23835   0.80214   0.94597
                0.5330    0.2515    0.7041    0.5048    0.0000    0.3923    0.0010    0.0001
                    15        15        15        15        15        15        13        15

NA            -0.42195   0.24061   0.33854   0.33167   0.23835   1.00000   0.62813   0.33669
                0.1172    0.3877    0.2171    0.2272    0.3923    0.0000    0.0215    0.2198
                    15        15        15        15        15        15        13        15

P             -0.16508   0.39105  -0.00612   0.20470   0.80214   0.62813   1.00000   0.90752
                0.5899    0.1864    0.9842    0.5023    0.0010    0.0215    0.0000    0.0001
                    13        13        13        13        13        13        13        13

PM            -0.14499   0.40959   0.04010   0.25480   0.94597   0.33669   0.90752   1.00000
                0.6061    0.1295    0.8872    0.3594    0.0001    0.2198    0.0001    0.0000
                    15        15        15        15        15        15        13        15
```

Table 1 cont.

Site 1 Stake 2 Profile 7 (Fig. 6b)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

                 H1        H2        CA        MG         K        NA         P        PM

H1          1.00000   0.06512   0.37376   0.04138  -0.15603   0.30078  -0.06536  -0.00828
             0.0000    0.8250    0.1880    0.8883    0.5943    0.2961    0.8320    0.9776
                 14        14        14        14        14        14        13        14

H2          0.06512   1.00000   0.65725   0.54952   0.75096   0.52195   0.19211   0.33659
             0.8250    0.0000    0.0106    0.0418    0.0020    0.0556    0.5295    0.2393
                 14        14        14        14        14        14        13        14

CA          0.37376   0.65725   1.00000   0.84871   0.67705   0.37321   0.32339   0.51858
             0.1880    0.0106    0.0000    0.0001    0.0078    0.1887    0.2811    0.0574
                 14        14        14        14        14        14        13        14

MG          0.04138   0.54952   0.84871   1.00000   0.59213   0.18428   0.32046   0.48400
             0.8883    0.0418    0.0001    0.0000    0.0257    0.5283    0.2857    0.0795
                 14        14        14        14        14        14        13        14

K          -0.15603   0.75096   0.67705   0.59213   1.00000   0.31413   0.29340   0.64125
             0.5943    0.0020    0.0078    0.0257    0.0000    0.2741    0.3306    0.0135
                 14        14        14        14        14        14        13        14

NA          0.30078   0.52195   0.37321   0.18428   0.31413   1.00000   0.58839  -0.03642
             0.2961    0.0556    0.1887    0.5283    0.2741    0.0000    0.0344    0.9016
                 14        14        14        14        14        14        13        14

P          -0.06536   0.19211   0.32339   0.32046   0.29340   0.58839   1.00000   0.14841
             0.8320    0.5295    0.2811    0.2857    0.3306    0.0344    0.0000    0.6285
                 13        13        13        13        13        13        13        13

PM         -0.00828   0.33659   0.51858   0.48400   0.64125  -0.03642   0.14841   1.00000
             0.9776    0.2393    0.0574    0.0795    0.0135    0.9016    0.6285    0.0000
                 14        14        14        14        14        14        13        14
```

Table 1 cont.

Site 1 Stake 4 Profile 11 (Fig. 6c)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

                H1        H2        CA        MG         K        NA         P        PM

H1         1.00000   0.76815   0.16631   0.60030   0.64447   0.71592   0.46458  -0.42715
            0.0000    0.0022    0.6054    0.0301    0.0174    0.0059    0.1281    0.1455
                13        13        12        13        13        13        12        13

H2         0.76815   1.00000   0.13707   0.48433   0.47501   0.69277   0.28566  -0.41041
            0.0022    0.0000    0.6710    0.0935    0.1009    0.0087    0.3681    0.1636
                13        13        12        13        13        13        12        13

CA         0.16631   0.13707   1.00000   0.59943   0.24779   0.27668   0.29864  -0.52519
            0.6054    0.6710    0.0000    0.0394    0.4374    0.3840    0.3724    0.0795
                12        12        12        12        12        12        11        12

MG         0.60030   0.48433   0.59943   1.00000   0.49603   0.57694   0.40499  -0.20453
            0.0301    0.0935    0.0394    0.0000    0.0847    0.0390    0.1916    0.5027
                13        13        12        13        13        13        12        13

K          0.64447   0.47501   0.24779   0.49603   1.00000   0.66222   0.88579  -0.08256
            0.0174    0.1009    0.4374    0.0847    0.0000    0.0137    0.0001    0.7886
                13        13        12        13        13        13        12        13

NA         0.71592   0.69277   0.27668   0.57694   0.66222   1.00000   0.35988  -0.18004
            0.0059    0.0087    0.3840    0.0390    0.0137    0.0000    0.2505    0.5561
                13        13        12        13        13        13        12        13

P          0.46458   0.28566   0.29864   0.40499   0.88579   0.35988   1.00000  -0.14587
            0.1281    0.3681    0.3724    0.1916    0.0001    0.2505    0.0000    0.6510
                12        12        11        12        12        12        12        12

PM        -0.42715  -0.41041  -0.52519  -0.20453  -0.08256  -0.18004  -0.14587   1.00000
            0.1455    0.1636    0.0795    0.5027    0.7886    0.5561    0.6510    0.0000
                13        13        12        13        13        13        12        13
```

Table 1 cont.

Site 1 Stake 1 Profile 10 (Fig. 6d)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

                  H1        H2        CA        MG         K        NA         P        PM

H1          1.00000   0.28197   0.39705  -0.07472  -0.04279  -0.05605   0.04499  -0.05990
             0.0000    0.3287    0.1792    0.7996    0.8845    0.8491    0.8955    0.8388
                 14        14        13        14        14        14        11        14

H2          0.28197   1.00000   0.24478  -0.25776   0.03790   0.24152   0.49802  -0.25861
             0.3287    0.0000    0.4202    0.3736    0.8977    0.4055    0.1190    0.3720
                 14        14        13        14        14        14        11        14

CA          0.39705   0.24478   1.00000   0.52292  -0.07682   0.41224   0.49154   0.02476
             0.1792    0.4202    0.0000    0.0667    0.8030    0.1616    0.1491    0.9360
                 13        13        13        13        13        13        10        13

MG         -0.07472  -0.25776   0.52292   1.00000   0.28630   0.46226   0.30851   0.38725
             0.7996    0.3736    0.0667    0.0000    0.3210    0.0961    0.3560    0.1713
                 14        14        13        14        14        14        11        14

K          -0.04279   0.03790  -0.07682   0.28630   1.00000   0.87997   0.70726  -0.20744
             0.8845    0.8977    0.8030    0.3210    0.0000    0.0001    0.0149    0.4767
                 14        14        13        14        14        14        11        14

NA         -0.05605   0.24152   0.41224   0.46226   0.87997   1.00000   0.89375  -0.19845
             0.8491    0.4055    0.1616    0.0961    0.0001    0.0000    0.0002    0.4964
                 14        14        13        14        14        14        11        14

P           0.04499   0.49802   0.49154   0.30851   0.70726   0.89375   1.00000  -0.56341
             0.8955    0.1190    0.1491    0.3560    0.0149    0.0002    0.0000    0.0711
                 11        11        10        11        11        11        11        11

PM         -0.05990  -0.25861   0.02476   0.38725  -0.20744  -0.19845  -0.56341   1.00000
             0.8388    0.3720    0.9360    0.1713    0.4767    0.4964    0.0711    0.0000
                 14        14        13        14        14        14        11        14
```

Table 1 cont.

Site 1 Stake 2 Profile 7 (Fig. 6d)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

                 H1         H2         CA         MG          K         NA          P         PM

H1          1.00000    0.38143    0.35873    0.19116   -0.16541    0.24976   -0.11740   -0.25453
             0.0000     0.1784     0.2078     0.5127     0.5720     0.4105     0.7025     0.4014
                 14         14         14         14         14         13         13         13

H2          0.38143    1.00000    0.18577   -0.33087    0.33599    0.39023   -0.31405    0.38821
             0.1784     0.0000     0.5249     0.2479     0.2402     0.1874     0.2960     0.1899
                 14         14         14         14         14         13         13         13

CA          0.35873    0.18577    1.00000    0.54673    0.09263    0.51020   -0.07087    0.05247
             0.2078     0.5249     0.0000     0.0349     0.7426     0.0623     0.8098     0.8586
                 14         14         15         15         15         14         14         14

MG          0.19116   -0.33087    0.54673    1.00000    0.08472    0.57609    0.28759   -0.16924
             0.5127     0.2479     0.0349     0.0000     0.7640     0.0311     0.3188     0.5630
                 14         14         15         15         15         14         14         14

K          -0.16541    0.33599    0.09263    0.08472    1.00000    0.45374    0.22191    0.35688
             0.5720     0.2402     0.7426     0.7640     0.0000     0.1032     0.4458     0.2104
                 14         14         15         15         15         14         14         14

NA          0.24976    0.39023    0.51020    0.57609    0.45374    1.00000   -0.25133   -0.11737
             0.4105     0.1874     0.0623     0.0311     0.1032     0.0000     0.4075     0.7026
                 13         13         14         14         14         14         13         13

P          -0.11740   -0.31405   -0.07087    0.28759    0.22191   -0.25133    1.00000   -0.03322
             0.7025     0.2960     0.8098     0.3188     0.4458     0.4075     0.0000     0.9102
                 13         13         14         14         14         13         14         14

PM         -0.25453    0.38821    0.05247   -0.16924    0.35688   -0.11737   -0.03322    1.00000
             0.4014     0.1899     0.8586     0.5630     0.2104     0.7026     0.9102     0.0000
                 13         13         14         14         14         13         14         14
```

Table 1 cont.

Site 1 Stake 4 Profile 12 (Fig. 6d)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

                H1        H2        CA        MG         K        NA         P        PM

H1         1.00000   0.70951   0.29836   0.26376   0.02128   0.14981   0.44027  -0.09867
            0.0000    0.0145    0.3728    0.4332    0.9505    0.6602    0.2029    0.7729
                11        11        11        11        11        11        10        11

H2         0.70951   1.00000   0.10660   0.35092   0.24314   0.17078   0.19653  -0.28920
            0.0145    0.0000    0.7551    0.2900    0.4713    0.6156    0.5863    0.3884
                11        11        11        11        11        11        10        11

CA         0.29836   0.10660   1.00000   0.10570  -0.41225   0.24773   0.53900  -0.37847
            0.3725    0.7551    0.0000    0.7437    0.1830    0.4376    0.1079    0.2251
                11        11        12        12        12        12        10        12

MG         0.26376   0.35092   0.10570   1.00000   0.40149   0.46873   0.53506   0.25051
            0.4332    0.2900    0.7437    0.0000    0.1938    0.1243    0.1110    0.4323
                11        11        12        12        12        12        10        12

K          0.02128   0.24314  -0.41225   0.40148   1.00000   0.62131  -0.44100   0.06168
            0.9505    0.4713    0.1830    0.1958    0.0000    0.0310    0.2020    0.8490
                11        11        12        12        12        12        10        12

NA         0.14981   0.17078   0.24773   0.46873   0.62131   1.00000  -0.00493  -0.10310
            0.6602    0.6156    0.4376    0.1243    0.0310    0.0000    0.9892    0.7498
                11        11        12        12        12        12        10        12

P          0.44027   0.19653   0.53900   0.53506  -0.44100  -0.00493   1.00000  -0.11135
            0.2029    0.5863    0.1079    0.1110    0.2020    0.9892    0.0000    0.7594
                10        10        10        10        10        10        10        10

PM        -0.09867  -0.28920  -0.37847   0.25051   0.06168  -0.10310  -0.11135   1.00000
            0.7729    0.3884    0.2251    0.4323    0.8490    0.7498    0.7594    0.0000
                11        11        12        12        12        12        10        12
```

Table 1 cont.

Site 2 Stake 1 Profile 1 (Fig. 6e)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / N = 3

              H1        H2        CA        MG         K        NA         P        PM

H1       1.00000   0.99578   0.87987   0.00000  -0.73704   0.02405   0.19684  -0.95382
          0.0000    0.0585    0.3153    1.0000    0.4724    0.9847    0.8739    0.1942

H2       0.99578   1.00000   0.91975   0.00000  -0.67193  -0.06777   0.28596  -0.97736
          0.0585    0.0000    0.2568    1.0000    0.5309    0.9568    0.8154    0.1357

CA       0.87987   0.91975   1.00000   0.00000  -0.32733  -0.45392   0.63912  -0.98198
          0.3153    0.2568    0.0000    1.0000    0.7877    0.7000    0.5586    0.1210

MG       0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
          1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000

K       -0.73704  -0.67193  -0.32733   0.00000   1.00000  -0.69338   0.51754   0.50000
          0.4724    0.5309    0.7877    1.0000    0.0000    0.5122    0.6537    0.6667

NA       0.02405  -0.06777  -0.45392   0.00000  -0.69338   1.00000  -0.97542   0.27735
          0.9847    0.9568    0.7000    1.0000    0.5122    0.0000    0.1415    0.8211

P        0.19684   0.28596   0.63912   0.00000   0.51754  -0.97542   1.00000  -0.48225
          0.8739    0.8154    0.5586    1.0000    0.6537    0.1415    0.0000    0.6796

PM      -0.95382  -0.97736  -0.98198   0.00000   0.50000   0.27735  -0.48225   1.00000
          0.1942    0.1357    0.1210    1.0000    0.6667    0.8211    0.6796    0.0000
```

Table 1 cont.

Site 2 Stake 4 Profile 2 (Fig. 6f)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS
                 H1        H2        CA        MG         K        NA         P        PM

H1          1.00000  -0.30936  -0.12379   0.85528  -0.70243   0.22542   0.99285   0.58881
             0.0000    0.6125    0.8428    0.0646    0.2976    0.7154    0.0007    0.2962
                  5         5         5         5         4         5         5         5

H2         -0.30936   1.00000   0.53480  -0.04303  -0.35013  -0.68306  -0.31574  -0.23682
             0.6125    0.0000    0.3531    0.9452    0.6499    0.2037    0.6048    0.7013
                  5         5         5         5         4         5         5         5

CA         -0.12379   0.53480   1.00000   0.40625   0.33333   0.06891  -0.09428   0.53017
             0.8428    0.3531    0.0000    0.4973    0.6667    0.9123    0.8801    0.3581
                  5         5         5         5         4         5         5         5

MG          0.85528  -0.04303   0.40625   1.00000  -0.77778   0.27565   0.86434   0.84000
             0.0646    0.9452    0.4973    0.0000    0.2222    0.6535    0.0587    0.0750
                  5         5         5         5         4         5         5         5

K          -0.70243  -0.35013   0.33333  -0.77778   1.00000   0.40226  -0.68921   0.51410
             0.2976    0.6499    0.6667    0.2222    0.0000    0.5977    0.3108    0.4859
                  4         4         4         4         4         4         4         4

NA          0.22542  -0.68306   0.06891   0.27565   0.40226   1.00000   0.30821   0.40209
             0.7154    0.2037    0.9123    0.6535    0.5977    0.0000    0.6139    0.5022
                  5         5         5         5         4         5         5         5

P           0.99285  -0.31574  -0.09428   0.86434  -0.68921   0.30821   1.00000   0.58161
             0.0007    0.6048    0.8801    0.0587    0.3108    0.6139    0.0000    0.3037
                  5         5         5         5         4         5         5         5

PM          0.58881  -0.23682   0.53017   0.84000   0.51410   0.40209   0.58161   1.00000
             0.2962    0.7013    0.3581    0.0750    0.4859    0.5022    0.3037    0.0000
                  5         5         5         5         4         5         5         5
```

Table 1 cont.

Site 2 Stake 5 Profile 3 (Fig. 6g)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

                   H1        H2        CA        MG         K        NA         P        PN

H1            1.00000  -0.61442   0.00000   0.00000   0.43769   0.80831   0.07947   0.36704
               0.0000    0.5788    1.0000    1.0000    0.5623    0.1917    0.9205    0.6330
                    4         3         4         4         4         4         4         4

H2           -0.61442   1.00000   0.00000   0.00000  -0.67193  -0.99492   0.44982   0.93976
               0.5788    0.0000    1.0000    1.0000    0.5309    0.0642    0.7030    0.2221
                    3         3         3         3         3         3         3         3

CA            0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
               1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
                    4         3         4         4         4         4         4         4

MG            0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
               1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
                    4         3         4         4         4         4         4         4

K             0.43769  -0.67193   0.00000   0.00000   1.00000   0.37619   0.42366  -0.66329
               0.5623    0.5309    1.0000    1.0000    0.0000    0.6238    0.5763    0.3367
                    4         3         4         4         4         4         4         4

NA            0.80831  -0.99492   0.00000   0.00000   0.37619   1.00000  -0.45329   0.17985
               0.1917    0.0642    1.0000    1.0000    0.6238    0.0000    0.5467    0.8201
                    4         3         4         4         4         4         4         4

P             0.07947   0.44982   0.00000   0.00000   0.42366  -0.45329   1.00000  -0.22366
               0.9205    0.7030    1.0000    1.0000    0.5763    0.5467    0.0000    0.7763
                    4         3         4         4         4         4         4         4

PN            0.36704   0.93976   0.00000   0.00000  -0.66329   0.17985  -0.22365   1.00000
               0.6330    0.2221    1.0000    1.0000    0.3367    0.8201    0.7763    0.0000
                    4         3         4         4         4         4         4         4
```

Table 1 cont.

Site 2 Stake 1 Profile 4 (Fig. 6e)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

                    H1        H2        CA        MG         K        NA         P        PM

H1             1.00000  -0.37732  -0.86711  -0.45017   0.21333  -0.25846  -0.36722  -0.25009
                0.0000    0.5312    0.0570    0.4468    0.7304    0.6746    0.6328    0.6849
                     5         5         5         5         5         5         4         5

H2            -0.37732   1.00000  -0.04264   0.40415   0.28284   0.79008  -0.53281  -0.40600
                0.5312    0.0000    0.9457    0.4998    0.6447    0.1118    0.4672    0.4976
                     5         5         5         5         5         5         4         5

CA            -0.86711  -0.04264   1.00000   0.43082  -0.07538  -0.15891   0.70390   0.63487
                0.0570    0.9457    0.0000    0.4689    0.9041    0.7985    0.2961    0.2498
                     5         5         5         5         5         5         4         5

MG            -0.45017   0.40415   0.43082   1.00000   0.40825  -0.21517  -0.20480   0.60439
                0.4468    0.4998    0.4689    0.0000    0.4950    0.7282    0.7952    0.2803
                     5         5         5         5         5         5         4         5

K              0.21333   0.28284  -0.07538   0.40825   1.00000   0.00000   0.00000   0.33010
                0.7304    0.6447    0.9041    0.4950    0.0000    1.0000    1.0000    0.5875
                     5         5         5         5         5         5         4         5

NA            -0.25846   0.79008  -0.15891  -0.21517   0.00000   1.00000  -0.26916  -0.76445
                0.6746    0.1118    0.7985    0.7282    1.0000    0.0000    0.7308    0.1323
                     5         5         5         5         5         5         4         5

P             -0.36722  -0.53281   0.70390  -0.20480   0.00000  -0.26916   1.00000   0.54162
                0.6328    0.4672    0.2961    0.7952    1.0000    0.7308    0.0000    0.4584
                     4         4         4         4         4         4         4         4

PM            -0.25009  -0.40600   0.63487   0.60439   0.33010  -0.76445   0.54162   1.00000
                0.6849    0.4976    0.2498    0.2803    0.5875    0.1323    0.4584    0.0000
                     5         5         5         5         5         5         4         5
```

Table 1 cont.

Site 2 Stake 4 Profile 5 (Fig. 6f)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

                 H1        H2        CA        MG         K        NA         P        PM

H1          1.00000   0.91237   0.52820   0.06906  -0.01981   0.37438  -0.01829   0.09616
             0.0000    0.0016    0.1438    0.8599    0.9597    0.3209    0.9627    0.8056
                  9         8         9         9         9         9         9         9

H2          0.91237   1.00000   0.68785   0.30761   0.19290   0.79649  -0.01775  -0.10140
             0.0016    0.0000    0.0593    0.4586    0.6472    0.0180    0.9667    0.8112
                  8         8         8         8         8         8         8         8

CA          0.52820   0.68785   1.00000   0.68641  -0.10127   0.80233  -0.32544  -0.54780
             0.1438    0.0593    0.0000    0.0412    0.7954    0.0093    0.3928    0.1268
                  9         8         9         9         9         9         9         9

MG          0.06906   0.30761   0.68641   1.00000  -0.38730   0.70711  -0.38542  -0.75571
             0.8599    0.4586    0.0412    0.0000    0.3031    0.0331    0.3056    0.0185
                  9         8         9         9         9         9         9         9

K          -0.01981   0.19290  -0.10127  -0.38730   1.00000   0.02608   0.76203   0.60760
             0.9597    0.6472    0.7954    0.3031    0.0000    0.9469    0.0170    0.0826
                  9         8         9         9         9         9         9         9

NA          0.37438   0.79649   0.80233   0.70711   0.02608   1.00000  -0.23793  -0.63873
             0.3209    0.0180    0.0093    0.0331    0.9469    0.0000    0.5376    0.0641
                  9         8         9         9         9         9         9         9

P          -0.01829  -0.01775  -0.32544  -0.38542   0.76203  -0.23793   1.00000   0.70959
             0.9627    0.9667    0.3928    0.3056    0.0170    0.5376    0.0000    0.0323
                  9         8         9         9         9         9         9         9

PM          0.09616  -0.10140  -0.54780  -0.75571   0.60760  -0.63873   0.70959   1.00000
             0.8056    0.8112    0.1268    0.0185    0.0826    0.0641    0.0323    0.0000
                  9         8         9         9         9         9         9         9
```

Table 1 cont.

Site 2 Stake 5 Profile 6 (Fig. 6g)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / N = 4

                H1         H2         CA         MG          K         NA          P         PM

H1         1.00000    0.99474    0.27328   -0.11448   -0.17835   -0.12322   -0.39033   -0.32304
            0.0000     0.0053     0.7267     0.8855     0.8216     0.8768     0.6097     0.6770

H2         0.99474    1.00000    0.28325   -0.13324   -0.23215   -0.02106   -0.31303   -0.35617
            0.0053     0.0000     0.7167     0.8668     0.7679     0.9789     0.6870     0.6438

CA         0.27328    0.28325    1.00000    0.87946    0.68101    0.03475    0.50505    0.71764
            0.7267     0.7167     0.0000     0.1205     0.3190     0.9652     0.4950     0.2824

MG        -0.11448   -0.13324    0.87946    1.00000    0.92717   -0.21630    0.44650    0.96261
            0.8855     0.8668     0.1205     0.0000     0.0728     0.7837     0.5535     0.0374

K         -0.17835   -0.23215    0.68101    0.92717    1.00000   -0.54433    0.13484    0.96900
            0.8216     0.7679     0.3190     0.0728     0.0000     0.4557     0.8652     0.0310

NA        -0.12322   -0.02106    0.03475   -0.21630   -0.54433    1.00000    0.75233   -0.33625
            0.8768     0.9789     0.9652     0.7837     0.4557     0.0000     0.2477     0.6637

P         -0.39033   -0.31303    0.50505    0.44650    0.13484    0.75233    1.00000    0.36585
            0.6097     0.6870     0.4950     0.5535     0.8652     0.2477     0.0000     0.6342

PM        -0.32304   -0.35617    0.71764    0.96261    0.96900   -0.33625    0.36585    1.00000
            0.6770     0.6438     0.2824     0.0374     0.0310     0.6637     0.6342     0.0000
```

Table 1 cont.

Site 2 Stake 1 Profile 7 (Fig. 6e)

```
 CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 /  N = 8

                  H1         H2         CA         MG          K         NA          P         PM

H1           1.00000    0.46285    0.02278    0.37289    0.08340    0.19269    0.09479    0.41113
              0.0000     0.2481     0.9573     0.3629     0.8443     0.6475     0.8233     0.3116

H2           0.46285    1.00000   -0.14274   -0.00902   -0.27345    0.07896   -0.13111    0.46351
              0.2481     0.0000     0.7360     0.9831     0.5123     0.8526     0.7570     0.2474

CA           0.02278   -0.14274    1.00000    0.84904    0.37504    0.28177    0.97110    0.68020
              0.9573     0.7360     0.0000     0.0077     0.3600     0.4990     0.0001     0.0634

MG           0.37289   -0.00902    0.84904    1.00000    0.61496    0.45951    0.91075    0.57163
              0.3629     0.9831     0.0077     0.0000     0.1047     0.2520     0.0017     0.1388

K            0.08340   -0.27345    0.37504    0.61496    1.00000    0.87026    0.40724   -0.20946
              0.8443     0.5123     0.3600     0.1047     0.0000     0.0049     0.3166     0.6186

NA           0.19269    0.07896    0.28177    0.45951    0.87026    1.00000    0.24822   -0.08595
              0.6475     0.8526     0.4990     0.2520     0.0049     0.0000     0.5533     0.8396

P            0.09479   -0.13111    0.97110    0.91075    0.40724    0.24822    1.00000    0.67452
              0.8233     0.7570     0.0001     0.0017     0.3166     0.5533     0.0000     0.0665

PM           0.41113    0.46351    0.68020    0.57163   -0.20946   -0.08595    0.67452    1.00000
              0.3116     0.2474     0.0634     0.1388     0.6186     0.8396     0.0665     0.0000
```

Table 1 cont.

Site 2 Stake 4 Profile 9 (Fig. 6f)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

                   H1        H2        CA        MG         K        NA         P        PM

H1            1.00000   0.30306   0.76776   0.73374   0.66476   0.52885   0.38904   0.44218
               0.0000    0.3650    0.0157    0.0157    0.0360    0.1160    0.2370    0.1733
                   11        11         9        10        10        10        11        11

H2            0.30306   1.00000   0.37799   0.29435   0.51387   0.12237   0.26432   0.38454
               0.3650    0.0000    0.3159    0.4091    0.1287    0.7363    0.4322    0.2429
                   11        11         9        10        10        10        11        11

CA            0.76776   0.37799   1.00000   0.96429   0.95474   0.78615   0.14011   0.90844
               0.0157    0.3159    0.0000    0.0001    0.0001    0.0120    0.7192    0.0007
                    9         9         9         9         9         9         9         9

MG            0.73374   0.29435   0.96429   1.00000   0.93879   0.88002   0.20813   0.84927
               0.0157    0.4091    0.0001    0.0000    0.0001    0.0008    0.5639    0.0019
                   10        10         9        10        10        10        10        10

K             0.66476   0.51387   0.95474   0.93879   1.00000   0.72596   0.20176   0.90732
               0.0360    0.1287    0.0001    0.0001    0.0000    0.0175    0.5762    0.0003
                   10        10         9        10        10        10        10        10

NA            0.52885   0.12237   0.78615   0.88002   0.72596   1.00000   0.26034   0.64979
               0.1160    0.7363    0.0120    0.0008    0.0175    0.0000    0.4676    0.0420
                   10        10         9        10        10        10        10        10

P             0.38904   0.26432   0.14011   0.20813   0.20176   0.26034   1.00000  -0.17972
               0.2370    0.4322    0.7192    0.5639    0.5762    0.4676    0.0000    0.5970
                   11        11         9        10        10        10        11        11

PM            0.44218   0.38454   0.90844   0.84927   0.90732   0.64979  -0.17972   1.00000
               0.1733    0.2429    0.0007    0.0019    0.0003    0.0420    0.5970    0.0000
                   11        11         9        10        10        10        11        11
```

Site 2 Stake 5 Profile 11 (Fig. 6g)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

                H1        H2        CA        MG         K        NA         P        PM

H1         1.00000   0.31731  -0.24557   0.00250  -0.09401  -0.05417  -0.06280  -0.00766
            0.0000    0.4880    0.6391    0.9962    0.8411    0.9311    0.8936    0.9870
                 7         7         6         6         7         5         7         7

H2         0.31731   1.00000   0.82909   0.54845   0.84461   0.55434   0.46665   0.43117
            0.4880    0.0000    0.0413    0.2598    0.0168    0.3322    0.2911    0.3341
                 7         7         6         6         7         5         7         7

CA        -0.24557   0.82909   1.00000   0.48818   0.95927   0.81631   0.43953   0.37020
            0.6391    0.0413    0.0000    0.3259    0.0025    0.0919    0.3832    0.4701
                 6         6         6         6         6         5         6         6

MG         0.00250   0.54845   0.48818   1.00000   0.65870   0.89330   0.98913   0.98815
            0.9962    0.2598    0.3259    0.0000    0.1548    0.0412    0.0002    0.0002
                 6         6         6         6         6         5         6         6

K         -0.09401   0.84461   0.95927   0.65870   1.00000   0.90820   0.63678   0.56180
            0.8411    0.0168    0.0025    0.1548    0.0000    0.0329    0.1241    0.1893
                 7         7         6         6         7         5         7         7

NA        -0.05417   0.55434   0.81631   0.89330   0.90820   1.00000   0.92368   0.90220
            0.9311    0.3322    0.0919    0.0412    0.0329    0.0000    0.0250    0.0362
                 5         5         5         5         5         5         5         5

P         -0.06280   0.46665   0.43953   0.98913   0.63678   0.92368   1.00000   0.98895
            0.8936    0.2911    0.3832    0.0002    0.1241    0.0250    0.0000    0.0001
                 7         7         6         6         7         5         7         7

PM        -0.00766   0.43117   0.37020   0.98815   0.56180   0.90220   0.98895   1.00000
            0.9870    0.3341    0.4701    0.0002    0.1893    0.0362    0.0001    0.0000
                 7         7         6         6         7         5         7         7
```

Table 1 cont.

Site 2 Stake 1 Profile 8 (Fig. 6h)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / N = 7

                H1         H2         CA         MG          K         NA          P         PM

 H1        1.00000    0.19715   -0.16393    0.08006    0.34561    0.31697    0.13407    0.06876
            0.0000     0.6718     0.7254     0.8645     0.4477     0.4885     0.7744     0.8835

 H2        0.19715    1.00000    0.58674    0.94219    0.98293    0.90610    0.68560   -0.41548
            0.6718     0.0000     0.1661     0.0015     0.0001     0.0049     0.0891     0.3539

 CA       -0.16393    0.58674    1.00000    0.52042    0.50778    0.48280    0.35419   -0.74066
            0.7254     0.1661     0.0000     0.2311     0.2447     0.2725     0.4357     0.0569

 MG        0.08006    0.94219    0.52042    1.00000    0.90741    0.84655    0.54525   -0.40801
            0.8645     0.0015     0.2311     0.0000     0.0048     0.0163     0.2056     0.3635

 K         0.34561    0.98293    0.50778    0.90741    1.00000    0.87668    0.71319   -0.42188
            0.4477     0.0001     0.2447     0.0048     0.0000     0.0096     0.0720     0.3458

 NA        0.31697    0.90610    0.48280    0.84655    0.87668    1.00000    0.43082   -0.11136
            0.4885     0.0049     0.2725     0.0163     0.0096     0.0000     0.3346     0.8121

 P         0.13407    0.68560    0.35419    0.54525    0.71319    0.43082    1.00000   -0.36463
            0.7744     0.0891     0.4357     0.2056     0.0720     0.3346     0.0000     0.4213

 PM        0.06876   -0.41548   -0.74066   -0.40801   -0.42188   -0.11136   -0.36463    1.00000
            0.8835     0.3539     0.0569     0.3635     0.3458     0.8121     0.4213     0.0000
```

Table 1 cont.

Site 2 Stake 4 Profile 10 (Fig. 6h)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

                   H1         H2         CA         MG          K         NA          P         PM

H1            1.00000    0.70543    0.52449    0.48848    0.15046    0.17369    0.14443    0.18223
               0.0000     0.0153     0.1196     0.1274     0.6588     0.6095     0.6718     0.5918
                   11         11         10         11         11         11         11         11

H2            0.70543    1.00000    0.17621    0.20940    0.35984    0.35899    0.63479    0.39911
               0.0153     0.0000     0.6263     0.5366     0.2770     0.2783     0.0359     0.2240
                   11         11         10         11         11         11         11         11

CA            0.52449    0.17621    1.00000    0.93747    0.02650    0.18330   -0.39557   -0.02170
               0.1196     0.6263     0.0000     0.0001     0.9421     0.6122     0.2579     0.9526
                   10         10         10         10         10         10         10         10

MG            0.48848    0.20940    0.93747    1.00000   -0.06419    0.11321   -0.34149   -0.06002
               0.1274     0.5366     0.0001     0.0000     0.8513     0.7403     0.3040     0.8608
                   11         11         10         11         11         11         11         11

K             0.15046    0.35984    0.02650   -0.06419    1.00000    0.97269    0.66391    0.57734
               0.5588     0.2770     0.9421     0.8513     0.0000     0.0001     0.0259     0.0629
                   11         11         10         11         11         11         11         11

NA            0.17369    0.35899    0.18330    0.11321    0.97269    1.00000    0.57977    0.52784
               0.6095     0.2783     0.6122     0.7403     0.0001     0.0000     0.0615     0.0951
                   11         11         10         11         11         11         11         11

P             0.14443    0.63479   -0.39557   -0.34149    0.66391    0.57977    1.00000    0.54769
               0.6718     0.0359     0.2579     0.3040     0.0259     0.0615     0.0000     0.0811
                   11         11         10         11         11         11         11         11

PM            0.18223    0.39911   -0.02170   -0.06002    0.57734    0.52784    0.54769    1.00000
               0.5918     0.2240     0.9526     0.8508     0.0629     0.0951     0.0811     0.0000
                   11         11         10         11         11         11         11         11
```

Table 1 cont.

Site 2 Stake 5 Profile 12 (Fig. 6h)

CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / N = 7

	H1	H2	CA	MG	K	NA	P	PH
H1	1.00000 0.0000	0.69765 0.0814	0.66419 0.1037	0.68604 0.0888	0.60596 0.1492	0.43378 0.3309	0.89988 0.0058	0.30063 0.5124
H2	0.69765 0.0814	1.00000 0.0000	0.34300 0.4513	0.82105 0.0236	0.06766 0.8854	0.35914 0.4289	0.86137 0.0127	-0.27319 0.5533
CA	0.66419 0.1037	0.34300 0.4513	1.00000 0.0000	0.49614 0.2574	0.67937 0.0932	0.38214 0.3976	0.52860 0.2225	0.04117 0.9302
MG	0.68604 0.0888	0.82105 0.0236	0.49614 0.2574	1.00000 0.0000	0.09129 0.8457	0.57054 0.1810	0.69479 0.0832	-0.26554 0.5649
K	0.60596 0.1492	0.06766 0.8854	0.67937 0.0932	0.09129 0.8457	1.00000 0.0000	0.12500 0.7894	0.29944 0.5141	0.26022 0.5730
NA	0.43378 0.3309	0.35914 0.4289	0.38214 0.3976	0.57054 0.1810	0.12500 0.7894	1.00000 0.0000	0.45211 0.3084	-0.30122 0.5115
P	0.89988 0.0058	0.86137 0.0127	0.52860 0.2225	0.69479 0.0832	0.29944 0.5141	0.45211 0.3084	1.00000 0.0000	0.13576 0.7717
PH	0.30063 0.5124	-0.27319 0.5533	0.04117 0.9302	-0.26554 0.5649	0.26022 0.5730	-0.30122 0.5115	0.13576 0.7717	1.00000 0.0000

Table 1 cont.

Site 3 Stake 1 Profile 1 (Fig. 6i)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS
                    H1        H2        CA        MG         K        NA         P        PM

H1             1.00000   0.02901  -0.86080  -0.55268  -0.49719  -0.42013  -0.40663  -0.51368
                0.0000    0.9508    0.0277    0.1982    0.2563    0.3480    0.3653    0.2383
                     7         7         6         7         7         7         7         7

H2             0.02901   1.00000  -0.33863  -0.35265  -0.19060  -0.02131  -0.22607  -0.17941
                0.9508    0.0000    0.5115    0.4378    0.6823    0.9638    0.6259    0.7003
                     7         7         6         7         7         7         7         7

CA            -0.86080  -0.33863   1.00000   0.97073   0.88264   0.51405   0.81384   0.85301
                0.0277    0.5115    0.0000    0.0013    0.0199    0.2968    0.0488    0.0308
                     6         6         6         6         6         6         6         6

MG            -0.55268  -0.35265   0.97073   1.00000   0.91735   0.43933   0.82953   0.92301
                0.1982    0.4378    0.0013    0.0000    0.0036    0.3240    0.0210    0.0030
                     7         7         6         7         7         7         7         7

K             -0.49719  -0.19060   0.88264   0.91735   1.00000   0.13972   0.96822   0.97517
                0.2563    0.6823    0.0199    0.0036    0.0000    0.7651    0.0003    0.0002
                     7         7         6         7         7         7         7         7

NA            -0.42013  -0.02131   0.51405   0.43933   0.13972   1.00000   0.02331   0.12986
                0.3480    0.9638    0.2968    0.3240    0.7651    0.0000    0.9604    0.7814
                     7         7         6         7         7         7         7         7

P             -0.40663  -0.22607   0.81384   0.82953   0.96822   0.02331   1.00000   0.89617
                0.3653    0.6259    0.0488    0.0210    0.0003    0.9604    0.0000    0.0063
                     7         7         6         7         7         7         7         7

PM            -0.51368  -0.17941   0.85301   0.92301   0.97517   0.12986   0.89617   1.00000
                0.2383    0.7003    0.0308    0.0030    0.0002    0.7814    0.0063    0.0000
                     7         7         6         7         7         7         7         7
```

Table 1 cont.

Site 3 Stake 4 Profile 6 (Fig. 6k)

CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / N = 6

	H1	H2	CA	MG	K	NA	P	PM
H1	1.00000 0.0000	-0.04363 0.9346	0.11454 0.8289	0.19769 0.7073	-0.01742 0.9739	0.61606 0.1928	-0.15907 0.7634	-0.06694 0.8997
H2	-0.04363 0.9346	1.00000 0.0000	0.60997 0.1985	0.71119 0.1131	0.71123 0.1130	0.52410 0.2858	0.47539 0.3406	0.79593 0.0582
CA	0.11454 0.8289	0.60997 0.1985	1.00000 0.0000	0.95005 0.0037	0.97562 0.0009	0.82555 0.0430	0.54938 0.2588	0.88809 0.0181
MG	0.19769 0.7073	0.71119 0.1131	0.95005 0.0037	1.00000 0.0000	0.92013 0.0093	0.87186 0.0236	0.38775 0.4475	0.95016 0.0037
K	-0.01742 0.9739	0.71123 0.1130	0.97562 0.0009	0.92013 0.0093	1.00000 0.0000	0.75750 0.0811	0.67854 0.1384	0.91552 0.0104
NA	0.61606 0.1928	0.52410 0.2858	0.82555 0.0430	0.87186 0.0236	0.75750 0.0811	1.00000 0.0000	0.37790 0.4601	0.71825 0.1079
P	-0.15907 0.7634	0.47539 0.3406	0.54938 0.2588	0.38775 0.4475	0.67854 0.1384	0.37790 0.4601	1.00000 0.0000	0.46123 0.3572
PM	-0.06694 0.8997	0.79593 0.0582	0.88809 0.0181	0.95016 0.0037	0.91552 0.0104	0.71825 0.1079	0.46123 0.3572	1.00000 0.0000

Table 1 cont.

Site 3 Stake 5 Profile 2 (Fig. 6j)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

               H1        H2        CA        MG         K        NA         P        PM

H1        1.00000   0.64441  -0.15584  -0.10735  -0.33314   0.36789  -0.47092  -0.29711
           0.0000    0.0846    0.7125    0.8003    0.4200    0.3699    0.2862    0.4748
                8         8         8         8         8         8         7         8

H2        0.64441   1.00000  -0.00281  -0.15209  -0.27107   0.57461  -0.45387  -0.23147
           0.0846    0.0000    0.9947    0.7192    0.5161    0.1363    0.3063    0.5812
                8         8         8         8         8         8         7         8

CA       -0.15584  -0.00281   1.00000   0.66155   0.82449   0.28254   0.62673   0.74830
           0.7125    0.9947    0.0000    0.0740    0.0118    0.4978    0.1320    0.0327
                8         8         8         8         8         8         7         8

MG       -0.10735  -0.15209   0.66155   1.00000   0.85384   0.29877   0.88285   0.91262
           0.8003    0.7192    0.0740    0.0000    0.0070    0.4723    0.0085    0.0016
                8         8         8         8         8         8         7         8

K        -0.33314  -0.27107   0.82449   0.85384   1.00000  -0.04503   0.79413   0.97259
           0.4200    0.5161    0.0118    0.0070    0.0000    0.9157    0.0329    0.0001
                8         8         8         8         8         8         7         8

NA        0.36789   0.57461   0.28254   0.29877  -0.04503   1.00000   0.07981   0.05859
           0.3699    0.1363    0.4978    0.4723    0.9157    0.0000    0.8649    0.8904
                8         8         8         8         8         8         7         8

P        -0.47092  -0.45387   0.62673   0.88285   0.79413   0.07981   1.00000   0.77824
           0.2862    0.3063    0.1320    0.0085    0.0329    0.8649    0.0000    0.0393
                7         7         7         7         7         7         7         7

PM       -0.29711  -0.23147   0.74830   0.91262   0.97259   0.05859   0.77824   1.00000
           0.4748    0.5812    0.0327    0.0016    0.0001    0.8904    0.0393    0.0000
                8         8         8         8         8         8         7         8
```

Table 1 cont.

Site 3 Stake 1 Profile 4 (Fig. 6i)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / N = 9
              H1        H2        CA        MG         K        NA         P        PM

H1       1.00000   0.88729   0.36006   0.32267   0.15705   0.83883  -0.04028  -0.06247
          0.0000    0.0014    0.3412    0.3971    0.6866    0.0047    0.9181    0.8732

H2       0.88729   1.00000   0.52395   0.46598   0.16325   0.90772   0.07001  -0.20786
          0.0014    0.0000    0.1477    0.2061    0.6747    0.0007    0.8580    0.5915

CA       0.36006   0.52395   1.00000   0.94004   0.70858   0.47981   0.58979   0.40177
          0.3412    0.1477    0.0000    0.0002    0.0326    0.1912    0.0946    0.2838

MG       0.32267   0.46598   0.94004   1.00000   0.88640   0.39876   0.48979   0.60571
          0.3971    0.2061    0.0002    0.0000    0.0015    0.2877    0.1808    0.0839

K        0.15705   0.16325   0.70858   0.88640   1.00000   0.10190   0.34699   0.88426
          0.6866    0.6747    0.0326    0.0015    0.0000    0.7942    0.3603    0.0015

NA       0.83883   0.90772   0.47981   0.39876   0.10190   1.00000   0.18016  -0.25699
          0.0047    0.0007    0.1912    0.2877    0.7942    0.0000    0.6428    0.5044

P       -0.04028   0.07001   0.58979   0.48979   0.34699   0.18016   1.00000   0.29586
          0.9181    0.8580    0.0946    0.1808    0.3603    0.6428    0.0000    0.4395

PM      -0.06247  -0.20786   0.40177   0.60571   0.88426  -0.25699   0.29586   1.00000
          0.8732    0.5915    0.2838    0.0839    0.0015    0.5044    0.4395    0.0000
```

Table 1 cont.

Site 3 Stake 5 Profile 2 (Fig. 6j)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / N = 9

             H1        H2        CA        MG         K        NA         P        PM

H1      1.00000   0.43337   0.45924   0.14247   0.09049   0.02769   0.16236  -0.28390
         0.0000    0.2439    0.2137    0.7146    0.8169    0.9436    0.6764    0.4591

H2      0.43337   1.00000   0.15396  -0.18068  -0.11338  -0.16036  -0.13354  -0.18692
         0.2439    0.0000    0.6925    0.6418    0.7715    0.6802    0.7320    0.6301

CA      0.45924   0.15396   1.00000   0.87571   0.87023   0.20203   0.87403  -0.17039
         0.2137    0.6925    0.0000    0.0020    0.0023    0.6022    0.0021    0.6612

MG      0.14247  -0.18068   0.87571   1.00000   0.92891   0.21621   0.95023  -0.12809
         0.7146    0.6418    0.0020    0.0000    0.0003    0.5763    0.0001    0.7426

K       0.09049  -0.11338   0.87023   0.92891   1.00000   0.28403   0.95829  -0.09339
         0.8169    0.7715    0.0023    0.0003    0.0000    0.4589    0.0001    0.8111

NA      0.02769  -0.16036   0.20203   0.21621   0.28403   1.00000   0.05190  -0.49187
         0.9436    0.6802    0.6022    0.5763    0.4589    0.0000    0.8945    0.1786

P       0.16236  -0.13354   0.87403   0.95023   0.95829   0.05190   1.00000  -0.05016
         0.6764    0.7320    0.0021    0.0001    0.0001    0.8945    0.0000    0.8980

PM     -0.28390  -0.18692  -0.17039  -0.12809  -0.09339  -0.49187  -0.05016   1.00000
         0.4591    0.6301    0.6612    0.7426    0.8111    0.1786    0.8980    0.0000
```

Table 1 cont.

Site 3 Stake 4 Profile 6 (Fig. 6k)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

                    H1        H2        CA        MG         K        NA         P        PM

H1             1.00000   0.76475   0.74389  -0.00853   0.58508   0.59660   0.23003  -0.15238
                0.0000    0.0100    0.0136    0.9813    0.0756    0.0687    0.5226    0.6743
                    10        10        10        10        10        10        10        10

H2             0.76475   1.00000   0.82160   0.23558   0.14028   0.86458  -0.05691  -0.48972
                0.0100    0.0000    0.0019    0.4856    0.6808    0.0006    0.8680    0.1263
                    10        11        11        11        11        11        11        11

CA             0.74389   0.82160   1.00000   0.04263   0.24952   0.74189   0.10940  -0.29436
                0.0136    0.0019    0.0000    0.8953    0.4342    0.0057    0.7350    0.3530
                    10        11        12        12        12        12        12        12

MG            -0.00853   0.23558   0.04263   1.00000   0.04608   0.48505   0.07496   0.05325
                0.9813    0.4856    0.8953    0.0000    0.8869    0.1100    0.8169    0.8695
                    10        11        12        12        12        12        12        12

K              0.58508   0.14028   0.24952   0.04608   1.00000   0.08298   0.94581  -0.00733
                0.0756    0.6808    0.4342    0.8869    0.0000    0.7976    0.0001    0.9820
                    10        11        12        12        12        12        12        12

NA             0.59660   0.86458   0.74189   0.48505   0.08298   1.00000  -0.08678  -0.24629
                0.0687    0.0006    0.0057    0.1100    0.7976    0.0000    0.7886    0.4403
                    10        11        12        12        12        12        12        12

P              0.23003  -0.05691   0.10940   0.07496   0.94581  -0.08678   1.00000   0.01323
                0.5226    0.8680    0.7350    0.8169    0.0001    0.7886    0.0000    0.9674
                    10        11        12        12        12        12        12        12

PM            -0.15238  -0.48972  -0.29436   0.05325  -0.00733  -0.24629   0.01323   1.00000
                0.6743    0.1263    0.3530    0.8695    0.9820    0.4403    0.9674    0.0000
                    10        11        12        12        12        12        12        12
```

Table 1 cont.

Site 3 Stake 1 Profile 7 (Fig. 6i)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

                  H1        H2        CA        MG         K        NA         P        PM

H1           1.00000   0.82617  -0.41054  -0.65828  -0.65945  -0.29446  -0.67701   0.54018
              0.0000    0.0061    0.2724    0.0539    0.0486    0.4418    0.0452    0.1669
                   9         9         9         9         9         9         9         8

H2           0.82617   1.00000  -0.12032  -0.61373  -0.62507  -0.46352  -0.61394   0.11521
              0.0061    0.0000    0.7578    0.0788    0.0719    0.2089    0.0786    0.7859
                   9         9         9         9         9         9         9         8

CA          -0.41054  -0.12032   1.00000   0.69055   0.69559  -0.32400   0.71013  -0.23331
              0.2724    0.7578    0.0000    0.0395    0.0375    0.3950    0.0321    0.5782
                   9         9         9         9         9         9         9         8

MG          -0.65828  -0.61373   0.69055   1.00000   0.99945   0.25591   0.98687  -0.01819
              0.0539    0.0788    0.0395    0.0000    0.0001    0.5063    0.0001    0.9659
                   9         9         9         9         9         9         9         8

K           -0.66945  -0.62507   0.69559   0.99945   1.00000   0.26327   0.99068  -0.01161
              0.0486    0.0719    0.0375    0.0001    0.0000    0.4937    0.0001    0.9782
                   9         9         9         9         9         9         9         8

NA          -0.29446  -0.46352  -0.32400   0.25591   0.26327   1.00000   0.30736   0.52052
              0.4418    0.2089    0.3950    0.5063    0.4937    0.0000    0.4211    0.1860
                   9         9         9         9         9         9         9         8

P           -0.57701  -0.61394   0.71013   0.98687   0.99068   0.30736   1.00000   0.02271
              0.0452    0.0786    0.0321    0.0001    0.0001    0.4211    0.0000    0.9574
                   9         9         9         9         9         9         9         8

PM           0.54018   0.11521  -0.23331  -0.01819  -0.01161   0.52052   0.02271   1.00000
              0.1669    0.7859    0.5782    0.9659    0.9782    0.1860    0.9574    0.0000
                   8         8         8         8         8         8         8         8
```

Table 1 cont.

Site 3 Stake 4 Profile 11 (Fig. 6k)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

                 H1         H2         CA         MG          K         NA          P         PM

H1          1.00000    0.29586   -0.36374   -0.32291   -0.35364   -0.03693   -0.30167   -0.29765
             0.0000     0.2843     0.1826     0.2404     0.1960     0.8960     0.3165     0.2813
                 15         15         15         15         15         15         13         15

H2          0.29586    1.00000   -0.41828   -0.43738   -0.49511   -0.22587   -0.57182   -0.48960
             0.2843     0.0000     0.1208     0.1030     0.0606     0.4183     0.0412     0.0640
                 15         15         15         15         15         15         13         15

CA         -0.36374   -0.41828    1.00000    0.97568    0.98817    0.28348    0.92609    0.97063
             0.1826     0.1208     0.0000     0.0001     0.0001     0.3059     0.0001     0.0001
                 15         15         15         15         15         15         13         15

MG         -0.32291   -0.43738    0.97568    1.00000    0.97315    0.22265    0.97400    0.96206
             0.2404     0.1030     0.0001     0.0000     0.0001     0.4251     0.0001     0.0001
                 15         15         15         15         15         15         13         15

K          -0.35364   -0.49511    0.98817    0.97315    1.00000    0.24452    0.94911    0.99108
             0.1960     0.0606     0.0001     0.0001     0.0000     0.3798     0.0001     0.0001
                 15         15         15         15         15         15         13         15

NA         -0.03693   -0.22587    0.28348    0.22265    0.24452    1.00000    0.09669    0.21081
             0.8960     0.4183     0.3059     0.4251     0.3798     0.0000     0.7533     0.4508
                 15         15         15         15         15         15         13         15

P          -0.30167   -0.57182    0.92609    0.97400    0.94911    0.09669    1.00000    0.95227
             0.3165     0.0412     0.0001     0.0001     0.0001     0.7533     0.0000     0.0001
                 13         13         13         13         13         13         13         13

PM         -0.29765   -0.48960    0.97063    0.96206    0.99108    0.21081    0.95227    1.00000
             0.2813     0.0640     0.0001     0.0001     0.0001     0.4508     0.0001     0.0000
                 15         15         15         15         15         15         13         15
```

Table 1 cont.

Site 3 Stake 5 Profile 9 (Fig. 6j)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 /  N = 13
                  H1         H2         CA         MG          K         NA          P         PM

H1           1.00000    0.47546    0.40600    0.30201    0.21144    0.44435    0.01026    0.14720
              0.0000     0.1006     0.1687     0.3159     0.4880     0.1282     0.9735     0.6313

H2           0.47546    1.00000    0.15822    0.05370   -0.09307    0.03228   -0.18441   -0.10525
              0.1006     0.0000     0.6057     0.8617     0.7623     0.9166     0.5464     0.7322

CA           0.40600    0.15822    1.00000    0.91438    0.88368    0.51144    0.80585    0.85567
              0.1687     0.6057     0.0000     0.0001     0.0001     0.0740     0.0009     0.0002

MG           0.30201    0.05370    0.91438    1.00000    0.96268    0.57938    0.92239    0.95499
              0.3159     0.8617     0.0001     0.0000     0.0001     0.0380     0.0001     0.0001

K            0.21144   -0.09307    0.88368    0.96268    1.00000    0.65430    0.93345    0.99192
              0.4880     0.7623     0.0001     0.0001     0.0000     0.0153     0.0001     0.0001

NA           0.44435    0.03228    0.51144    0.57938    0.65430    1.00000    0.49171    0.64824
              0.1282     0.9166     0.0740     0.0380     0.0153     0.0000     0.0879     0.0166

P            0.01026   -0.18441    0.80585    0.92239    0.93345    0.49171    1.00000    0.92321
              0.9735     0.5464     0.0009     0.0001     0.0001     0.0879     0.0000     0.0001

PM           0.14720   -0.10525    0.85567    0.95499    0.99192    0.64824    0.92321    1.00000
              0.6313     0.7322     0.0002     0.0001     0.0001     0.0166     0.0001     0.0000
```

Table 1 cont.

Site 3 Stake 1 Profile 8 (Fig. 61)

CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

	H1	H2	CA	MG	K	NA	P	PM
H1	1.00000 0.0000 7	0.28094 0.5417 7	-0.53757 0.2713 6	-0.59969 0.2083 6	-0.39945 0.4327 6	-0.40454 0.4263 6	0.15146 0.7458 7	-0.70152 0.0790 7
H2	0.28094 0.5417 7	1.00000 0.0000 7	0.69093 0.1285 6	0.61712 0.1918 6	0.62560 0.1840 6	0.43755 0.3856 6	0.81753 0.0247 7	-0.34520 0.4483 7
CA	-0.53757 0.2713 6	0.69093 0.1285 6	1.00000 0.0000 9	0.50489 0.1657 9	0.47868 0.1924 9	0.42574 0.2532 9	0.45118 0.3096 7	0.50070 0.3117 6
MG	-0.59969 0.2083 6	0.61712 0.1918 6	0.50489 0.1657 9	1.00000 0.0000 9	0.99573 0.0001 9	0.99119 0.0001 9	0.40515 0.3672 7	0.57679 0.2308 6
K	-0.39945 0.4327 6	0.62560 0.1840 6	0.47868 0.1924 9	0.99573 0.0001 9	1.00000 0.0000 9	0.99511 0.0001 9	0.49698 0.2565 7	0.55967 0.2481 6
NA	-0.40454 0.4263 6	0.43755 0.3856 6	0.42574 0.2532 9	0.99119 0.0001 9	0.99511 0.0001 9	1.00000 0.0000 9	0.39571 0.3796 7	0.63328 0.1771 6
P	0.15146 0.7458 7	0.81753 0.0247 7	0.45118 0.3096 7	0.40515 0.3672 7	0.49698 0.2565 7	0.39571 0.3796 7	1.00000 0.0000 8	-0.19708 0.6719 7
PM	-0.70152 0.0790 7	-0.34520 0.4483 7	0.50070 0.3117 6	0.57679 0.2308 6	0.55967 0.2481 6	0.63328 0.1771 6	-0.19708 0.6719 7	1.00000 0.0000 7

Table 1 cont.

Site 3 Stake 5 Profile 10 (Fig. 61)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 /  N = 12

               H1         H2         CA         MG          K         NA          P         PM

H1        1.00000    0.89057    0.53062    0.59145    0.14135    0.81517   -0.02967    0.03074
           0.0000     0.0001     0.0759     0.0428     0.6613     0.0012     0.9271     0.9244

H2        0.89057    1.00000    0.63393    0.47544   -0.01587    0.59678   -0.14149    0.16429
           0.0001     0.0000     0.0269     0.1182     0.9610     0.0405     0.6609     0.6099

CA        0.53062    0.63393    1.00000    0.64643    0.34071    0.53360   -0.00318   -0.01654
           0.0759     0.0269     0.0000     0.0231     0.2785     0.0740     0.9922     0.9593

MG        0.59145    0.47544    0.64643    1.00000    0.42269    0.77549   -0.10212    0.14889
           0.0428     0.1182     0.0231     0.0000     0.1710     0.0030     0.7521     0.6442

K         0.14135   -0.01587    0.34071    0.42269    1.00000    0.31496    0.49463    0.22239
           0.6613     0.9610     0.2785     0.1710     0.0000     0.3187     0.1021     0.4872

NA        0.81517    0.59678    0.53360    0.77549    0.31496    1.00000    0.12093   -0.20724
           0.0012     0.0405     0.0740     0.0030     0.3187     0.0000     0.7081     0.5181

P        -0.02967   -0.14149   -0.00318   -0.10212    0.49463    0.12093    1.00000   -0.03495
           0.9271     0.6609     0.9922     0.7521     0.1021     0.7081     0.0000     0.9141

PM        0.03074    0.16429   -0.01654    0.14889    0.22239   -0.20724   -0.03495    1.00000
           0.9244     0.6099     0.9593     0.6442     0.4872     0.5181     0.9141     0.0000
```

Table 1 cont.

Site 3 Stake 4 Profile 12 (Fig. 61)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS
                      H1        H2        CA        MG         K        NA         P        PM

H1               1.00000   0.43600   0.01054   0.29151   0.00362  -0.00313   0.15517  -0.28004
                  0.0000    0.1042    0.9703    0.2918    0.9898    0.9912    0.5808    0.3322
                      15        15        15        15        15        15        15        14

H2               0.43600   1.00000  -0.23710  -0.25896  -0.36607  -0.04044  -0.28541  -0.42693
                  0.1042    0.0000    0.3949    0.3514    0.1796    0.8862    0.3025    0.1279
                      15        15        15        15        15        15        15        14

CA               0.01054  -0.23710   1.00000   0.80882   0.75876   0.63439   0.30018   0.89617
                  0.9703    0.3949    0.0000    0.0003    0.0010    0.0111    0.2770    0.0001
                      15        15        15        15        15        15        15        14

MG               0.29151  -0.25896   0.80882   1.00000   0.72337   0.58334   0.46554   0.65604
                  0.2918    0.3514    0.0003    0.0000    0.0023    0.0224    0.0803    0.0108
                      15        15        15        15        15        15        15        14

K                0.00362  -0.36607   0.75876   0.72337   1.00000   0.43016   0.62045   0.85401
                  0.9898    0.1796    0.0010    0.0023    0.0000    0.1095    0.0136    0.0001
                      15        15        15        15        15        15        15        14

NA              -0.00313  -0.04044   0.63439   0.58334   0.43016   1.00000   0.13495   0.59240
                  0.9912    0.8862    0.0111    0.0224    0.1095    0.0000    0.6316    0.0256
                      15        15        15        15        15        15        15        14

P                0.15517  -0.28541   0.30018   0.46554   0.62045   0.13495   1.00000   0.36995
                  0.5808    0.3025    0.2770    0.0803    0.0136    0.6316    0.0000    0.1929
                      15        15        15        15        15        15        15        14

PM              -0.28004  -0.42693   0.89617   0.65504   0.85401   0.59240   0.36995   1.00000
                  0.3322    0.1279    0.0001    0.0108    0.0001    0.0256    0.1929    0.0000
                      14        14        14        14        14        14        14        14
```

Table 1 cont.

Site 4 Stake 1 Profile 1 (Fig. 6m)

```
 CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS
                    H1        H2        CA        MG         K        NA         P        PM

H1             1.00000   0.70787  -0.58044  -0.59576  -0.57746  -0.09254  -0.44440  -0.54379
                0.0000    0.0751    0.1718    0.1581    0.2301    0.8436    0.3178    0.2070
                     7         7         7         7         6         7         7         7

H2             0.70787   1.00000  -0.37336  -0.41934  -0.59865  -0.30607  -0.41649  -0.42645
                0.0751    0.0000    0.4094    0.3490    0.2093    0.5044    0.3526    0.3400
                     7         7         7         7         6         7         7         7

CA            -0.58044  -0.37336   1.00000   0.99705   0.97883   0.30968   0.93772   0.99071
                0.1718    0.4094    0.0000    0.0001    0.0007    0.4991    0.0018    0.0001
                     7         7         7         7         6         7         7         7

MG            -0.59576  -0.41934   0.99705   1.00000   0.98862   0.28742   0.95270   0.99562
                0.1581    0.3490    0.0001    0.0000    0.0002    0.5320    0.0009    0.0001
                     7         7         7         7         6         7         7         7

K             -0.57746  -0.59865   0.97883   0.98862   1.00000   0.24580   0.98031   0.99198
                0.2301    0.2093    0.0007    0.0002    0.0000    0.6387    0.0006    0.0001
                     6         6         6         6         6         6         6         6

NA            -0.09254  -0.30607   0.30968   0.28742   0.24580   1.00000   0.34405   0.29939
                0.8436    0.5044    0.4991    0.5320    0.6387    0.0000    0.4499    0.5142
                     7         7         7         7         6         7         7         7

P             -0.44440  -0.41649   0.93772   0.95270   0.98031   0.34405   1.00000   0.96289
                0.3178    0.3526    0.0018    0.0009    0.0006    0.4499    0.0000    0.0005
                     7         7         7         7         6         7         7         7

PM            -0.54379  -0.42645   0.99071   0.99562   0.99193   0.29939   0.96289   1.00000
                0.2070    0.3400    0.0001    0.0001    0.0001    0.5142    0.0005    0.0000
                     7         7         7         7         6         7         7         7
```

Table 1 cont.

Site 4 Stake 3 Profile 2 (Fig. 6n)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

                    H1        H2        CA        MG         K        NA         P        PM

H1             1.00000   0.14734  -0.39580  -0.33334  -0.54964  -0.26860   0.45166  -0.23346
                0.0000    0.7277    0.3317    0.4197    0.1582    0.5201    0.3090    0.5779
                     8         8         8         8         8         8         7         8

H2             0.14734   1.00000  -0.67700  -0.65782  -0.59433  -0.54776   0.32798  -0.86031
                0.7277    0.0000    0.0652    0.0762    0.1202    0.1599    0.4727    0.0061
                     8         8         8         8         8         8         7         8

CA            -0.39580  -0.67700   1.00000   0.98302   0.97661   0.76868  -0.03434   0.93731
                0.3317    0.0652    0.0000    0.0001    0.0001    0.0258    0.9417    0.0006
                     8         8         8         8         8         8         7         8

MG            -0.33334  -0.65782   0.98302   1.00000   0.96785   0.75156  -0.09471   0.90315
                0.4197    0.0762    0.0001    0.0000    0.0001    0.0315    0.8399    0.0021
                     8         8         8         8         8         8         7         8

K             -0.54964  -0.59433   0.97661   0.96785   1.00000   0.74512  -0.11812   0.85926
                0.1582    0.1202    0.0001    0.0001    0.0000    0.0339    0.8009    0.0063
                     8         8         8         8         8         8         7         8

NA            -0.26860  -0.54776   0.76868   0.75156   0.74512   1.00000  -0.00876   0.71491
                0.5201    0.1599    0.0258    0.0315    0.0339    0.0000    0.9851    0.0462
                     8         8         8         8         8         8         7         8

P              0.45166   0.32798  -0.03434  -0.09471  -0.11812  -0.00876   1.00000  -0.06321
                0.3090    0.4727    0.9417    0.8399    0.8009    0.9851    0.0000    0.8929
                     7         7         7         7         7         7         7         7

PM            -0.23346  -0.86031   0.93731   0.90315   0.85926   0.71491  -0.06321   1.00000
                0.5779    0.0061    0.0006    0.0021    0.0063    0.0462    0.8929    0.0000
                     8         8         8         8         8         8         7         8
```

Table 1 cont.

Site 4 Stake 4 Profile 3 (Fig. 6o)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

                   H1        H2        CA        MG         K        NA         P        PM

H1            1.00000   0.67208   0.32573  -0.49812  -0.38089   0.43992  -0.48297  -0.17884
               0.0000    0.0679    0.5287    0.3146    0.5270    0.3233    0.2723    0.7012
                    8         8         6         6         5         7         7         7

H2            0.67208   1.00000   0.41881  -0.23953  -0.18189   0.82624  -0.15011   0.25378
               0.0679    0.0000    0.4085    0.6476    0.7697    0.0220    0.7480    0.5829
                    8         8         6         6         5         7         7         7

CA            0.32573   0.41881   1.00000   0.64022   0.73499   0.45977   0.65396   0.85080
               0.5287    0.4085    0.0000    0.1709    0.1571    0.3589    0.1589    0.0317
                    6         6         6         6         5         6         6         6

MG           -0.49812  -0.23953   0.64022   1.00000   0.93815  -0.30460   0.98628   0.91497
               0.3146    0.6476    0.1709    0.0000    0.0183    0.5572    0.0003    0.0105
                    6         6         6         6         5         6         6         6

K            -0.38089  -0.18189   0.73499   0.93815   1.00000  -0.30500   0.96383   0.97891
               0.5270    0.7697    0.1571    0.0183    0.0000    0.6178    0.0082    0.0037
                    5         5         5         5         5         5         5         5

NA            0.43992   0.82624   0.45977  -0.30460  -0.30500   1.00000  -0.10438   0.38242
               0.3233    0.0220    0.3589    0.5572    0.6178    0.0000    0.8238    0.3972
                    7         7         6         6         5         7         7         7

P            -0.48297  -0.15011   0.65396   0.98528   0.96383  -0.10438   1.00000   0.85085
               0.2723    0.7480    0.1589    0.0003    0.0082    0.8238    0.0000    0.0152
                    7         7         6         6         5         7         7         7

PM           -0.17884   0.25378   0.85080   0.91497   0.97891   0.38242   0.85085   1.00000
               0.7012    0.5829    0.0317    0.0105    0.0037    0.3972    0.0152    0.0000
                    7         7         6         6         5         7         7         7
```

Table 1 cont.

Site 4 Stake 1 Profile 4   (Fig. 6m)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

                H1        H2        CA        MG         K        NA         P        PM

H1         1.00000   0.20014   0.44001  -0.39814  -0.21508   0.46361  -0.24845  -0.60886
            0.0000    0.5793    0.1756    0.2252    0.5253    0.1509    0.4888    0.0818
                11        10        11        11        11        11        10         9

H2         0.20014   1.00000   0.32220  -0.12476  -0.24163  -0.03682  -0.29135  -0.37647
            0.5793    0.0000    0.3639    0.7313    0.5012    0.9196    0.4141    0.3180
                10        10        10        10        10        10        10         9

CA         0.44001   0.32220   1.00000   0.40319   0.49382   0.71522   0.36982  -0.20590
            0.1756    0.3639    0.0000    0.2189    0.1226    0.0134    0.2929    0.5951
                11        10        11        11        11        11        10         9

MG        -0.39814  -0.12476   0.40319   1.00000   0.77287   0.05656   0.80445   0.61233
            0.2252    0.7313    0.2189    0.0000    0.0053    0.8688    0.0050    0.0796
                11        10        11        11        11        11        10         9

K         -0.21508  -0.24163   0.49382   0.77287   1.00000   0.45158   0.97127   0.73189
            0.5253    0.5012    0.1226    0.0053    0.0000    0.1632    0.0001    0.0250
                11        10        11        11        11        11        10         9

NA         0.46361  -0.03682   0.71522   0.05656   0.45158   1.00000   0.37004  -0.21897
            0.1509    0.9196    0.0134    0.8688    0.1632    0.0000    0.2926    0.5714
                11        10        11        11        11        11        10         9

P         -0.24845  -0.29135   0.36982   0.80445   0.97127   0.37004   1.00000   0.80104
            0.4888    0.4141    0.2929    0.0050    0.0001    0.2926    0.0000    0.0095
                10        10        10        10        10        10        10         9

PM        -0.60886  -0.37647  -0.20590   0.61233   0.73189  -0.21897   0.80104   1.00000
            0.0818    0.3180    0.5951    0.0796    0.0250    0.5714    0.0095    0.0000
                 9         9         9         9         9         9         9         9
```

Table 1 cont.

Site 4 Stake 3 Profile 5

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

                   H1        H2        CA        MG         K        NA         P        PM

H1            1.00000   0.22453  -0.12543  -0.16731  -0.16807   0.26384  -0.03862  -0.20030
               0.0000    0.5329    0.7299    0.6441    0.6426    0.4614    0.9214    0.5790
                   10        10        10        10        10        10         9        10

H2            0.22453   1.00000   0.13479  -0.32455  -0.23980   0.75257  -0.35938  -0.33901
               0.5329    0.0000    0.7104    0.3602    0.5046    0.0120    0.3422    0.3379
                   10        10        10        10        10        10         9        10

CA           -0.12543   0.13479   1.00000   0.86002   0.89213   0.47396   0.96075   0.84535
               0.7299    0.7104    0.0000    0.0014    0.0005    0.1664    0.0001    0.0021
                   10        10        10        10        10        10         9        10

MG           -0.16731  -0.32455   0.86002   1.00000   0.98374   0.05390   0.92092   0.98841
               0.6441    0.3602    0.0014    0.0000    0.0001    0.8824    0.0004    0.0001
                   10        10        10        10        10        10         9        10

K            -0.16807  -0.23980   0.89213   0.98374   1.00000   0.12591   0.92167   0.99203
               0.6426    0.5046    0.0005    0.0001    0.0000    0.7289    0.0004    0.0001
                   10        10        10        10        10        10         9        10

NA            0.26384   0.75257   0.47396   0.05390   0.12591   1.00000   0.39842   0.01561
               0.4614    0.0120    0.1664    0.8824    0.7289    0.0000    0.2882    0.9659
                   10        10        10        10        10        10         9        10

P            -0.03862  -0.35938   0.96075   0.92092   0.92167   0.39842   1.00000   0.90226
               0.9214    0.3422    0.0001    0.0004    0.0004    0.2882    0.0000    0.0009
                    9         9         9         9         9         9         9         9

PM           -0.20030  -0.33901   0.84535   0.98841   0.99203   0.01561   0.90226   1.00000
               0.5790    0.3379    0.0021    0.0001    0.0001    0.9659    0.0009    0.0000
                   10        10        10        10        10        10         9        10
```

Table 1 cont.

Site 4 Stake 4 Profile 6 (Fig. 6σ)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS
                     H1        H2        CA        MG         K        NA         P        PM

H1              1.00000   0.62058  -0.22423  -0.43041  -0.43915   0.33524  -0.35251  -0.18218
                 0.0000    0.0313    0.4835    0.1625    0.1532    0.2868    0.2611    0.6144
                     12        12        12        12        12        12        12        10

H2              0.62058   1.00000  -0.35065  -0.61146  -0.62661   0.66901  -0.28193  -0.44037
                 0.0313    0.0000    0.2638    0.0346    0.0292    0.0174    0.3747    0.2028
                     12        12        12        12        12        12        12        10

CA             -0.22423  -0.35065   1.00000   0.92057   0.91580   0.19853   0.03805  -0.25349
                 0.4835    0.2638    0.0000    0.0001    0.0001    0.5362    0.9066    0.4798
                     12        12        12        12        12        12        12        10

MG             -0.43041  -0.61146   0.92057   1.00000   0.99947  -0.06515   0.09246   0.10151
                 0.1625    0.0346    0.0001    0.0000    0.0001    0.8406    0.7750    0.7802
                     12        12        12        12        12        12        12        10

K              -0.43915  -0.62661   0.91580   0.99947   1.00000  -0.07861   0.08461   0.61381
                 0.1532    0.0292    0.0001    0.0001    0.0000    0.8081    0.7937    0.0591
                     12        12        12        12        12        12        12        10

NA              0.33524   0.66901   0.19853  -0.06515  -0.07861   1.00000  -0.49902  -0.21181
                 0.2868    0.0174    0.5362    0.8406    0.8081    0.0000    0.0986    0.5569
                     12        12        12        12        12        12        12        10

P              -0.35251  -0.28193   0.03805   0.09246   0.08461  -0.49902   1.00000  -0.16700
                 0.2611    0.3747    0.9066    0.7750    0.7937    0.0986    0.0000    0.6447
                     12        12        12        12        12        12        12        10

PM             -0.18218  -0.44037  -0.25349   0.10151   0.61381  -0.21181  -0.16700   1.00000
                 0.6144    0.2028    0.4798    0.7802    0.0591    0.5569    0.6447    0.0000
                     10        10        10        10        10        10        10        10
```

Table 1 cont.

Site 4 Stake 1 Profile 7 (Fig. 6m)

```
CORRELATION COEFFICIENTS / PRCB > |R| UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

                  H1        H2        CA        MG         K        NA         P        PM

H1           1.00000   0.52459  -0.66821  -0.60683  -0.63022  -0.37280  -0.58347  -0.49982
              0.0000    0.0976    0.0491    0.0477    0.0377    0.2588    0.0595    0.1175
                  11        11         9        11        11        11        11        11

H2           0.52459   1.00000  -0.70542  -0.57218  -0.27146   0.13684  -0.59007  -0.53042
              0.0976    0.0000    0.0338    0.0659    0.4194    0.6883    0.0560    0.0932
                  11        11         9        11        11        11        11        11

CA          -0.66821  -0.70542   1.00000   0.99585   0.99444   0.54742   0.99728   0.97473
              0.0491    0.0338    0.0000    0.0001    0.0001    0.1014    0.0001    0.0001
                   9         9        10        10        10        10         9         9

MG          -0.60683  -0.57218   0.99585   1.00000   0.86215   0.38896   0.99432   0.94642
              0.0477    0.0659    0.0001    0.0000    0.0003    0.2114    0.0001    0.0001
                  11        11        10        12        12        12        11        11

K           -0.63022  -0.27146   0.99444   0.86215   1.00000   0.71173   0.81307   0.75829
              0.0377    0.4194    0.0001    0.0003    0.0000    0.0094    0.0023    0.0068
                  11        11        10        12        12        12        11        11

NA          -0.37280   0.13684   0.54742   0.38896   0.71173   1.00000   0.31256   0.23195
              0.2588    0.6883    0.1014    0.2114    0.0094    0.0000    0.3494    0.4925
                  11        11        10        12        12        12        11        11

P           -0.58347  -0.59007   0.99728   0.99432   0.81307   0.31256   1.00000   0.95499
              0.0595    0.0560    0.0001    0.0001    0.0023    0.3494    0.0000    0.0001
                  11        11         9        11        11        11        11        11

PM          -0.49982  -0.53042   0.97473   0.94642   0.75829   0.23195   0.95499   1.00000
              0.1175    0.0932    0.0001    0.0001    0.0068    0.4925    0.0001    0.0000
                  11        11         9        11        11        11        11        11
```

Table 1 cont.

Site 4 Stake 3 Profile 9 (Fig. 6n)

CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	H1	H2	CA	MG	K	NA	P	PM
H1	1.00000 0.0000 14	0.15556 0.5954 14	-0.00329 0.9919 12	-0.02346 0.9423 12	0.06300 0.8458 12	0.11111 0.7310 12	-0.36178 0.2245 13	-0.46257 0.1300 12
H2	0.15556 0.5954 14	1.00000 0.0000 14	-0.15046 0.6407 12	-0.27758 0.3824 12	-0.32576 0.3015 12	-0.19423 0.5453 12	-0.45684 0.1166 13	0.10917 0.7356 12
CA	-0.00329 0.9919 12	-0.15046 0.6407 12	1.00000 0.0000 12	0.63013 0.0281 12	0.44699 0.1451 12	0.37720 0.2268 12	0.35260 0.2875 11	0.13629 0.7074 10
MG	-0.02346 0.9423 12	-0.27758 0.3824 12	0.63013 0.0281 12	1.00000 0.0000 12	0.65870 0.0198 12	0.53699 0.0718 12	0.67932 0.0215 11	0.44356 0.1991 10
K	0.06300 0.8458 12	-0.32576 0.3015 12	0.44699 0.1451 12	0.65870 0.0198 12	1.00000 0.0000 12	0.93581 0.0001 12	0.36005 0.2767 11	0.30707 0.3881 10
NA	0.11111 0.7310 12	-0.19423 0.5453 12	0.37720 0.2268 12	0.53699 0.0718 12	0.93581 0.0001 12	1.00000 0.0000 12	0.35443 0.2849 11	0.20380 0.5722 10
P	-0.36178 0.2245 13	-0.45684 0.1166 13	0.35260 0.2875 11	0.67932 0.0215 11	0.36005 0.2767 11	0.35443 0.2849 11	1.00000 0.0000 13	0.53637 0.0889 11
PM	-0.46257 0.1300 12	0.10917 0.7356 12	0.13629 0.7074 10	0.44356 0.1991 10	0.30707 0.3881 10	0.20380 0.5722 10	0.53637 0.0889 11	1.00000 0.0000 12

Table 1 cont.

Site 4 Stake 4 Profile 11 (Fig. 6o)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS
                  H1        H2        CA        MG         K        NA         P        PM

H1           1.00000   0.63454  -0.56785  -0.54929  -0.64471  -0.39751  -0.61029  -0.38709
              0.0000    0.0360    0.0684    0.0801    0.0322    0.2260    0.0461    0.2395
                  11        11        11        11        11        11        11        11

H2           0.63454   1.00000  -0.51560  -0.49095  -0.66340  -0.71853  -0.56462  -0.45928
              0.0360    0.0000    0.1045    0.1252    0.0261    0.0127    0.0704    0.1553
                  11        11        11        11        11        11        11        11

CA          -0.56785  -0.51560   1.00000   0.99733   0.80822   0.48205   0.95140   0.38254
              0.0684    0.1045    0.0000    0.0001    0.0015    0.1125    0.0001    0.2197
                  11        11        12        12        12        12        12        12

MG          -0.54929  -0.49095   0.99733   1.00000   0.77951   0.43918   0.93997   0.34708
              0.0801    0.1252    0.0001    0.0000    0.0028    0.1532    0.0001    0.2690
                  11        11        12        12        12        12        12        12

K           -0.64471  -0.66340   0.80822   0.77951   1.00000   0.83011   0.91062   0.78288
              0.0322    0.0261    0.0015    0.0028    0.0000    0.0008    0.0001    0.0026
                  11        11        12        12        12        12        12        12

NA          -0.39751  -0.71853   0.48205   0.43918   0.83011   1.00000   0.59185   0.66243
              0.2260    0.0127    0.1125    0.1532    0.0008    0.0000    0.0426    0.0189
                  11        11        12        12        12        12        12        12

P           -0.61029  -0.56462   0.95140   0.93997   0.91062   0.59185   1.00000   0.61088
              0.0461    0.0704    0.0001    0.0001    0.0001    0.0426    0.0000    0.0349
                  11        11        12        12        12        12        12        12

PM          -0.38709  -0.45928   0.38254   0.34708   0.78288   0.66243   0.61088   1.00000
              0.2395    0.1553    0.2197    0.2690    0.0026    0.0189    0.0349    0.0000
                  11        11        12        12        12        12        12        12
```

Table 1 cont.

Site 4 Stake 1 Profile 8 (Fig. 6p)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

                  H1        H2        CA        MG         K        NA         P        PH

H1           1.00000   0.91855   0.78028   0.27729  -0.17670   0.18793  -0.29600  -0.46875
              0.0000    0.0001    0.0077    0.4091    0.6032    0.5800    0.3768    0.1459
                  12        12        10        11        11        11        11        11

H2           0.91855   1.00000   0.63295   0.46441  -0.01999   0.03479  -0.34888  -0.25075
              0.0001    0.0000    0.0495    0.1501    0.9535    0.9191    0.2930    0.4570
                  12        12        10        11        11        11        11        11

CA           0.78028   0.63295   1.00000   0.35981  -0.35372   0.43869   0.58012   0.43753
              0.0077    0.0495    0.0000    0.3071    0.3160    0.2047    0.1015    0.2389
                  10        10        10        10        10        10         9         9

MG           0.27729   0.46441   0.35981   1.00000   0.19365   0.22553   0.49576   0.44402
              0.4091    0.1501    0.3071    0.0000    0.5683    0.5049    0.1451    0.1986
                  11        11        10        11        11        11        10        10

K           -0.17670  -0.01999  -0.35372   0.19365   1.00000  -0.01081   0.22351  -0.17876
              0.6032    0.9535    0.3160    0.5683    0.0000    0.9748    0.5348    0.6212
                  11        11        10        11        11        11        10        10

NA           0.18793   0.03479   0.43869   0.22553  -0.01081   1.00000   0.76633   0.42526
              0.5800    0.9191    0.2047    0.5049    0.9748    0.0000    0.0097    0.2205
                  11        11        10        11        11        11        10        10

P           -0.29600  -0.34888   0.58012   0.49576   0.22351   0.76633   1.00000   0.47483
              0.3768    0.2930    0.1015    0.1451    0.5348    0.0097    0.0000    0.1400
                  11        11         9        10        10        10        11        11

PH          -0.46875  -0.25075   0.43753   0.44402  -0.17876   0.42526   0.47483   1.00000
              0.1459    0.4570    0.2389    0.1986    0.6212    0.2205    0.1400    0.0000
                  11        11         9        10        10        10        11        11
```

Table 1 cont.

Site 4 Stake 3 Profile 10 (Fig. 6p)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

                    H1         H2         CA         MG          K         NA          P         PH

H1             1.00000    0.74302   -0.07903   -0.15801    0.15885    0.25068   -0.54451   -0.47893
                0.0000     0.0036     0.7975     0.6062     0.6042     0.4320     0.0544     0.0978
                    13         13         13         13         13         12         13         13

H2             0.74302    1.00000   -0.20516   -0.12163   -0.01796   -0.04593   -0.42046   -0.30408
                0.0036     0.0000     0.5013     0.6922     0.9536     0.8873     0.1525     0.3125
                    13         13         13         13         13         12         13         13

CA            -0.07903   -0.20516    1.00000    0.60350    0.13488    0.45084    0.03931    0.17768
                0.7975     0.5013     0.0000     0.0223     0.6457     0.1221     0.8939     0.5434
                    13         13         14         14         14         13         14         14

MG            -0.15801   -0.12163    0.60350    1.00000    0.42907    0.00566    0.45143    0.49148
                0.6062     0.6922     0.0223     0.0000     0.1258     0.9854     0.1052     0.0743
                    13         13         14         14         14         13         14         14

K              0.15885   -0.01796    0.13488    0.42907    1.00000    0.20889   -0.05378   -0.31613
                0.6042     0.9536     0.6457     0.1258     0.0000     0.4934     0.8551     0.2708
                    13         13         14         14         14         13         14         14

NA             0.25068   -0.04593    0.45084    0.00566    0.20889    1.00000   -0.13243   -0.19654
                0.4320     0.8873     0.1221     0.9854     0.4934     0.0000     0.6663     0.5199
                    12         12         13         13         13         13         13         13

P             -0.54451   -0.42046    0.03931    0.45143   -0.05378   -0.13243    1.00000    0.42781
                0.0544     0.1525     0.8939     0.1052     0.8551     0.6663     0.0000     0.1270
                    13         13         14         14         14         13         14         14

PH            -0.47893   -0.30408    0.17768    0.49148   -0.31613   -0.19654    0.42781    1.00000
                0.0978     0.3125     0.5434     0.0743     0.2708     0.5199     0.1270     0.0000
                    13         13         14         14         14         13         14         14
```

Table 1 cont.

Site 4 Stake 4 Profile 12 (Fig. 6p)

```
CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

                H1        H2        CA        MG         K        NA         P        PH

H1         1.00000   0.88193   0.01578  -0.45922   0.48770   0.44768  -0.61672  -0.35625
            0.0000    0.0017    0.9704    0.2137    0.1829    0.2269    0.0769    0.3467
                 9         9         8         9         9         9         9         9

H2         0.88193   1.00000  -0.01477  -0.43973   0.47216   0.26494  -0.77542  -0.62975
            0.0017    0.0000    0.9723    0.2363    0.1994    0.4909    0.0141    0.0691
                 9         9         8         9         9         9         9         9

CA         0.01578  -0.01477   1.00000  -0.12039   0.76455   0.29464   0.23295   0.50106
            0.9704    0.9723    0.0000    0.7404    0.0100    0.4086    0.5464    0.1401
                 8         8        10        10        10        10         9        10

MG        -0.45922  -0.43973  -0.12039   1.00000  -0.42949  -0.19371   0.31981   0.39584
            0.2137    0.2363    0.7404    0.0000    0.1874    0.5682    0.3677    0.2282
                 9         9        10        11        11        11        10        11

K          0.48770   0.47216   0.76455  -0.42949   1.00000   0.49970  -0.08026   0.31028
            0.1829    0.1994    0.0100    0.1874    0.0000    0.1176    0.8255    0.3531
                 9         9        10        11        11        11        10        11

NA         0.44768   0.26494   0.29464  -0.19371   0.49970   1.00000  -0.05719  -0.13912
            0.2269    0.4909    0.4086    0.5682    0.1176    0.0000    0.8753    0.6833
                 9         9        10        11        11        11        10        11

P         -0.61672  -0.77542   0.23295   0.31981  -0.08026  -0.05719   1.00000   0.25088
            0.0769    0.0141    0.5464    0.3677    0.8255    0.8753    0.0000    0.4844
                 9         9         9        10        10        10        10        10

PH        -0.35625  -0.62975   0.50106   0.39584   0.31028  -0.13912   0.25088   1.00000
            0.3467    0.0691    0.1401    0.2282    0.3531    0.6833    0.4844    0.0000
                 9         9        10        11        11        11        10        11
```

Table 2: Within-site differences in snowpack chemistry, Student's t-test

December

Between-Profile Comparisons	Site 1 1vs2 t	 1vs3 t	 2vs3 t	Site 2 1vs2 t	 1vs3 t	 2vs3 t
pH(1)	0.17	0.56	0.84	0.72	2.73	2.49
pH(2)	0.13	0.19	0.31	2.18	1.75	1.86
Ca	1.98	0.00	0.21	2.82	0.67	7.21
Mg	0.46	0.00	0.66	1.49	-	1.78
K	2.45	2.04	0.22	1.99	0.59	4.08
Na	5.23	4.13	0.95	0.54	0.89	0.49
TDP	0.59	1.16	9.46	1.54	0.41	1.57
pm	0.01	0.46	0.28	1.97	2.45	1.38

February

Between-Profile Comparisons	4vs5 t	4vs6 t	5vs6 t	4vs5 t	4vs6 t	5vs6 t
pH(1)	1.36	0.96	0.20	1.50	1.86	3.57
pH(2)	0.70	3.20	3.39	0.38	0.68	1.00
Ca	0.39	0.12	0.50	1.04	1.11	1.41
Mg	0.58	0.49	0.74	1.27	1.28	1.93
K	1.12	0.00	1.12	1.25	4.00	1.67
Na	1.52	2.08	0.38	0.52	2.56	1.44
TDP	0.15	0.73	0.63	1.54	2.17	1.39
pm	-	-	-	0.14	1.06	1.00

April/May
control profiles

Between-Profile Comparisons	9vs7 t	9vs11 t	7vs11 t	7vs9 t	7vs11 t	9vs11 t
pH(1)	1.76	3.80	5.48	1.39	2.30	1.15
pH(2)	2.76	3.95	1.47	2.42	2.10	0.10
Ca	1.91	0.31	1.44	0.08	0.94	1.33
Mg	0.49	1.06	0.47	0.00	1.14	1.14
K	1.69	1.24	1.43	1.21	0.35	0.93
Na	2.39	1.68	1.06	0.11	1.56	1.55
TDP	0.02	1.38	1.74	1.84	0.24	0.87
pm	0.72	0.92	1.51	0.93	0.78	0.85

April/May
experimental profiles

Between-Profile Comparisons	10vs8 t	10vs12 t	8vs12 t	8vs10 t	8vs12 t	10vs12 t
pH(1)	2.80	4.48	1.21	4.61	4.54	0.57
pH(2)	2.44	3.23	3.33	0.96	0.70	1.47
Ca	1.10	0.08	1.59	1.27	0.00	1.25
Mg	0.49	1.06	0.47	0.56	0.88	1.83
K	1.69	1.24	1.43	0.58	0.82	1.22
Na	2.39	1.68	1.06	1.42	1.06	0.98
TDP	0.02	1.38	1.74	0.68	0.02	1.81
pm	0.72	0.92	1.51	1.91	5.65	2.31

— significant differences ($\alpha \leq 0.05$)

Table 2 cont.

	Site 3			Site 4		
	December					
Between-Profile Comparisons	1vs2 t	1vs3 t	2vs3 t	1vs2 t	1vs3 t	2vs3 t
pH(1)	0.36	0.50	0.59	1.19	0.09	1.26
pH(2)	2.07	2.32	0.37	0.48	1.11	1.58
Ca	0.10	0.95	0.84	1.10	1.67	0.60
Mg	0.83	0.84	0.00	0.25	0.09	0.35
K	0.16	0.65	0.54	0.64	1.12	0.89
Mn	1.85	1.19	0.84	1.31	2.31	0.82
TDP	1.00	0.11	1.29	0.08	0.13	0.33
pm	0.65	0.34	0.38	0.84	0.33	0.73
	February					
Between-Profile Comparisons	4vs5 t	4vs6 t	5vs6 t	4vs5 t	4vs6 t	5vs6 t
pH(1)	1.23	0.11	1.66	1.20	1.73	0.79
pH(2)	0.96	1.41	0.60	1.12	1.42	1.94
Ca	1.29	1.55	0.43	0.13	0.68	0.67
Mg	1.51	1.36	0.06	0.25	1.09	1.06
K	0.03	1.58	1.54	0.38	0.96	0.88
Mn	0.65	0.90	1.64	1.58	5.48	4.39
TDP	0.51	0.55	0.02	0.78	1.42	1.32
pm	0.22	1.54	1.83	0.84	0.84	1.11
	April/May **control profiles**					
Between-Profile Comparisons	7vs9 t	7vs11 t	9vs11 t	7vs9 t	7vs11 t	9vs11 t
pH(1)	0.49	3.92	2.54	3.35	1.04	1.96
pH(2)	0.74	0.44	1.11	0.79	0.65	1.45
Ca	1.81	1.65	1.30	1.47	1.17	1.09
Mg	1.58	1.52	1.05	1.13	0.57	0.98
K	1.27	1.24	0.09	1.39	1.34	0.40
Mn	1.36	1.23	0.50	1.76	0.08	1.82
TDP	2.24	2.80	1.23	0.41	0.27	0.35
pm	3.27	2.50	4.99	1.77	0.19	2.19
	April/May **experimental profiles**					
Between-Profile Comparisons	8vs10 t	8vs12 t	10vs12 t	8vs10 t	8vs12 t	10vs12 t
pH pH(1)	0.49	3.92	2.54	2.96	4.74	1.90
pH(2)	0.74	0.44	1.11	2.86	1.48	0.58
Ca	1.81	1.65	1.30	1.40	1.32	1.80
Mg	1.58	1.52	1.45	1.49	0.39	0.80
K	1.27	1.24	0.09	1.28	0.96	1.14
Mn	1.36	1.23	0.05	0.15	0.15	0.45
TDP	2.24	2.80	1.23	2.99	2.08	0.86
pm	3.27	2.50	4.99	0.25	1.71	0.73

—significant differences ($\alpha<0.05$)

Table 3: Between-site differences in snowpack chemistry, Student's t-test

Site 1 vs Site 2

December

Between-Profile Comparisons	1vs1 t	1vs2 t	1vs3 t	2vs1 t	2vs2 t	2vs3 t	3vs1 t	3vs2 t	3vs3 t
pH(1)	-0.08	+0.55	+2.43	+0.89	+0.95	+2.98	-0.70	-0.10	+2.04
pH(2)	-2.66	-0.68	+1.15	-2.55	-0.77	+0.97	-2.72	-0.53	+1.39
Ca	-0.83	+3.78	-5.00	=0.00	+5.09	-2.04	-0.73	+2.80	-2.41
Mg	+1.13	+1.87	-1.70	+0.81	+1.69	-3.23	+2.83	+2.27	-3.39
K	-2.01	-0.13	-3.79	-0.37	+2.53	-2.67	-0.47	+2.05	-1.93
Na	-2.38	-1.86	-0.74	+0.05	+0.83	+1.13	-0.29	+0.43	+0.56
TDP	-2.25	-0.65	-2.42	-1.07	+0.74	-1.13	-1.54	+0.43	-1.87
pm	-1.93	+1.38	+0.04	-1.15	+1.30	+0.03	-4.04	+1.56	+0.61

February

Between-Profile Comparisons	4vs4 t	4vs5 t	4vs6 t	5vs4 t	5vs5 t	5vs6 t	6vs4 t	6vs5 t	6vs6 t
pH(1)	+0.46	+2.27	-1.73	+1.56	+2.96	=0.00	-1.19	+2.44	-0.23
pH(2)	-2.23	-1.92	-2.42	-1.34	-1.02	-1.75	-4.78	-4.61	-4.46
Ca	-0.62	-1.03	-0.27	-0.61	-2.02	+0.81	-0.88	-1.71	-0.25
Mg	-1.06	-1.76	+0.23	-0.59	-1.51	+0.77	-0.95	-1.21	-0.36
K	-2.81	+0.95	-0.85	-0.45	-0.81	-1.32	+3.64	+0.98	-0.91
Na	+2.12	+1.01	-0.01	-1.12	-1.24	-1.64	-1.68	-1.78	-2.20
TDP	+1.90	+0.76	-0.34	+1.85	+0.64	-0.56	+1.37	-0.12	-1.13
pm	-	-	-	-	-	-	+2.41	+2.51	+2.83

April/May

Between-Profile Comparisons	9vs7 t	9vs9 t	9vs11 t	7vs7 t	7vs9 t	7vs11 t	11vs7 t	11vs9 t	11vs11 t
pH(1)	+2.23	+2.03	-0.05	+3.26	+2.24	+0.62	+0.30	-1.78	-3.11
pH(2)	-2.42	-3.14	-3.92	+1.92	-0.70	-0.51	+3.46	+0.59	+0.65
Ca	-2.68	-2.25	-0.68	-1.55	-1.25	+0.07	-2.30	-2.04	-0.79
Mg	-0.24	-0.23	+1.03	=0.00	=0.00	+1.15	+0.95	+1.21	+0.36
K	+1.50	+0.57	+1.28	-0.74	-1.53	-1.00	+1.04	-0.44	+0.72
Na	-0.68	-0.73	+0.91	-2.88	-2.82	-1.47	-2.32	-2.24	-0.57
TDP	+0.99	-0.64	+0.45	+1.22	-0.98	+0.51	-2.34	-1.20	-1.38
pm	+0.95	+0.13	+0.87	+7.67	+1.06	+0.97	-0.49	+0.87	+0.64

Site 1 vs Site 3

December

Between-Profile Comparisons	1vs1 t	1vs2 t	1vs3 t	2vs1 t	2vs2 t	2vs3 t	3vs1 t	3vs2 t	3vs3 t
pH(1)	+0.83	+1.67	+1.12	+1.00	+2.05	+1.45	+0.50	+1.25	+0.64
pH(2)	+1.64	-0.41	-0.72	+1.48	-0.51	-0.81	+1.85	-0.22	-0.57
Ca	+1.97	+1.90	+1.93	+2.41	+2.36	+1.47	+1.89	+1.82	+0.87
Mg	+1.69	+1.48	+1.57	+1.61	+1.33	+1.43	+1.71	+1.53	+1.64
K	+0.94	+0.89	+0.56	+1.28	+1.31	+1.40	+1.25	+1.28	+1.32
Na	-7.06	-2.06	-3.79	-3.19	+0.69	-0.42	-3.53	+0.29	-0.91
TDP	+0.66	+1.78	+1.30	+0.87	+1.96	+1.86	+0.82	+1.92	+1.75
pm	+1.07	+0.43	+0.92	+1.02	+0.40	+0.85	+1.21	+0.63	+1.15

February

Between-Profile Comparisons	4vs4 t	4vs5 t	4vs6 t	5vs4 t	5vs5 t	5vs6 t	6vs4 t	6vs5 t	6vs6 t
pH(1)	+0.80	-0.78	+1.33	+1.66	+0.42	+2.25	+1.37	+0.20	+1.79
pH(2)	-1.22	-2.91	-3.43	-0.55	-1.76	-2.25	-3.61	-5.66	-6.06
Ca	+1.00	-0.12	-0.37	+1.60	-0.49	-0.00	+1.30	-0.00	-0.43
Mg	+2.08	+1.22	+0.96	+2.29	+1.74	+1.29	+1.52	+0.28	+0.29
K	+2.53	+2.49	+2.67	+1.87	+1.84	+0.71	+2.53	+2.49	+2.69
Na	+1.43	+2.20	+0.62	-1.12	-0.91	-1.38	-1.66	-1.45	-1.94
TDP	+2.28	+1.69	+2.23	+2.25	+1.66	+2.19	+2.06	+1.46	+1.91
pm	-	-	-	-	-	-	+2.48	+2.76	+3.00

__ significant differences (α<0.05)

Site 1 vs 2, mean values at
site 2 > or < at site 1
Site 1 vs 3, mean values at
site 3 > or < at site 1

Table 3 cont.

Site 1 vs Site 3

April/May

Between-Profile Comparisons	9vs7 t	9vs9 t	9vs11 t	7vs7 t	7vs9 t	7vs11 t	11vs7 t	11vs9 t	11vs11 t
pH(1)	+2.20	+2.64	+1.35	+3.40	+6.01	+3.31	±0.00	−1.79	−2.18
pH(2)	−1.82	−1.47	−2.15	−0.07	−0.82	±0.00	+0.73	+0.69	+1.03
Ca	+1.72	+0.82	−0.41	+1.81	+1.17	+2.05	+1.70	+0.71	−0.55
Mg	+1.44	+1.41	+1.20	+1.45	+1.62	+1.36	+1.46	+1.94	+1.54
K	+1.56	+1.68	+1.74	+1.24	+0.43	+0.79	+1.52	+1.50	+1.61
Mn	+4.44	+1.91	+1.62	+0.69	−0.38	−0.87	+2.37	+0.61	+0.14
TDP	+1.53	+1.68	+2.24	+1.54	+1.69	+2.52	+1.79	+1.89	+2.35
pm	+0.54	+0.63	+1.49	+4.11	+1.07	+1.97	−1.51	−1.07	+1.97

Site 1 vs Site 4

December

Between-Profile Comparisons	1vs1 t	1vs2 t	1vs3 t	2vs1 t	2vs2 t	2vs3 t	3vs1 t	3vs2 t	3vs3 t
pH(1)	+1.25	−0.06	+1.36	+1.44	+0.07	+1.61	+0.92	+0.53	+0.97
pH(2)	−0.55	−1.02	+0.53	−0.67	−1.13	+0.39	−0.40	−0.90	+0.70
Ca	+1.96	+1.00	+0.10	+1.26	+0.16	+2.12	+1.94	+0.99	+0.87
Mg	+0.56	+1.39	+1.09	+0.55	+1.34	+1.07	+0.56	+1.51	+1.09
K	+0.88	+0.38	−2.68	+1.09	+0.82	−0.60	+1.08	+0.79	−0.67
Mn	−7.30	−0.11	−3.58	−3.39	+0.93	+0.46	−3.64	+0.79	−0.19
TDP	+0.12	+0.32	−0.03	+0.78	+1.46	+1.25	+0.64	+1.23	+0.98
pm	+0.48	−0.61	+0.19	+0.42	−0.43	+0.15	+0.75	−0.34	+0.62

February

Between-Profile Comparison	4vs4 t	4vs5 t	4vs6 t	5vs4 t	5vs5 t	5vs6 t	6vs4 t	6vs5 t	6vs6 t
pH(1)	−1.85	−0.63	+0.37	−0.43	+0.74	+1.35	−0.60	+0.44	+1.06
pH(2)	+4.57	+6.11	+0.65	+4.53	+5.75	+0.97	+0.97	+2.06	−0.91
Ca	−0.10	−0.17	+0.45	+0.80	+0.27	+0.96	+0.04	−0.09	+0.66
Mg	−1.69	−0.93	+0.91	−1.41	−0.57	+0.98	−1.21	−0.98	+0.77
K	+1.22	+1.13	+0.08	−0.51	−0.17	+0.83	+1.12	+0.17	+0.83
Mn	+5.19	+4.04	−0.15	+0.08	−0.47	−1.55	−0.44	−1.00	−2.11
TDP	+1.74	+1.41	+0.58	+1.72	+1.40	+0.51	+1.52	+1.34	+0.09
pm	-	-	-	-	-	-	+0.03	+0.84	−0.85

April/May

Between-Profile Comparisons	9vs7 t	9vs9 t	9vs11 t	7vs7 t	7vs9 t	7vs11 t	11vs7 t	11vs9 t	11vs11 t
pH(1)	+4.43	+0.95	+2.83	+6.08	+2.56	+4.15	+2.96	−2.19	+0.57
pH(2)	−1.09	−2.79	−0.16	+0.62	−0.34	+1.32	+1.34	+0.92	+1.95
Ca	+1.35	+5.02	+0.57	+1.40	+3.15	+0.79	+1.34	+3.04	+0.50
Mg	+1.10	−2.19	+0.95	−1.11	+1.42	−0.93	+1.11	−1.02	+0.95
K	+1.50	+2.47	+1.50	+1.01	−1.26	−1.05	+1.43	+0.83	+0.81
Mn	+1.58	+4.26	+1.57	−0.23	+1.71	−0.33	+0.58	+2.97	+0.51
TDP	+0.57	+0.35	+0.93	+0.58	+0.39	+0.94	+0.91	+1.18	+1.25
pm	−0.02	−1.01	+0.10	+1.36	−1.04	+1.83	−1.04	−1.68	−0.98

Site 2 vs Site 3

December

Between-Profile Comparisons	1vs1 t	1vs2 t	1vs3 t	2vs1 t	2vs2 t	2vs3 t	3vs1 t	3vs2 t	3vs3 t
pH(1)	+0.92	+1.88	+1.29	+0.57	+1.51	+0.83	−0.80	−0.61	−1.26
pH(2)	+3.49	+2.80	+1.46	+2.12	+0.34	±0.00	+0.60	−1.65	−1.95
Ca	+2.17	+2.10	+1.26	+0.74	+0.63	−0.53	+2.80	+2.76	+1.93
Mg	+1.53	+1.19	+1.27	+1.23	+0.60	+0.64	+2.00	+2.10	+2.25
K	+1.33	+1.36	+1.46	+0.96	+0.92	+0.62	+1.43	+1.50	+1.43
Mn	−1.11	+0.44	−0.28	−1.97	−0.11	−0.96	−1.89	−0.57	−1.22
TDP	+0.99	+2.05	+2.14	+0.76	+1.87	+1.55	+0.96	+2.03	+2.16
pm	+1.57	+1.15	+1.66	−0.11	−0.84	−0.51	+1.07	+0.43	+0.93

___ significant differences ($\alpha \leq 0.05$)

Site 2 vs 3, mean values at site 3 > or < at site 2

Table 3 cont.

Site 2 vs Site 3

February

Between-Profile Comparisons	4vs4 t	4vs5 t	4vs6 t	5vs4 t	5vs5 t	5vs6 t	6vs4 t	6vs5 t	6vs6 t
pH(1)	+0.42	-1.03	+0.69	-0.74	-2.34	-0.86	+1.85	+0.48	+2.73
pH(2)	+0.66	-0.27	-0.79	+0.34	-0.72	-1.26	+1.18	+0.52	+0.10
Ca	+0.66	+0.87	+0.48	+0.34	+1.69	+1.43	+1.44	+0.25	-0.16
Mg	+2.44	+2.19	+1.55	+2.61	+2.70	+1.87	+2.00	+1.01	+0.81
K	+2.24	+2.20	+1.78	+2.19	+2.35	+2.21	+2.62	+2.58	+2.97
Mn	-0.05	+0.76	-1.36	+0.37	+1.03	-0.49	+1.83	+2.56	+1.15
TDP	+1.35	+0.75	+0.95	+2.12	+1.52	+2.00	+2.37	+1.78	+2.36
pm	+0.57	+0.83	-1.15	+0.71	+0.98	-1.10	+1.47	+1.77	-0.16

May

Between-Profile Comparisons	7vs7 t	7vs9 t	7vs11 t	9vs7 t	9vs9 t	9vs11 t	11vs7 t	11vs9 t	11vs11 t
pH(1)	-0.24	-1.03	-1.42	+1.25	+0.84	+0.15	+2.25	+2.27	+1.48
pH(2)	-1.10	-2.84	-1.33	+0.35	-0.00	+0.53	+0.27	-0.10	+0.40
Ca	+1.91	+1.57	+1.12	+1.90	+1.52	+1.01	+1.79	+1.05	+0.18
Mg	+1.45	+1.17	+1.16	+1.45	+1.13	+1.14	+0.92	-0.95	-0.88
K	+1.41	+1.03	+1.27	+1.54	+1.57	+1.66	+1.45	+1.22	+1.40
Mn	+5.18	+2.39	+2.17	+4.80	+2.36	+2.13	+2.74	+1.04	+0.65
TDP	+1.32	+1.51	+2.16	+1.63	+1.76	+2.28	+1.36	+1.54	+2.18
pm	-1.17	+0.22	+1.20	+0.44	+0.57	+1.46	-0.81	-0.68	-0.41

Site 2 vs Site 4

December

Between-Profile Comparisons	1vs1 t	1vs2 t	1vs3 t	2vs1 t	2vs2 t	2vs3 t	3vs1 t	3vs2 t	3vs3 t
pH(1)	+1.35	-0.00	+1.50	+1.03	-0.51	+1.13	-0.37	-2.09	-0.58
pH(2)	+2.09	+1.49	+3.34	+0.10	-0.41	+1.27	-1.69	-2.13	-0.06
Ca	+2.09	+1.21	+1.30	+1.51	+0.31	-0.76	+2.25	+1.46	+2.14
Mg	+0.54	+1.30	+1.04	+0.51	+1.15	+0.97	+0.58	+1.53	+1.16
K	+1.12	+0.88	+0.05	+0.90	+0.41	+2.84	+1.18	+1.02	+1.46
Mn	-1.02	+0.85	+0.18	-1.89	+0.59	-0.51	-1.82	+0.29	-0.90
TDP	+1.15	+2.06	+1.94	+0.43	+0.81	+0.52	+1.08	+2.07	+1.99
pm	+1.44	+1.23	+1.79	-0.96	-1.61	-1.27	+0.47	+0.72	+0.18

February

Between-Profile Comparisons	4vs4 t	4vs5 t	4vs6 t	5vs4 t	5vs5 t	5vs6 t	6vs4 t	6vs5 t	6vs6 t
pH(1)	-1.89	-0.95	-0.00	-3.17	-2.51	-1.25	-0.50	+0.89	+1.53
pH(2)	+6.00	+7.30	+1.72	+3.90	+7.30	+1.54	+3.34	+6.25	+2.03
Ca	+1.27	+0.59	+1.17	+2.68	+1.18	+1.57	+0.35	+0.12	+0.81
Mg	-1.11	-0.25	+1.03	-0.00	+0.26	+1.10	-1.88	-1.10	+0.88
K	-0.21	+0.30	+0.94	+0.55	+0.75	+1.02	+1.68	+1.40	+1.13
Mn	+1.99	+2.59	-2.54	+3.79	+2.83	-1.18	+3.49	+4.11	+0.53
TDP	+0.83	+1.12	-1.07	+1.58	+1.36	+0.18	+1.83	+1.44	+0.78
pm	-2.45	-0.74	-2.90	-2.56	-0.65	-3.10	-1.12	-0.12	-4.67

May

Between-Profile Comparisons	7vs7 t	7vs9 t	7vs11 t	9vs7 t	9vs9 t	9vs11 t	11vs7 t	11vs9 t	11vs11 t
pH(1)	+1.07	-1.53	+0.15	+3.00	-0.07	+1.75	+4.02	+1.19	+2.76
pH(2)	+0.38	-1.99	+0.52	+0.99	+0.31	+1.62	+0.88	+0.19	+1.51
Ca	+1.47	-0.06	+1.06	+1.46	-0.15	+1.03	+1.40	-1.11	+1.05
Mg	+1.11	+0.73	-0.93	+1.11	+0.69	-0.93	+0.79	+1.24	-0.31
K	+1.26	-0.75	-0.41	+1.46	+1.17	+1.05	+1.33	-0.37	-0.03
Mn	+1.95	+4.72	+2.35	+1.95	+4.69	+2.35	+0.95	+3.35	+0.90
TDP	+0.31	-0.28	+0.67	+0.79	+0.71	+1.06	+0.39	-0.65	+0.74
pm	-1.81	-5.06	-2.75	-0.19	-1.38	-0.06	-0.86	-1.01	-0.88

__ significant differences $(\alpha \leq 0.05)$ Site 2 vs 4, mean values at site 4 > or < at site 2

Table 3 cont.

Site 3 vs Site 4

December

Between-Profile Comparisons	1vs1 t	1vs2 t	1vs3 t	2vs1 t	2vs2 t	2vs3 t	3vs1 t	3vs2 t	3vs3 t
pH(1)	+0.15	−0.81	+0.28	+0.05	−1.49	−0.06	+0.47	−1.01	+0.43
pH(2)	−1.99	−2.34	−1.16	−0.21	−0.75	+1.01	+0.10	−0.64	+1.30
Ca	+1.16	−0.10	−1.10	+1.21	−0.03	−1.01	+1.61	−0.52	−0.10
Mg	+0.37	+0.48	+0.64	+0.47	+0.97	+0.89	+0.47	+0.97	+0.89
K	+0.29	−0.64	−2.07	+0.40	−0.39	−1.37	+0.72	+1.52	−1.52
Mn	+0.34	+1.35	+2.39	−1.76	+0.64	−0.38	−1.07	+1.01	+0.66
TDP	−0.59	−0.59	−0.66	−1.71	−1.72	−1.79	−0.99	−1.09	−1.29
pm	−0.73	−1.27	−0.98	−0.05	−0.72	−0.32	−0.47	−1.21	−0.80

February

Between-Profile Comparisons	4vs4 t	4vs5 t	4vs6 t	5vs4 t	5vs5 t	5vs6 t	6vs4 t	6vs5 t	6vs6 t
pH(1)	−2.02	−1.16	−0.37	−0.83	+0.23	−0.90	−2.68	−1.72	−0.58
pH(2)	+6.61	+5.67	+1.27	+7.17	+8.04	+1.92	+7.54	+9.15	+2.19
Ca	−1.35	−1.27	−0.56	+0.04	−0.09	+0.66	+0.61	+0.25	+0.92
Mg	−2.61	−2.09	+0.09	−2.65	−1.90	+0.70	−1.85	−1.50	+0.68
K	−2.25	−2.82	−0.13	−2.21	−1.99	−0.11	−1.54	−1.98	+0.11
Mn	+3.40	+2.09	−1.61	+2.80	+1.42	−2.42	+4.61	+3.38	−0.81
TDP	−0.41	+0.60	−2.93	+0.09	+0.83	−1.35	+0.08	+0.84	−1.72
pm	−2.50	−1.13	−2.83	−2.78	−1.35	−3.09	−3.41	−0.08	−5.52

May

Between-Profile Comparisons	7vs7 t	7vs9 t	7vs11 t	9vs7 t	9vs9 t	9vs11 t	11vs7 t	11vs9 t	11vs11 t
pH(1)	+2.87	−1.40	+0.42	+3.12	−1.10	+1.47	+3.36	−0.28	+1.87
pH(2)	+0.54	−0.14	+1.15	+1.04	+0.35	+1.67	+0.55	+0.26	+1.21
Ca	+0.24	−1.92	−1.41	+1.21	−1.63	+0.03	+1.38	−1.31	+0.67
Mg	+0.14	−6.97	−0.93	+1.49	−2.48	−0.07	+0.58	−1.88	+0.83
K	−0.46	−1.49	−1.46	−0.79	−1.39	+1.25	−0.51	−1.52	+1.42
Mn	−0.79	+1.43	−0.10	+0.09	+2.07	−0.80	+0.46	+2.67	+0.38
TDP	−0.85	−1.37	−0.61	−1.11	−1.55	−0.89	−1.97	−2.19	−1.85
pm	−0.99	−4.02	−0.84	−0.70	−1.22	−0.64	−1.60	−2.10	−1.56

__ significant differences ($\alpha \le 0.05$)

± Site 3 vs 4, mean values at site 4 > or < at site 3

Table 4: Temporal differences in snowpack chemistry, Student's t-test

Site 1

Between-Profile ccComparisons	Stake Location 1 1vs4 t	 1vs9 t	 4vs9 t	Stake Location 2 2vs5 t	 2vs7 t	 5vs7 t
pH(1)	+0.10	-1.25	-1.98	-0.73	-3.33	-2.68
pH(2)	-1.22	+0.62	+3.51	-1.48	-0.96	+1.26
Ca	+1.22	+3.81	-0.32	+4.19	+3.21	-1.48
Mg	+2.15	+0.26	+2.25	+1.80	-0.68	-2.38
K	-3.12	-3.84	-0.83	+0.83	+1.22	+0.30
Na	-6.30	-3.45	+3.44	+1.15	+3.77	0.06
TDP	-2.71	-3.34	-1.11	-1.56	-2.80	-1.64
pm	-	+0.88	-	-	+0.37	-

Stake Location 4

Between-Profile Comparisons	3vs6 t	3vs11 t	6vs11 t
pH(1)	-1.26	+1.24	+2.84
pH(2)	+0.41	-1.49	-3.70
Ca	+1.99	+2.12	-0.08
Mg	+1.47	-0.45	-1.53
K	-1.27	-0.97	+0.34
Na	-1.52	+2.43	-0.95
TDP	-1.39	-4.30	-2.55
pm	+0.39	+1.73	+1.51

Site 2

Between-Profile Comparisons	Stake Location 1 1vs4 t	 1vs7 t	 4vs7 t	Stake Location 4 2vs5 t	 2vs9 t	 5vs9 t
pH(1)	+0.52	+1.40	+1.19	+1.23	-0.73	-1.47
pH(2)	+1.11	+5.28	+4.58	-1.37	-0.48	+1.41
Ca	+1.81	+0.04	-1.71	-2.42	-2.21	-0.83
Mg	+1.49	-0.16	-1.69	-1.38	-1.74	-0.90
K	+1.24	+0.80	+0.03	-2.12	-3.20	-1.01
Na	-0.00	+0.35	+0.88	-0.98	-0.42	+0.98
TDP	+1.52	-0.41	-2.01	-1.56	-2.87	-3.18
pm	+1.05	+13.3	-1.32	+0.99	-0.40	-1.64

Stake Location 5

Between-Profile Comparisons	3vs6 t	3vs11 t	6vs11 t
	-4.16	-3.59	-1.01
pH(2)	-3.49	-2.38	+1.95
Ca	+3.08	+1.63	-0.61
Mg	+3.54	+1.34	+0.59
K	-0.63	+1.15	+1.30
Na	-1.84	-0.25	+4.02
TDP	-3.57	-1.22	-0.15
pm	+3.88	+0.99	+0.72

Profiles 1,2,3: December
Profiles 4,5,6: February
Profiles 7,9,11: April/May

± mean values in Februaty and May or in December
and mean values in May or in February

—significant differences (α≤0.05)

Table 4 cont.

Site 3

	Stake Location 1			Stake Location 5		
Between-Profile Comparisons	1vs4 t	1vs7 t	4vs7 t	2vs5 t	2vs9 t	5vs9 t
pH(1)	$^{-}0.43$	$^{+}0.14$	$^{+}0.69$	$^{-}\underline{2.32}$	$^{-}1.47$	$^{+}1.48$
pH(2)	$^{+}\underline{3.10}$	$^{-}\underline{2.34}$	$^{+}0.97$	$^{-}\underline{2.40}$	$^{-}1.02$	$^{-}\underline{2.52}$
Ca	$^{+}0.97$	$^{+}1.63$	$^{+}1.40$	$^{-}0.26$	$^{+}0.51$	$^{+}0.67$
Mg	$^{+}0.91$	$^{+}0.95$	$^{+}0.59$	$^{+}0.78$	$^{-}0.96$	$^{-}0.30$
K	$^{+}0.60$	$^{+}0.81$	$^{+}0.49$	$^{+}0.81$	$^{-}0.30$	$^{-}1.23$
Mn	$^{+}\underline{2.03}$	$^{+}\underline{9.38}$	$^{+}\underline{4.68}$	$^{-}0.16$	$^{+}1.26$	$^{+}\underline{2.00}$
TDP	$^{-}0.32$	$^{-}0.61$	$^{-}0.71$	$^{-}1.66$	$^{-}1.58$	$^{-}0.14$
pm	$^{-}1.59$	$^{-}0.03$	$^{+}\underline{1.85}$	$^{+}\underline{2.47}$	$^{+}0.88$	$^{-}1.26$

Stake Location 4

Between-Profile Comparisons	3vs6 t	3vs11 t	6vs11 t
pH(1)	$^{-}0.57$	$^{-}1.33$	$^{-}1.12$
pH(2)	$^{-}\underline{2.33}$	$^{-}0.07$	$^{+}\underline{2.58}$
Ca	$^{+}0.39$	$^{+}0.68$	$^{-}0.28$
Mg	$^{+}0.72$	$^{-}0.77$	$^{+}1.45$
K	$^{+}0.14$	$^{+}0.67$	$^{+}0.64$
Mn	$^{-}0.31$	$^{+}\underline{2.46}$	$^{+}\underline{3.72}$
P	$^{-}0.92$	$^{+}0.84$	$^{+}1.45$
TDP	$^{+}1.22$	$^{+}1.53$	$^{+}1.09$

Site 4

	Stake Location 1			Stake Location 3		
Between-Profile Commprisons	1vs4 t	1vs7 t	4vs7 t	2vs5 t	2vs9 t	5vs9 t
pH(1)	$^{-}\underline{2.07}$	$^{+}1.04$	$^{+}\underline{4.38}$	$^{-}0.15$	$^{-}0.19$	$^{-}0.10$
pH(2)	$^{+}1.36$	$^{+}0.30$	$^{-}1.04$	$^{+}\underline{2.52}$	$^{+}0.25$	$^{-}\underline{4.20}$
Ca	$^{-}1.37$	$^{+}1.04$	$^{+}1.33$	$^{-}0.17$	$^{-}1.26$	$^{-}\underline{1.93}$
Mg	$^{-}0.67$	$^{+}0.12$	$^{+}1.07$	$^{-}1.23$	$^{-}1.46$	$^{-}1.54$
K	$^{-}1.02$	$^{+}0.10$	$^{+}1.30$	$^{-}0.49$	$^{-}0.84$	$^{-}0.82$
Mn	$^{+}\underline{5.85}$	$^{+}\underline{3.78}$	$^{-}0.54$	$^{-}0.37$	$^{+}0.51$	$^{+}\underline{2.98}$
TDP	$^{+}0.27$	$^{+}0.86$	$^{+}1.21$	$^{+}0.91$	$^{-}2.37$	$^{-}1.45$
pm	$^{-}0.33$	$^{+}0.65$	$^{+}1.20$	$^{+}1.01$	$^{+}0.36$	$^{-}0.95$

Stake Location 4

Between-Profile Comparisons	3vs6 t	3vs11 t	6vs11 t
pH(1)	$^{-}1.20$	$^{+}0.27$	$^{+}1.55$
pH(2)	$^{-}1.11$	$^{-}0.17$	$^{+}0.89$
Ca	$^{+}1.20$	$^{+}0.73$	$^{+}0.14$
Mg	$^{-}0.21$	$^{-}0.34$	$^{-}0.16$
K	$^{+}1.05$	$^{+}0.61$	$^{-}0.99$
Mn	$^{-}\underline{1.99}$	$^{+}\underline{1.96}$	$^{+}\underline{3.66}$
TDP	$^{-}1.51$	$^{-}0.71$	$^{+}0.31$
pm	$^{-}1.18$	$^{+}1.57$	$^{+}\underline{2.91}$

—significant differences ($\alpha < 0.05$)

Profiles 1,2,3: December $\overset{+}{-}$ mean values in February and May or in December
Profiles 4,5,6: February and mean values in May or in February
Profiles 7,9,11: May

Table 5: Analysis of variance comparing the chemistry of the surface snow samples from the four study sites

	source of variance	sum of squares	degrees of freedom	variance estimate	F
pH1	between sample	1.18	3	0.39	13.0:
	within sample	0.54	16	0.03	
pH2	between sample	0.87	3	0.13	4.33·
	within sample	0.48	16	0.03	
Ca	between sample	0.0009	3	0.0003	2.00
	within sample	0.0102	16	0.0006	
Mg	between sample	0.00002	3	0.000007	2.33
	within sample	0.00040	16	0.000003	
K	between sample	0.0049	3	0.0016	1.81
	within sample	0.0460	16	0.0024	
Na	between sample	0.0070	3	0.0023	2.13
	within sample	0.0691	14	0.0049	
TDP	between sample	24.2	3	8.06	1.54
	within sample	84.0	16	5.25	
pm	between sample	1340.	3	447.	1.25
	within sample	5709.	16	357.	

Level of significance
: 0.01
· 0.05

Table 6: Between-site comparisons (t-test) of the surface snow chemistry

Comparison	Site 1vs2 t	Site 1vs3 t	Site 1vs4 t	Site 2vs3 t	Site 2vs4 t	Site 3vs4 t
pH(1)	+2.93:	−1.38	−5.36!	−2.06·	−11.3!	−0.38
pH(2)	+1.21	=0.00	−1.05	−2.44·	−3.16:	−2.16·
Ca	−0.61	−0.57	−0.00	+0.29	+1.12	+1.02
Mg	−0.18	=0.00	+0.18	−0.18	=0.00	−0.18
K	−1.07	=0.00	+1.08	−0.71	+0.79	−0.67
Na	+1.44	+1.06	+0.75	+1.48	+1.07	+0.04
TDP	−0.84	+1.58	+2.14·	+0.73	+1.11	−0.47
pm	+0.94	+1.62	+0.80	+0.55	−0.61	−1.48

± mean values at sites 2, 3 and 4 > or < at site 1; values at sites 3, 4 > or< at site 2 and values at site 4 > or < at site 3

level of significance
! 0.001
: 0.01 one-tailed test
· 0.05

Table 7: Differences in snowpack chemistry between the control and experimental profiles, Student's t-test

Site 1

Between-Profile comparisons	10vs9 t	8vs7 t	12vs11 t
pH(1)	0.74	3.94	0.85
pH(2)	0.94	0.26	0.40
Ca	0.14	0.55	0.49
Mg	0.55	0.97	0.52
K	0.76	1.66	1.33
Na	0.52	2.44	2.49
TDP	0.51	1.88	0.84
pm	0.19	1.74	0.96

control profiles: 7, 9, 11
experimental profiles: 8, 10, 12

Site 2

Between-Profile Comparisons	8vs7 t	10vs9 t	12vs11 t
pH(1)	0.79	1.63	0.14
pH(2)	0.75	0.19	1.31
Ca	0.73	0.76	1.51
Mg	0.18	0.76	1.24
K	1.41	0.24	1.53
Na	0.72	5.38	1.39
TDP	1.05	0.57	0.36
pm	0.87	0.49	1.05

control profiles: 7, 9, 11
experimental profiles: 8, 10, 12

— significant differences ($\alpha \leq 0.05$)

Table 7 cont.

Site 3

Between-Profile Comparisons	8vs7 t	10vs9 t	12vs11 t
pH(1)	0.00	0.99	0.66
pH(2)	0.30	0.85	0.75
Ca	0.20	1.21	0.59
Mg	0.03	0.81	0.33
K	0.10	0.13	0.55
Na	0.82	0.61	0.31
TDP	1.21	0.88	1.51
pm	0.02	1.14	0.58

control profiles: 7, 9, 11
experimental profiles:

Site 4

Between-Profile Comparisons	8vs7 t	10vs9 t	12vs11 t
pH(1)	0.27	0.78	2.78
pH(2)	1.36	1.19	2.38
Ca	1.37	1.30	1.09
Mg	0.67	1.58	0.94
K	1.47	0.81	1.04
Na	0.08	2.58	0.14
TDP	0.86	0.05	0.89
pm	1.30	0.06	0.19

control profiles: 7, 9, 11
experimental profiles: 8, 10, 12

— significant differences ($\alpha \leqslant 0.05$)

Table B: Comparison of mean snowpack concentrations calculated using the full data set and omitting the base sample values

Site 1

Stake	Profile		pH(1)	pH(2)	Ca	Mg	K	Na	TDP	pm
						mg/1			ug/1	mg/1
		a	4.41±0.30	5.01±0.45	0.030±0.012	0.004±0.010	0.070±0.044	0.194±0.043	10.5±5.74	23.1±6.77
1	1		t=0.00	t=0.12	t=0.46	t=0.39	t=0.34	t=0.43	t=0.49	t=0.93
		b	4.41±0.27	4.98±0.42	0.033±0.013	0.006±0.013	0.078±0.048	0.204±0.047	11.5±6.04	31.6±24.8
		a	4.42±0.13	4.78±0.15	0.083±0.138	0.020±0.021	0.011±0.020	0.078±0.036	4.46±1.35	
	4		t=0.00	t=0.00	t=0.02	t=0.11	t=0.63	t=0.13	t=0.80	
		b	4.42±0.12	4.78±0.14	0.082±0.132	0.021±0.020	0.018±0.030	0.080±0.035	5.25±2.87	
		a	4.15±0.30	5.00±0.30	0.067±0.043	0.006±0.005	0.001±0.005	0.118±0.025	3.34±0.95	66.1±63.5
	10		t-0.26	t=0.00		t=0.00	t=0.96	t=0.66	t=0.42	t=0.13
		b	4.18±0.31	5.00±0.22		0.006±0.005	0.004±0.011	0.126±0.039	3.59±1.10	53.1±62.3
		a	4.36±0.29	5.11±0.31	0.068±0.003	0.007±0.005	0.004±0.005	0.132±0.046	3.45±1.94	31.4±39.1
	9		t=0.00	t=0.18	t=0.08	t=0.00	t=0.82	t=0.12	t=0.60	t=0.87
		b	4.26±0.28	5.09±0.30	0.069±0.032	0.007±0.005	0.009±0.023	0.134±0.045		
		a	4.39±0.22	5.01±0.44	0.018±0.013	0.007±0.008	0.027±0.014	0.114±0.016	7.82±4.01	17.3±9.90
2	2		t=0.00		t=0.28	t=0.26	t=0.68	t=0.61	t=0.01	t=0.94
		b	4.39±0.20		0.020±0.013	0.008±0.007	0.033±0.020	0.108±0.022	7.01±3.71	31.5±41.2
		a	4.29±0.21	4.70±0.18	0.061±0.031	0.014±0.011	0.026±0.034	0.125±0.095	5.08±2.67	
	5		t=0.45	t=0.38	t=0.37	t=0.55	t=0.96	t=0.87	t=0.31	
		b	4.32±0.23	4.73±0.21	0.066±0.034	0.017±0.015	0.075±0.174	0.195±0.260	5.42±2.84	
		a	4.12±0.17	4.88±0.19	0.043±0.018	0.005±0.005	0.062±0.150	0.188±0.078	3.90±1.53	34.7±7.85
	7		t=0.15	t=0.27	t=0.57	t=0.47	t=0.53	t=0.07	t=0.02	t=0.63
		b	4.11±0.17	4.83±0.20	0.048±0.027	0.006±0.006	0.097±0.194	0.190±0.-76	3.97±1.49	37.1±11.7
		a	4.50±0.35	4.81±0.21	0.053±0.022	0.007±0.005	0.005±0.007	0.132±0.023	2.68±2.09	50.8±27.0
	8		t=0.22	t=0.00	t=0.00	t=0.84	t=0.06	t=0.50		
		b	4.53±0.36	4.81±0.20	0.053±0.021	0.008±0.005	0.006±0.007	0.137±0.029		
		a	4.45±0.24	4.91±0.41	0.030±0.028	0.006±0.005	0.031±0.032	0.117±0.033	8.63±3.25	25.0±6.53
4	3		t=0.28	t=0.15	t=0.21	t=0.00	t=0.30	t=0.24		t=0.58
		b	4.32±0.23	4.94±0.39	0.033±0.027	0.006±0.005	0.036±0.033	0.121±0.032		
		a	4.32±0.26	4.98±0.17	0.078±0.072	0.014±0.011	0.157±0.044	0.248±0.265	5.65±3.74	30.8±53.2
	6		t=0.18	t=0.26	t=0.03	t=0.95	t=0.77	t=0.12	t=0.27	t=0.12
		b	4.34±0.26	5.00±0.18	0.077±0.069	0.029±0.054	0.018±0.028	0.235±0.256	6.30±3.85	33.5±51.2
		a	4.63±0.17	4.74±0.18	0.071±0.062	0.004±0.005	0.014±0.011	0.157±0.044	2.03±1.01	61.3±17.1
	11		t=0.43	t=0.27	t=0.16	t=0.50	t=0.87	t=0.38	t=0.82	t=0.98
		b	4.60±0.19	4.72±0.19	0.075±0.060	0.008±0.005	0.022±0.031	0.164±0.049	2.63±2.29	106 ±164
		a	4.69±0.29	4.75±0.19	0.066±0.024	0.005±0.005	0.010±0.010	0.136±0.033	3.32±2.34	56.3±21.3
	12		t=0.09	t=0.00	t=0.00	t=0.52	t=0.00	t=0.96	t=0.11	t=0.54
		b	4.68±0.28	4.75±0.19	0.066±0.023	0.006±0.005	0.010±0.010	0.124±0.032	3.41±2.25	61.7±27.9

a: mean values calculated omitting the base sample values
b: mean values calculated using the full data set

Table 8 cont.

Site 2

Stake	Profile		pH(1)	pH(2)	Ca	Mg	K	Na	TDP	[illegible]
						mg/l			ug/l	mg/l
1	1	a	4.34±0.12	4.47±0.12	0.025±0.035	0.010±0.000	0.000±0.000	0.135±0.064	4.98±2.97	14.5±0.71
			t=0.51	t=0.46	t=0.17	t=1.24	t=1.24	t=0.43	t=0.30	t=0.33
		b	4.40±0.14	4.52±0.12	0.020±0.026	0.010±0.000	0.025±0.035	0.110±0.062	5.73±2.47	14.7±0.57
	4	a	4.46±0.14	4.59±0.13	0.047±0.026	0.013±0.005	-0.050±0.020	0.117±0.015	8.53±4.63	97.0±10.0
			t=0.11	t=0.34	t=0.49	t=0.27	t=0.16	t=0.58	t=0.35	t=0.99
		b	4.45±0.12	4.62±0.13	0.056±0.029	0.014±0.006	0.052±0.018	0.110±0.021	9.63±4.77	137 ±89.4
	7	a	4.69±0.47	4.97±0.15	0.005±0.012	0.003±0.005	0.041±0.080	0.120±0.033	4.33±0.99	79.5±11.6
			t=0.17	t=0.60	t=0.97	t-0.79	t=0.29	t=0.18	t=0.82	t=0.52
		b	4.65±0.45	4.97±0.14	0.021±0.045	0.006±0.011	0.053±0.081	0.123±0.032	5.06±2.27	83.4±14.6
	8	a	4.77±0.29	4.90±0.31	0.006±0.010	0.007±0.012	0.012±0.024	0.120±0.039	4.11±1.23	81.8±13.4
			t=0.19	t=0.12	t=0.51	t=0.00	t=0.08	t=0.47	t=0.00	t=0.69
		b	4.80±0.28	4.88±0.29	0.009±0.011	0.007±0.022	0.011±0.022	0.110±0.037	4.11±1.12	74.9±22.0
4	2	a	4.50±0.12	4.87±0.33	0.063±0.015	0.013±0.005	0.075±0.030	0.130±0.083	8.53±4.63	46.8±25.4
			t=0.37	t=0.14	t=0.45	t=0.27		t=0.11	t=0.36	t=0.88
		b	4.47±0.12	4.48±0.29	0.068±0.018	0.016±0.009		0.136±0.073	9.68±4.78	76.6±70.3
	3	a	4.57±0.16	4.65±0.16	0.043±0.074	0.011±0.004	0.025±0.032	0.109±0.045	5.53±1.56	95.5±26.7
			t=0.13	t=0.00	t=0.25	t=0.46	t=0.46	t=0.39	t=0.63	t=0.94
		b	4.56±0.15	4.65±0.15	0.040±0.025	0.010±0.005	0.033±0.039	0.100±0.050	6.13±2.34	129 ±105
	5	a	4.43±0.35	4.80±0.22	0.003±0.007	0.002±0.004	0.006±0.008	0.111±0.032	3.45±0.98	40.0±30.6
			t=0.32	t=0.31	t=1.06	t=0.93	t=0.90	t=0.58	t=0.10	t=0.85
		b	4.38-0.37	4.77-0.22	0.023-0.056	0.006-0.013	0.016-0.034	0.121-0.043	3.49-0.94	61.1-75.7
	10	a	4.18±0.30	4.76±0.27	0.018±0.023	0.007±0.005	0.022±0.044	0.159±0.111	3.93±0.97	50.7±37.8
			t=1.03	t=0.09	t=0.98	t=0.82	t=0.11	t=0.00	t=0.42	t=0.13
		b	4.14±0.32	4.75±0.26	0.045±0.089	0.010±0.011	0.020±0.043	0.159±0.105	3.74±1.12	48.6±36.3
5	3	a	4.68±0.18	5.43±0.18	0.010±0.000	0.000±0.000	0.013±0.006	0.210±0.046	6.23±0.25	31.7±17.2
			t=0.30	t=0.76	t=0.00	t=0.00	t=0.00	t=0.79	t=0.46	t=0.00
		b	4.72±0.17	5.26±0.32	0.010±0.000	0.000±0.000	0.013±0.005	0.165±0.100	6.32±0.27	32.0±14.1
	6	a	4.32±0.10	4.53±0.21	0.056±0.035	0.016±0.006	0.000±0.000	0.077±0.025	4.08±0.69	78.3±8.33
			t=0.00	t=0.14	t=0.50	t=0.95	t=1.07	t=0.37	t=0.08	t=0.91
		b	4.32±0.09	4.55±0.17	0.070±0.039	0.023±0.013	0.008±0.015	0.070±0.025	4.93±0.73	92.0±27.5
		a	4.19±0.34	4.82±0.19	0.040±0.068	0.008±0.013	0.027±0.056	0.138±0.019	3.36±0.55	31.0±24.3
			t=0.00	t=0.34	t=0.25	t=1.07	t=0.40	t=0.75	t=0.98	t=1.00
		b	4.19±0.32	4.78±0.20	0.050±0.065	0.042±0.083	0.040±0.062	0.152±0.036	4.68±3.53	248 ±575
	12	a	4.23±0.22	5.06±0.48	0.010±0.017	0.003±0.005	0.003±0.005	0.130±0.022	4.06±2.07	19.7±13.3
			t=0.17	t=0.18	t=0.11	t=0.00	t=0.35	t=0.25	t=0.06	t=0.17
		b	4.21±0.20	5.02±0.44	0.009±0.016	0.003±0.005	0.004±0.005	0.127±0.021	4.13±1.90	20.9±12.5

a: mean values calculated omitting the base sample values
b: mean values calculated using the full data set

Table 8 cont.

Site 3

Stake	Profile		pH(1)	pH(2)	Ca	Mg	K	Na	TDP	PT
						mg/l			ug/l	mg/l
1	1	a	4.48±0.40	5.38±0.65	0.066±0.043	0.025±0.035	0.075±0.097	0.068±0.027	5.57±2.07	36.2±47.0
			t=0.39	t=0.18	t=0.70	t=0.70	t=0.93	t=0.07	t=1.00	t=0.86
		b	4.57±0.44	5.45±0.63	0.090±0.070	0.043±0.057	0.204±0.353	0.069±0.025	23.1±46.3	71.2±95.4
	4	a	4.45±0.23	4.65±0.20	0.129±0.144	0.066±0.073	0.279±0.355	0.114±0.054	14.3±13.7	152 ±160
			t=0.35	t=0.30	t=0.22	t=0.17	t=0.18	t=0.19	t=0.41	t=0.30
		b	4.49±0.24	4.68±0.21	0.144±0.143	0.072±0.071	0.310±0.345	0.109±0.052	17.2±15.5	176 ±166
	7	a	4.47±0.15	4.71±0.17	0.339±0.611	0.043±0.023	0.174±0.092	0.203±0.035	6.96±3.44	72.7±25.8
			t=0.89	t=0.78	t=0.49	t=0.93	t=0.99	t=0.18	t=0.91	t=0.03
		b	4.60±0.41	4.83±0.38	0.503±0.755	0.122±0.240	0.462±0.869	0.706±0.034	12.0±15.6	72.3±23.9
	8	a	4.60±0.11	4.78±0.12	0.340±0.622	0.040±0.044	0.195±0.152	0.195±0.061	5.68±1.90	72.0±28.7
					t=0.31	t=0.92	t=0.95	t=0.94		
					0.437±0.650	0.089±0.152	0.424±0.703	0.269±0.228		
4	3	a	4.56±0.23	4.87±0.29	0.046±0.059	0.022±0.027	0.084±0.131	0.094±0.061	14.5±8.79	53.0±57.8
			t=0.00	t=0.18	t=0.26	t=0.06	t=0.32	t=0.11	t=0.77	t=0.08
		b	4.56±0.23	4.84±0.37	0.055±0.057	0.023±0.025	0.110±0.134	0.098±0.055	21.0±17.1	56.2±61.1
	6	a	4.50±0.16	4.56±0.17	0.066±0.059	0.035±0.048	0.086±0.294	0.093±0.043	10.2±3.95	88.9±37.4
				t=0.00	t=0.00	t=0.00	t=0.34	t=0.17	t=0.68	t=0.02
				4.56±0.16	0.065±0.056	0.035±0.046	0.119±0.127	0.090±0.042	13.7±12.8	89.2±35.7
	11	a	4.35±0.22	4.77±0.28	0.029±0.019	0.009±0.005	0.086±0.066	0.164±0.067	20.2±17.8	97.1±52.9
			t=0.53	t=0.50	t=0.59	t=0.86	t=0.98	t=0.12	t=0.95	t=0.95
		b	4.40±0.29	4.83±0.36	0.057±0.108	0.014±0.022	0.189±0.401	0.167±0.065	33.5±50.9	156 ±234
	12	a	4.32±0.18	4.74±0.20	0.077±0.089	0.012±0.009	0.131±0.142	0.176±0.058	13.1±10.5	120 ±60.7
			t=0.28	t=0.13	t=0.03	t=0.00	t=0.04	t=0.09	t=0.05	
		b	4.34±0.20	4.75±0.20	0.078±0.086	0.012±0.009	0.129±0.137	0.174±0.057	13.1±10.2	
[illegible]	2	a	4.59±0.26	4.89±0.35	0.066±0.057	0.014±0.021	0.071±0.089	0.139±0.095	36.5±48.1	19.3±21.4
			t=0.36	t=0.06	t=0.57	t=0.67	t=0.92	t=0.16	t=0.48	t=0.87
		b	4.64±0.28	4.90±0.33	0.086±0.078	0.023±0.031	0.176±0.308	0.131±0.091	50.4±57.4	42.9±69.6
	5	a	4.38±0.23	4.60±0.15	0.060±0.037	0.026±0.014	0.199±0.158	0.124±0.051	8.98±4.66	191 ±195
			t=0.20	t=0.00	t=0.73	t=0.82	t=0.85	t=0.04	t=0.91	t=0.03
		b	4.36±0.23	4.60±0.15	0.077±0.067	0.034±0.029	0.305±0.381	0.125±0.058	13.6±10.1	194 ±186
	9	a	4.49±0.16	4.77±0.18	0.110±0.220	0.008±0.004	0.062±0.046	0.167±0.063	8.86±9.13	41.8±30.5
			t=0.16	t=0.00	t=0.11	t=1.14	t=0.97	t=0.44	t=0.85	t=0.98
		b	4.48±0.15	4.77±0.18	0.120±0.220	0.018±0.012	0.136±0.272	0.179±0.074	14.7±22.9	95.5±196
	11	a	4.54±0.24	4.83±0.19	0.046±0.046	0.009±0.007	0.123±0.101	0.166±0.051	24.6±29.9	33.5±22.9
			t=0.20	t=0.00	t=0.06	t=0.00	t=0.05	t=0.10	t=0.08	t=0.08
		b	4.56±0.25	4.83±0.18	0.045±0.044	0.009±0.006	0.125±0.097	0.164±0.049	23.7±28.9	33.2±22.1

a: mean values calculated omitting the base sample values
b: mean values calculated using the full data set

Table 8 cont.

Site 4

Stake	Profile		pH(1)	pH(2)	Ca	Mg	K	Mn	TDP	pm
Stake						mg/l			ug/l	mg/l
1	1	a	4.55±0.38	4.78±0.35	0.088±0.110	0.038±0.074	0.056±0.097	0.072±0.019	6.80±2.70	23.5±14.2
			t=0.45	t=0.39	t=0.86	t=0.90	t=0.97	t=0.10	t=0.97	t=0.92
		b	4.65±0.44	4.86±0.39	0.187±0.280	0.119±0.223	0.273±0.539	0.073±0.018	12.2±14.4	41.4±49.2
	4	a	4.23±0.17	5.05±0.15	0.076±0.040	0.008±0.004	0.027±0.031	0.199±0.072	9.48±6.50	23.0±19.9
			t=0.59	t=0.29	t=0.12	t=0.73	t=0.83	t=0.06	t=0.86	t=0.69
		b	4.28±0.22	5.07±0.15	0.078±0.038	0.010±0.008	0.047±0.073	0.201±0.069	14.2±16.0	34.0±39.5
	7	a	4.76±0.18	4.80±0.20	0.512±1.31	0.020±0.037	0.142±0.408	0.173±0.095	2.31±0.92	43.2±14.6
			t=0.78	t=0.80	t=0.17	t=0.99	t=0.69	t=0.22	t=0.99	t=0.91
		b	4.86±0.38	4.92±0.45	0.616±1.28	0.143±0.429	0.302±0.677	0.182±0.097	6.36±13.5	56.5±46.1
	8	a	4.79±0.34	4.91±0.20	0.278±0.587	0.006±0.005	0.013±0.014	0.169±0.072	2.68±0.94	39.4±22.3
			t=0.21	t=0.24	t=0.08	t=0.00	t=0.16	t=0.31	t=0.41	t=0.31
		b	4.82±0.34	4.93±0.20	0.258±0.557	0.006±0.005	0.014±0.014	0.179±0.076	2.86±1.09	35.3±23.6
3	2	a	4.30±0.23	4.66±0.32	0.034±0.032	0.024±0.036	0.014±0.005	0.101±0.014	21.3±8.85	17.6±12.2
			t=0.65	t=0.53	t=0.96	t=0.93	t=1.01	t=1.01	t=0.08	t=0.74
		b	4.40±0.36	4.76±0.41	0.084±0.143	0.066±0.122	0.118±0.292	0.194±0.261	12.7±8.13	24.4±22.3
	5	a	4.36±0.16	5.12±0.12	0.051±0.053	0.004±0.005	0.026±0.024	0.159±0.056	13.1±21.6	26.4±26.8
			t=0.27	t=0.35	t=0.71	t=1.03	t=0.95	t=0.00	t=1.41	t=0.98
		b	4.38±0.16	5.14±0.13	0.074±0.087	0.012±0.024	0.084±0.124	0.159±0.052	36.8±45.7	84.6±186
	9	a	4.37±0.25	4.75±0.20	0.020±0.018	0.003±0.005	0.031±0.024	0.24 ±0.078	3.17±1.99	26.7±27.6
			t=0.52	t=0.56					t=0.87	t=0.16
		b	4.37±0.34	4.80±0.26					4.58±5.46	28.4±26.9
	10	a	4.44±0.26	4.66±0.21	0.012±0.018	0.002±0.004	0.062±0.142	0.177±0.049	4.30±2.39	24.2±14.4
			t=0.19	t=0.35	t=0.15	t=0.58	t=0.02	t=0.10	t=0.37	t=0.38
		b	4.46±0.26	4.69±0.22	0.011±0.017	0.003±0.005	0.061±0.137	0.175±0.047	4.66±2.67	26.0±15.4
4	3	a	4.56±0.33	5.05±0.46	0.040±0.042	0.014±0.015	0.018±0.010	0.123±0.048	8.93±2.21	26.5±22.2
			t=0.39	t=0.21	t=0.44	t=1.00	t=0.83	t=0.23	t=0.91	t=0.55
		b	4.63±0.37	5.10±0.45	0.052±0.048	0.100±0.211	0.026±0.021	0.117±0.047	11.4±6.76	34.3±28.9
			t=0							
	6	a	4.40±0.20	4.74±0.15	0.069±0.065	0.016±0.009	0.038±0.041	0.079±0.030	4.87±4.00	18.9±23.7
			t=0.72	t=0.93	t=0.83	t=1.00	t=1.00	t=0.08	t=0.71	
		b	4.45±0.25	4.87±0.46	0.108±0.147	0.078±0.215	0.275±0.821	0.078±0.029	6.51±6.86	
	11	a	4.57±0.21	4.92±0.29	0.029±0.034	0.007±0.007	0.025±0.045	0.168±0.087	4.02±5.43	56.1±41.9
			t=0.33	t=0.74	t=0.99	t=0.95	t=0.60	t=0.30	t=0.87	t=0.23
		b	4.68±0.43	5.06±0.55	0.123±0.328	0.064±0.207	0.039±0.066	0.179±0.091	7.93±14.5	60.1±42.3
	12	a	4.25±0.11	4.60±0.15	0.026±0.021	0.004±0.007	0.020±0.011	0.189±0.036	3.82±1.36	57.4±34.3
			t=0.61	t=0.50	t=0.11	t=0.33	t=0.22	t=0.36	t=0.52	t=0.02
		b	4.29±0.16	4.64±0.18	0.025±0.020	0.005±0.007	0.019±0.010	0.183±0.040	4.19±1.73	57.1±32.6

a: mean values calculated omitting the base sample values

b: mean values calculated using the full data set

Table 9a; **Analysis of variance comparing the chemistry of the control profile base samples between the four study sites**

	source of variance	sum of squares	degrees of freedom	variance estimate	F
pH1	between sample	18.13	3	6.04	$75.5^{:}$
	within sample	2.93	36	0.08	
pH2	between sample	17.20	3	5.73	$88.2^{:}$
	within sample	2.33	36	0.07	
Ca	between sample	21.39	3	7.13	$10.2^{:}$
	within sample	24.24	34	0.71	
Mg	between sample	13.65	3	4.55	$14.7^{:}$
	within sample	10.79	35	0.31	
K	between sample	10.47	3	3.49	$10.2^{:}$
	within sample	12.11	36	0.34	
Na	between sample	0.06	3	0.02	2.0
	within sample	0.17	36	0.01	
TDP	between sample	18803	3	6257	$10.8^{:}$
	within sample	20331	35	581	

Table 9b: **Analysis of variance comparing the chemistry of the experimental profile base samples between the four study sites**

	source of variance	sum of squares	degrees of freedom	variance estimate	F
pH1	between sample	10.73	3	3.58	$32.5^{:}$
	within sample	3.80	36	0.11	
pH2	between sample	7.83	3	2.61	$16.3^{:}$
	within sample	5.61	36	0.16	
Ca	between sample	8.71	3	2.90	$7.07^{:}$
	within sample	13.83	34	0.41	
Mg	between sample	4.37	3	1.46	$9.13^{:}$
	within sample	6.07	36	0.16	
K	between sample	0.84	3	0.28	$4.67^{:}$
	within sample	2.09	36	0.06	
Na	between sample	0.02	3	0.007	1.75
	within sample	0.13	36	0.004	
TDP	between sample	761	3	254	$8.49^{:}$
	within sample	1077	36	29.2	

level of significance :0.01

Table 10: Between-site comparisons (t-test) of the snowpack-base sample chemistry

Chemical Parameter	Site 1vs2 t	Site 1vs3 t	Site 1vs4 t	Site 2vs3 t	Site 2vs4 t	Site 3vs4 t
pH1 control	-1.48	+8.03:	+10.3:	+9.60:	+11.2:	+4.52:
pH1 epxerimental	-3.63:	+3.21:	+5.54:	+5.07:	+6.90:	+4.51:
pH2 control	+3.61:	+6.67:	+9.76:	+4.34:	+8.50:	+5.56:
pH2 experimental	+1.20	+2.49•	+4.89:	+1.46	+4.45:	+3.66:
Ca control	+1.67	+4.15:	+3.49:	+2.10•	+3.15:	+3.33:
Ca experimental	+1.35	+2.03•	+2.89:	+0.91	+2.79:	+2.65:
Mg control	+2.23•	+3.78:	+3.81:	+1.32	+3.84:	+3.51:
Mg experimental	+0.86	+1.93•	+3.00:	+1.51	+2.97:	+2.85:
K control	-0.81	+3.82:	+3.97:	+3.37:	+1.72	+2.73:
K experimental	+0.85	+2.20•	+0.50	+2.74:	+2.14•	+2.08•
Na control	-1.00	+0.28	+2.17•	+1.46	+3.04:	+2.07•
Na experimental	-1.79	+0.38	+0.14	+2.25•	+0.93	+0.05
TDP control	-2.92:	+3.09:	-1.47	+3.52:	+0.94	-3.33:
TDP experimental	-0.10	+3.43:	+1.17	+3.37:	+1.13	-2.78:

+ mean values at sites 2, 3 and 4 > or < at site 1; mean values at sites 3 and 4
- > or < at site 2; mean vlaues at site 3 > or < at site 4

: significant at the 0.01 level
• significant at the 0.05 level

Table 11: Between-site comparisons of fall and spring surface soil chemistry, Student's t-test.

Between-site Comparisons		1vs2	1vs3	1vs4	2vs3	2vs4	3vs4
pH(1)	a	-10.84	-4.77	-19.19	-1.67	-14.11	-6.10
	b	-5.08	-5.18	-19.31	-3.81	-16.51	-3.57
	c	-8.12	-4.07	-21.94	-2.46	-16.58	-3.31
pH(2)	a	-4.77	-1.52	-3.73	-2.57	-1.49	-4.19
	b	-0.37	-2.93	-6.72	-1.55	-10.91	-7.18
	c	-0.06	-0.83	-5.08	-0.72	-4.51	-4.85
Ca	a	-0.06	-4.50	-20.57	-4.45	-20.83	-6.83
	b	-2.55	-5.96	-11.27	-5.63	-10.73	-1.10
	c	-1.43	-4.84	-8.86	-4.67	-7.82	-2.35
Mg	a	-0.74	-2.72	-19.50	-2.82	-19.74	-9.88
	b	-0.62	-4.03	-19.29	-4.12	-19.33	-13.36
	c	-1.21	-3.11	-19.47	-2.54	-17.14	-9.13
K	a	-3.95	-1.21	-1.02	-1.42	-1.25	-0.19
	b	-3.30	-8.23	-1.72	-13.27	-4.61	-4.80
	c	-1.67	-7.42	-3.46	-13.13	-6.58	-4.92
Mn	a	-4.39	-2.00	-3.30	-3.77	-6.00	-0.29
	b	-1.11	-0.84	-0.79	-0.19	-0.46	-0.22
	c	-1.66	-2.45	-0.70	-1.10	-1.39	-2.27
P	a	-0.23	-2.63	-0.35	-3.08	-0.59	-2.18
	b	-0.93	-5.62	-2.26	-5.44	-1.83	-4.36
	c	-2.41	-1.29	-1.84	-0.10	-2.06	-2.03
CEC	a	-3.81	-3.56	-22.30	-8.46	-21.73	-7.81
	b	-0.27	-7.63	-11.37	-7.06	-10.38	-2.27
	c	-0.17	-7.42	-4.81	-6.47	-4.67	-0.84
%BS	a	-1.61	-2.80	-22.36	-2.48	-25.12	-3.89
	b	-2.34	-7.31	-25.84	-6.50	-22.44	-4.20
	c	-1.62	-4.49	-22.24	-3.82	-15.10	-4.30
%OC	a	-11.89	-1.80	-13.90	-2.66	-20.58	-14.50
	b	-4.90	-0.45	[illegible]	-4.24	-11.97	-9.71
	c	-1.07	-2.89	-10.16	-2.78	-7.48	-6.36

+ mean values at sites 2, 3 and 4 > or < at site 1; mean values at sites
− 3 and 4 > or < at site 2 and mean values at site 4 > or < at site 3

— significant differences ($\alpha \leq 0.05$)

a fall samples

b spring control samples

c spring experimental samples

Table 11: Between-site comparisons of fall and spring surface soil chemistry, Student's t-test.

Between-site Comparisons		1vs2	1vs3	1vs4	2vs3	2vs4	3vs4
pH(1)	a	-10.84	-4.77	-19.19	-1.67	-14.11	-6.10
	b	-5.08	-5.18	-19.31	-3.81	-16.51	-3.57
	c	-8.12	-4.07	-21.94	-2.46	-16.58	-3.31
pH(2)	a	-4.77	-1.52	-3.73	-2.57	-1.49	-4.19
	b	-0.37	-2.93	-6.72	-1.55	-10.91	-7.18
	c	-0.06	-0.83	-5.08	-0.72	-4.51	-4.85
Ca	a	-0.06	-4.50	-20.57	-4.45	-20.83	-6.83
	b	-2.55	-5.96	-11.27	-5.63	-10.73	-1.10
	c	-1.43	-4.84	-8.86	-4.67	-7.82	-2.35
Mg	a	-0.74	-2.72	-19.50	-2.82	-19.74	-9.80
	b	-0.62	-4.03	-19.29	-4.12	-19.33	-11.36
	c	-1.21	-3.11	-19.47	-2.54	-17.14	-9.13
K	a	-3.95	-1.21	-1.02	-1.42	-1.25	-0.19
	b	-3.30	-8.23	-1.72	-11.27	-4.61	-4.80
	c	-1.67	-7.42	-3.46	-11.13	-6.58	-4.92
Mn	a	-4.39	-2.00	-3.30	-3.77	-6.00	-0.29
	b	-1.11	-0.84	-0.79	-0.19	-0.46	-0.22
	c	-1.66	-2.45	-0.70	-1.10	-1.39	-2.27
P	a	-0.23	-2.63	-0.35	-3.08	-0.59	-2.18
	b	-0.93	-5.62	-2.26	-5.44	-1.83	-4.36
	c	-2.41	-1.29	-1.84	-0.10	-2.06	-2.03
CEC	a	-3.81	-3.56	-22.30	-4.46	-21.73	-7.91
	b	-0.27	-7.63	-11.37	-7.06	-10.28	-2.27
	c	-0.17	-7.42	-4.81	-6.47	-4.67	-0.84
%BS	a	-1.61	-2.80	-22.36	-2.48	-25.32	-3.89
	b	-2.34	-7.31	-25.84	-6.50	-22.44	-4.20
	c	-1.62	-4.49	-22.24	-3.82	-15.10	-4.38
%OC	a	-13.89	-1.80	-13.00	-2.66	-20.58	-14.50
	b	-4.90	-0.45	-9.86	-4.24	-11.97	-9.71
	c	-1.07	-2.89	-10.16	-2.78	-7.48	-6.36

\+ mean values at sites 2, 3 and 4 > or < at site 1; mean values at sites
\- 3 and 4 > or < at site 2 and mean values at site 4 > or < at site 3

—— significant differences ($\alpha \leq 0.05$)

a fall samples

b spring control samples

c spring experimental samples